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Evaluating and selecting supplier in textile industry using hierarchical fuzzy TOPSIS

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Abstract

In textile industries, the costs of raw material or cotton make the main part of the prime cost. Reduction of purchasing costs is one the most important issues to bring down the selling price. In this paper, the Mazandaran textile factory, one of the biggest textile industrial units, in Iran is considered for the cotton supplier selection problems. The effective criteria for ranking the suitable suppliers are evaluated using hierarchical fuzzy TOPSIS model. Based on the results, the quality of cotton is considered as the most important criterion in evaluation of cotton suppliers. Also, among different provinces, cotton produced in Golestan is considered as the best quality in the region. Ali-abad cotton factory located in Golestan ranked first which matched with the quality-oriented strategy of Mazandaran textile factory. Supplier's enough storage to meet the customers' regular and emergency needs is another important criterion. In addition, the flexibility, financial stability and strength and pricing and payment policies play critical roles in selection of the suppliers.

Keywords: Supply chain, Textile, Supplier, Fuzzy Logic, TOPSIS.

Introduction

The textile industry is considered as a fundamental basis of each society as everybody needs clothing. Cost of raw materials forms a large amount of total cost of products. In a good purchasing process, all required materials should be bought in good condition and quality (to meet the quality requirements), in suitable time and location, from appropriate sources (a reliable supplier that meets its commitments in due- dates), with suitable prices and service back-ups (Leenders & Fearon, 1997). A correct selection of suppliers will lead to decrease in costs, increase in profit, quality improvement, and guarantee the on-time delivery. In many industries, this cost creates around 70% of overall cost (Ghodsypour & O'brien, 1998). Thus, the supplier selection problem must be considered in the supply chain management process.

Despite the necessity of good relation between textile industry and suppliers, no research has been done in this regard. Therefore, our study is focused on the supplier selection problem in the Iran's textile industry.

One of the important rules in selecting the suppliers is the applying right supplier selection criteria. In this research, we, by review of related literature, extracted the basic and influential criteria on supplier selection problem in the textile industry which would lead to the best decision making.

De Boer *et al*. (2001) mention different steps of selection of suppliers as follows: first, the problem and all decision making criteria are designed. Then, all potential suppliers are selected. Finally, the best supplier is chosen.

One of the most valid and basic supplier selection problems was researched by Dickson (1966). In which 23 criteria have been chosen (Table 1) as the most basic and important ones. The considered criteria, still after 40 years, have been applied in many supplier selection problems.

Mandal and Deshmukh (1994) presented an Interpretive Structural Modeling (ISM) as a technique for identifying and summarizing relations between supplier selection criteria. They divided the supplier selection criteria into dependent and independent categories. They stated that dependent criteria played important roles in the final phase of supplier selection while independent criteria were important in the creation of the list of potential acceptable suppliers before the final selection. Handfield *et al*. (2002) studied the environmental criteria that could influence on the supplier selection process. They clarified 55 and categorized the 20 fundamental ones into two 10-size groups of "very important" and "very easy assessment". Chang *et al*. (2010) applied the Fuzzy DEMATEL method to identify effective criteria in selecting the supplier.

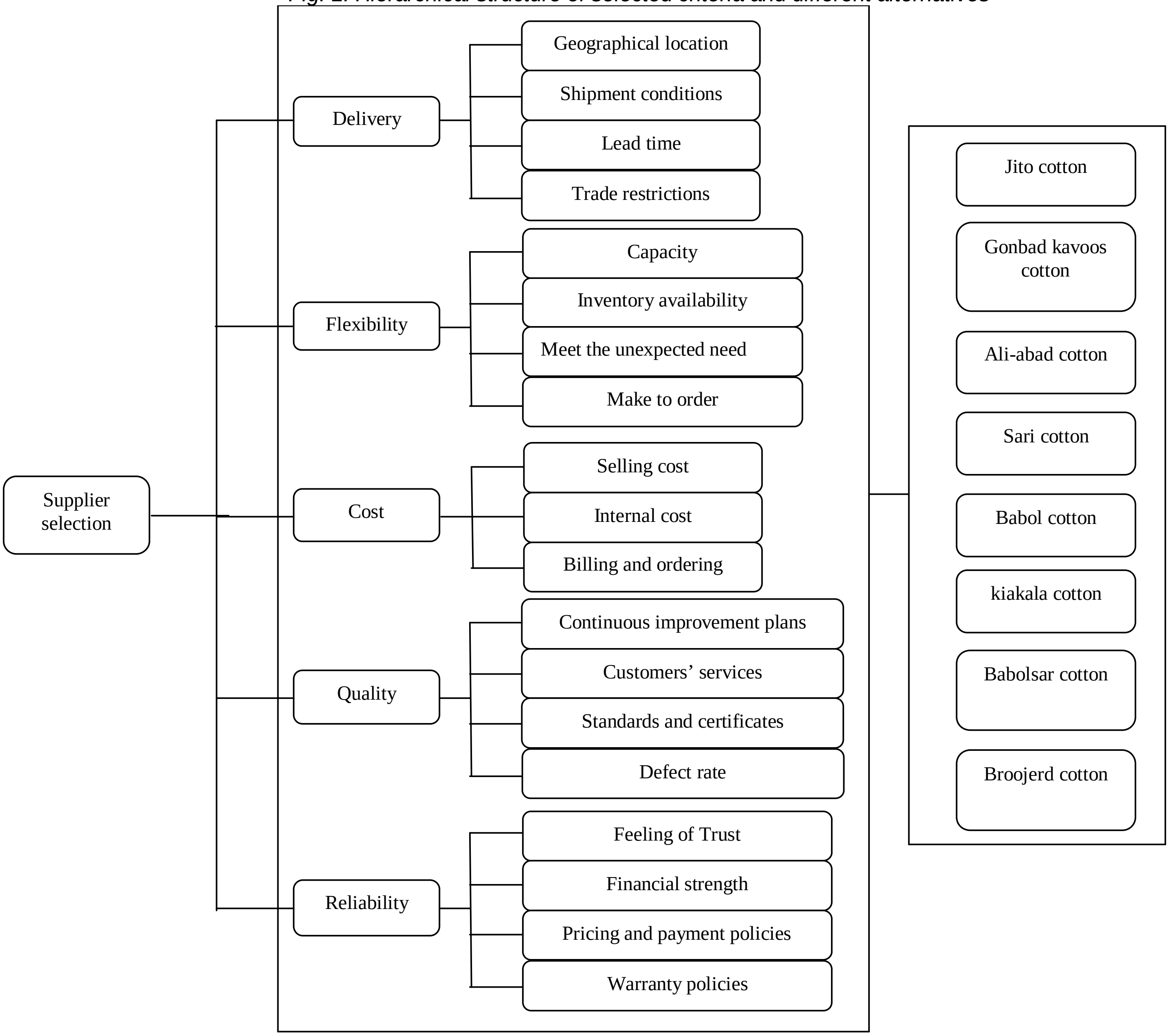
Different researchers have been taken into account the supplier selection problem as a multi-criteria decision making (MCDM) problem and solved that by one of the MCDM methods. For instance, Liu and Hai (2005) firstly introduced some deficiencies of Analytic Hierarchy Process (AHP) method in high number of pair comparisons. Then, they proposed a method simpler than AHP called Voting Analytic Hierarchy Process (VAHP). They showed the superiority of VAHP on other methods by solving an example. Pi and Low (2006) used Taguchi Loss Function and AHP to select the best supplier. They considered the supplier selection as a multi criteria decision making problem and introduced quality, on-time delivery, price, and services as the effective criteria on selection of suppliers. Chen *et al*. (2006) used fuzzy TOPSIS method with criteria such as profitability, closeness in relationship, technological ability, and quality

Table 1. Different criteria considered in the literature

Author	Year	Dickson's (1966) criteria																							Other criteria					
		1 Quality	2 Delivery of product	3 Efficient record	4 guarantees and policies on damage claim	5 Production capacity	6 Price	7 Industrial ability	8 Financial state	9 Fulfilling the needs procedure	10 Relation system	11 Reputation and position in the industry	12 Tend to trade	13 Management and organization	14 Operations control	15 Compensation service	16 Behavior	17 Belief	18 Packaging ability	19 Relation with labors records	20 Geographical position	21 Amount of previous trades	22 Training and support	23 Mutual rules	1 Indirect costs	2 Profitability	3 Number of products	4 Number of returned products	5 Flexibility	6 Environment management
Pi & Low	2006	✓	✓		✓		✓									✓														
Narasimhan	2006	✓	✓				✓															✓			✓					
Petroni &	2000	✓	✓			✓	✓	✓						✓																
Chen *et al*.	2006	✓						✓			✓															✓				
Ng	2008	✓	✓				✓														✓						✓			
Gencer & Gürpinar	2007	✓	✓		✓	✓	✓		✓		✓			✓		✓			✓				✓							
Demirtas & Üstün	2008	✓	✓			✓	✓				✓													✓						
Ha & Krishnan	2008	✓	✓											✓																
Amid *et al*.	2009	✓	✓			✓	✓																					✓		
Chou & Chang	2008			✓		✓			✓					✓																
Lee	2009	✓	✓	✓			✓		✓																				✓	
Li *et al*.	2007	✓	✓		✓		✓									✓														
Liao & Rittscher	2007	✓	✓				✓																						✓	
Hong *et al*.	2005	✓	✓				✓																				✓			
Lee *et al*.	2009	✓				✓			✓					✓															✓	✓
Wadhwa& Ravindran	2007	✓	✓				✓																							
Liu & Hai	2005	✓	✓				✓																						✓	
Masella & Rangone	2000			✓				✓																✓						
Kahraman *et*	2003	✓						✓					✓																	
Xia & Wu	2007		✓		✓	✓		✓								✓														

to solve the supplier selection problem. They used fuzzy logic and linguistic values for ranking and weighting of criteria. Xia and Wu (2007) considered the supplier selection problem in accompanying the discount conditions. They believed that the supplier selection process is a multi criteria decision making problem which when discount is included into it, it will become more complex. They applied a combination of AHP, Rough Sets Theory, and multi-objective complex integer programming for concurrently determination of number of colleague suppliers and amount of assigned order to each of them in case of multi-product and limited capacity

Fig. 1. Hierarchical structure of selected criteria and different alternatives



of suppliers. Gencer and Gürpinar (2007) introduced and applied the analytic network process (ANP) method to select the best supplier in the electronic industry. De Almeida (2007) presented a multi criteria decision making model based on utility function and ELECTRE method to solve the supplier selection problem. In their proposed model, each criterion was evaluated by a utility function. Demirtas and Ustun (2008) used a combination of analytic network process and multi-objective complex integer programming for selection of the best supplier and determination of order size with regarding the tangible and intangible criteria.

Since fuzzy logic can handle the uncertainty and ambiguity environments especially in supplier selection problem, In our research, hierarchical fuzzy TOPSIS, a developed version of TOPSIS (Kahraman *et al*. 2007), is applied to select the best supplier in the textile and clothing industry in Iran. Fuzzy TOPSIS method has been applied by many researchers for making decision in different fields (Wang *et al*., 2009; Azadeh *et al.,* 2011). Azadeh *et al*. (2011) applied an integrated fuzzy AHP-TOPSIS approach for assigning productive operators' in cellular manufacturing systems. Wang *et al*. (2009) proposed the fuzzy hierarchical TOPSIS, which not only is well suited for evaluating fuzziness and uncertainty problems, but also can provide more objective and accurate criterion weights, while simultaneously avoiding the problem of Chen's (2000) Fuzzy TOPSIS. This method as well as calculating efficiency has following advantages highlighted in Table 2.

Table 2. Advantages of HFTOPSIS

Feature	AHP	TOPSIS	Fuzzy TOPSIS	Hierarchical fuzzy TOPSIS
Support of hierarchical structure	✓			✓
Support of fuzzy concept			✓	✓
Realistic weighting of criteria	✓			✓
Ranking ability	✓	✓	✓	✓
Easily understandable	✓	✓	✓	✓
Comparability with the ideal solution		✓	✓	✓

Research design

There are many textile factories (around 8700 small and big size factories) in Iran. One of the biggest textile factories in Iran is Mazandaran textile factory. The products of Mazandaran textile factory include different kind of string, fabric, gunny, cotton fiber and polyester. Cotton is one of the most basic raw materials of this factory. Thus, in this paper we evaluate the main suppliers and producers of cotton to select the best supplier from the point of view of the factory. Table 3 indicates a list of eight main suppliers of cotton considered in this paper.

Table 3. Cotton suppliers

Row	Factory
1	Jito cotton factory
2	Gonbad-Kavoos cotton factory
3	Ali-abad cotton factory
4	Sari cotton factory
5	Babol cotton factory
6	Kiakala cotton factory
7	Babolsar cotton factory
8	Broojerd cotton factory

To identify the criteria, as well as related previous research in the literature, check list is used as a tool for adjust the criteria, textile industry, and environmental conditions in Iran. To do so, 22 experts in different sections of Mazandaran textile factory have been interviewed about the check list and finally, the criteria which were the most related to the Iranian textile industry were determined. The hierarchical model should be able to break the existing complex decision problem into manageable components of different layers/levels (Azadeh *et al*., 2010). Fig. 1 shows the selected criteria and different alternatives in a hierarchical structure.

As can be seen, the above structure includes 19 criteria which are assorted in five main categories. A questionnaire was used to collect data related to these 19 criteria. In this questionnaire, importance choices of "very low, low, medium, much, very much" were considered to determine the importance of criteria and sub-criteria. It should be mentioned that a similar classification has been done for getting experts' opinions about the importance of each alternative than each sub-criterion. The used linguistic scales are "very weak, weak, medium, good, and very good". Fuzzy numbers corresponding to linguistic scales are from Kahraman *et al*. (2007) and shown in Tables 4 and 5. Statistical population includes 22 experts in the Mazandaran textile factory. After data gathering, 16 valid questionnaires were collected.

Table 5. Linguistic variables for scoring the alternatives than sub-criteria

Linguistic variable	Corresponding triangular fuzzy number
Very weak	(0،0،20)
Weak	(0،20،40)
Medium	(30،50،70)
Good	(60،80،100)
Very good	(80،100،100)

Table 4. Linguistic scales for importance of weight of each criterion and sub-criterion

Linguistic variables	Corresponding triangular fuzzy number
Very low	(0.0،0.2)
Low	(0.0.2،0.4)
Medium	(0.3،0.5،0.7)
Much	(0.6،0.8،1)
Very much	(0.8،1،1)

Hierarchical fuzzy TOPSIS method

As the proposed hierarchical structure has sub-criteria as well as criteria (more than three levels), classic and fuzzy TOPSIS methods cannot be applied. Thus, in this section, developed fuzzy TOPSIS and hierarchical fuzzy TOPSIS methods introduced by Kahraman *et al*. (2007) are presented.

Suppose a problem with n main criteria, m sub-criteria, and k alternatives. Each main criterion has r_i sub-criteria. Total number of these sub-criteria for each main criterion is m $(m = \sum_{i=1}^{n} r_i)$. For a hierarchical structure, such this problem has four levels objective, main criterion, sub-criterion, and alternatives. Thus, there should exist three weight matrixes as follows:

- Matrix (vector) of weights for main criteria than the objective which is presented by $\tilde{I}_{MA}$.
- Matrix of weights of sub-criteria than the corresponding main criterion which is presented by $\tilde{I}_{SA}$
- Matrix of scores of alternatives than the sub-criteria which is presented by $\tilde{I}_A$.

Fig.2 shows different steps of hierarchical fuzzy TOPSIS.

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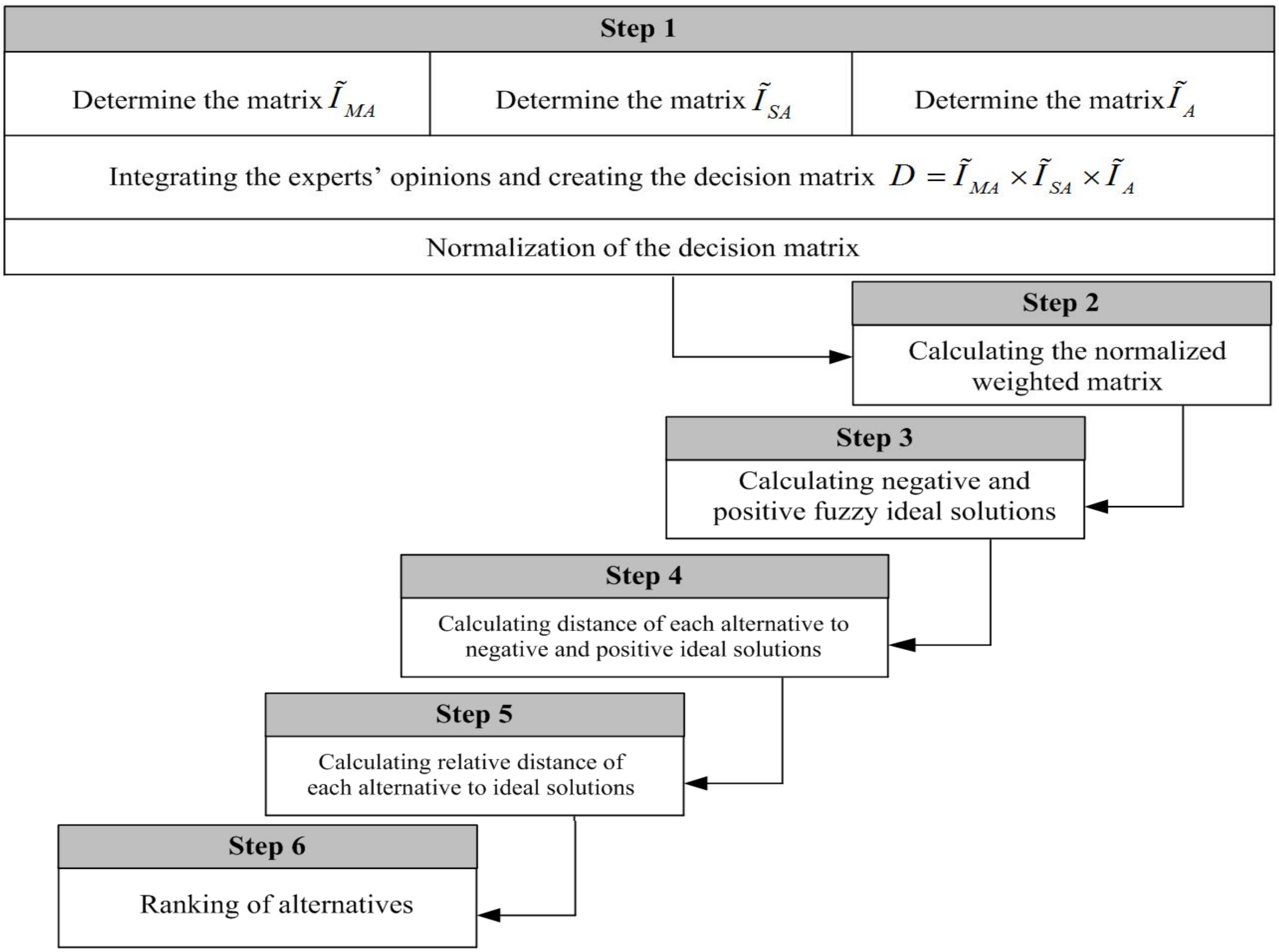
Fig. 2. Hierarchical fuzzy TOPSIS algorithm



Obtaining the decision matrix (step 1)

First, we form three above-mentioned matrixes. The first matrix, matrix of weights of main criteria than the objective, $\tilde{I}_{MA}$ is created as equation (1):

$$\tilde{I}_{MA} = \begin{matrix} MA_1 \\ MA_2 \\ \vdots \\ MA_p \\ \vdots \\ MA_n \end{matrix} \overset{Goal}{\begin{bmatrix} \tilde{w}_1 \\ \tilde{w}_2 \\ \vdots \\ \tilde{w}_p \\ \vdots \\ \tilde{w}_n \end{bmatrix}} \qquad (1)$$

Where, $\tilde{w}_p$ is the average of the weights assigned by decision makers to the main criterion *p* and is calculated by equation (2):

In equation (2), $\tilde{q}_{pi}$ represents the fuzzy number corresponding to opinion of expert i for weight of criterion p than the objective. This overall average is a positive triangular fuzzy number which shows the importance of each criterion. Summary of calculations are shown in Table 6.

The second matrix, matrix of weights of sub-criteria than the main criteria, is calculated by equation (3):

Table 6. Importance of criteria

Row	Criterion	Weight
1	Delivery	(0.569,0.769,0.906)
2	Flexibility	(0.675,0.875,0.963)
3	Cost	(0.606,0.806,0.906)
4	Quality	(0.713,0.913,0.963)
5	Reliability	(0.638,0.838,0.925)

Indian Journal of Science and Technology Vol. 4 No. 10 (Oct 2011) ISSN: 0974- 6846

Table 7.

Sub-criteria (Code)	Delivery	Flexibility	Cost	Quality	Reliability
Geographical Location (D1)	(0.56875,0.76875,0.90625)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
Installation And Shipment Condition (D2)	(0.25625,0.43125,0.61875)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
Lead Time (D3)	(0.49375,0.69375,0.83125)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
Trade Restrictions (D4)	(0.09375,0.21875,0.41875)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)
Capacity (F1)	(0,0,0)	(0.5875,0.7875, 0.925)	(0,0,0)	(0,0,0)	(0,0,0)
Inventory Availability (F2)	(0,0,0)	(0.56875,0.76875,0.90625)	(0,0,0)	(0,0,0)	(0,0,0)
Meeting The Unexpected Needs (F3)	(0,0,0)	(0.58125,0.78125,0.90625)	(0,0,0)	(0,0,0)	(0,0,0)
Make To Order (F4)	(0,0,0)	(0.61875,0.81875,0.98125)	(0,0,0)	(0,0,0)	(0,0,0)
Selling Cost (C1)	(0,0,0)	(0,0,0)	(0.675,0.875,0.9625)	(0,0,0)	(0,0,0)
Internal Cost (C2)	(0,0,0)	(0,0,0)	(0.29375,0.49375, 0.68125)	(0,0,0)	(0,0,0)
Billing And Ordering (C3)	(0,0,0)	(0,0,0)	(0.5375,0.7375,0.85)	(0,0,0)	(0,0,0)
Continuous Improvement Plans (Q1)	(0,0,0)	(0,0,0)	(0,0,0)	(0.425,0.625,0.775)	(0,0,0)
Customers Services (Q2)	(0,0,0)	(0,0,0)	(0,0,0)	(0.49375,0.69375,0.83125)	(0,0,0)
Standards And Certificates (Q3)	(0,0,0)	(0,0,0)	(0,0,0)	(0.65,0.85,0.925)	(0,0,0)
Defect Rate (Q4)	(0,0,0)	(0,0,0)	(0,0,0)	(0.64375,0.84375,0.94375)	(0,0,0)
Feeling Of Trust (R1)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0.4125,0.6125,0.775)
Financial Strength (R2)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0.6875,0.8875,0.9625)
Pricing And Payment Policies (R3)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0.33125,0.53125,0.71875)
Warranty Policies (R4)	(0,0,0)	(0,0,0)	(0,0,0)	(0,0,0)	(0.46875,0.66875,0.86875)

$$\tilde{I}_{SA} = \begin{array}{c} \\ SA_{11} \\ SA_{12} \\ \vdots \\ SA_{1r_1} \\ SA_{21} \\ SA_{22} \\ \vdots \\ SA_{2r_2} \\ \vdots \\ SA_{pl} \\ \vdots \\ SA_{n1} \\ SA_{n2} \\ \vdots \\ SA_{nr_n} \end{array} \begin{array}{c} \begin{array}{cccccc} MA_1 & MA_2 & \cdots & MA_p & \cdots & MA_n \end{array} \\ \begin{bmatrix} \tilde{w}_{11} & 0 & \cdots & 0 & \cdots & 0 \\ \tilde{w}_{12} & 0 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ \tilde{w}_{1r_1} & 0 & \cdots & 0 & \cdots & 0 \\ 0 & \tilde{w}_{21} & \cdots & 0 & \cdots & 0 \\ 0 & \tilde{w}_{22} & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ 0 & \tilde{w}_{2r_2} & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & \tilde{w}_{pl} & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & 0 & \cdots & \tilde{w}_{n1} \\ 0 & 0 & \cdots & 0 & \cdots & \tilde{w}_{n2} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & 0 & \cdots & \tilde{w}_{nr_n} \end{bmatrix} \end{array} \quad (3)$$

Where, $\tilde{w}_{pl}$ indicates the average of weights obtained from the decision makers and is calculated by equation (4):

$$\tilde{w}_{pl} = \frac{\sum_{i=1}^{s} \tilde{q}_{pl_i}}{s} \qquad p = 1, 2, \ldots n \quad (4)$$

$\tilde{q}_{pl_i}$ stands for the fuzzy number corresponding to judgment of the decision maker *i for the* weight of sub-criterion *l* than the criterion *p*. This matrix is shown in Table 7.

The final weight of each sub-criterion is computed from the fuzzy multiplication of weight of each sub-criterion than its corresponding main criterion into the weight of criterion than the objective. The final results are reflected in Table 8.

The third matrix, matrix of scoring the alternatives than the sub-criteria, follows equation (5):

$$\tilde{I}_A = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_q \\ \vdots \\ A_k \end{array} \begin{array}{c} \begin{array}{ccccccccc} SA_{11} & SA_{12} & \cdots & SA_{1r_1} & \cdots & SA_{pl} & \cdots & SA_{nr_n} \end{array} \\ \begin{bmatrix} \tilde{c}_{111} & \tilde{c}_{112} & \cdots & \tilde{c}_{11r_1} & \cdots & \tilde{c}_{1pl} & \cdots & \tilde{c}_{1nr_n} \\ \tilde{c}_{211} & \tilde{c}_{212} & \cdots & \tilde{c}_{21r_1} & \cdots & \tilde{c}_{2pl} & \cdots & \tilde{c}_{2nr_n} \\ \vdots & \vdots & & \vdots & & \vdots & & \vdots \\ \tilde{c}_{q11} & \tilde{c}_{q12} & \cdots & \tilde{c}_{q1r_1} & \cdots & \tilde{c}_{qpl} & & \tilde{c}_{qnr_n} \\ \vdots & \vdots & & \vdots & & \vdots & & \vdots \\ \tilde{c}_{k11} & \tilde{c}_{k12} & \cdots & \tilde{c}_{k1r_1} & \cdots & \tilde{c}_{kpl} & \cdots & \tilde{c}_{knr_n} \end{bmatrix} \end{array} \quad (5)$$

Where, fuzzy values of $\tilde{c}_{qpl}$ indicates the average value of scores given by decision makers and is calculated by equation (6):

$$\tilde{c}_{qpl} = \frac{\sum_{i=1}^{s} \tilde{q}_{qpl_i}}{s} \qquad p = 1, 2, \ldots n \quad (6)$$

$\tilde{q}_{qpl_i}$ stands for the fuzzy number corresponding to opinion of decision maker *i* about the score of alternative *q* than the sub-criterion *l* of criterion *p*. This matrix is shown in Table 9.

The final matrix is obtained by equation (7):

$$D = \tilde{I}_{MA} \times \tilde{I}_{SA} \times \tilde{I}_A = \begin{array}{c} \\ A_1 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccccc} X_1 & \cdots & X_j & \cdots & X_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1j} & \cdots & \tilde{x}_{1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{x}_{i1} & \cdots & \tilde{x}_{ij} & \cdots & \tilde{x}_{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mj} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array} \quad (7)$$

This matrix is an $m \times n$ matrix which *m* and *n* indicate the number of alternatives and features, respectively. Also,

Table 8. Final weight of each sub-criterion

Sub-criterion	Geographical Location	Installation and shipment conditions	Lead time	Trade restriction
Weight	(0.323,0.591,0.821)	(0.146,0.332,0.561)	(0.281,0.533,0.753)	(0.053,0.168,0.379)
Sub-criterion	Capacity	Inventory availability	Meeting the unexpected needs	Make to order
Weight	(0.397,0.689,0.890)	(0.384,0.673,0.872)	(0.392,0.684,0.872)	(0.418,0.716,0.944)
Sub-criterion	Selling cost	Internal cost	Ordering and billing	continuous improvement plans
Weight	(0.409,0.705,0.872)	(0.178,0.398,0.617)	(0.326,0.595,0.770)	(0.303,0.570,0.746)
Sub-criterion	Customers services	Standards and certificates	Defect rate	Feeling of trust
Weight	(0.352,0.633,0.800)	(0.463,0.776,0.890)	(0.459,0.770,0.908)	(0.263,0.513,0.717)
Sub-criterion	Financial strength	Pricing and payment policies	warranty policies	
Weight	(0.438,0.743,0.890)	(0.211,0.445,0.665)	(0.299,0.560,0.804)	

Table 9. Scoring the suppliers

	D1			D2			D3			D4			F1		
ALT1	73.75	93.75	96.25	78.75	98.75	100.00	59.38	79.38	98.13	23.75	43.75	62.50	31.88	51.88	71.88
ALT2	31.88	51.88	71.88	59.38	79.38	98.13	58.13	78.13	98.13	23.75	43.75	62.50	48.13	68.13	83.13
ALT3	54.38	74.38	94.38	31.88	51.88	71.88	59.38	79.38	98.13	59.38	79.38	98.13	61.25	81.25	100.00
ALT4	36.25	56.25	73.75	33.13	53.13	71.88	71.88	91.88	94.38	18.75	38.75	58.75	12.50	32.50	51.25
ALT5	33.75	53.75	73.75	31.88	51.88	71.88	33.75	53.75	73.75	35.63	55.63	75.63	33.75	53.75	73.75
ALT6	57.50	77.50	96.25	8.75	28.75	47.50	33.13	53.13	71.88	24.38	44.38	64.38	58.13	78.13	98.13
ALT7	54.38	74.38	94.38	28.13	48.13	68.13	71.88	91.88	94.38	28.75	48.75	66.25	61.25	81.25	100.00
ALT8	56.25	76.25	96.25	31.88	51.88	71.88	38.13	58.13	75.63	68.13	88.13	94.38	73.75	93.75	96.25
	F2			F3			F4			C1			C2		
ALT1	55.63	75.63	90.63	56.88	76.88	90.63	74.38	94.38	98.13	61.25	81.25	100.00	58.75	78.75	96.25
ALT2	74.38	94.38	98.13	51.88	71.88	86.88	76.25	96.25	100.00	60.63	80.63	98.13	3.75	23.75	43.75
ALT3	59.38	79.38	98.13	52.50	72.50	88.75	70.63	90.63	94.38	15.63	35.63	53.13	3.75	23.75	43.75
ALT4	14.38	34.38	53.13	47.50	67.50	85.00	31.88	51.88	71.88	9.38	29.38	49.38	28.13	48.13	68.13
ALT5	33.13	53.13	71.88	43.75	63.75	81.25	30.00	50.00	70.00	7.50	27.50	47.50	11.88	31.88	49.38
ALT6	28.13	48.13	68.13	66.88	86.88	94.38	33.13	53.13	71.88	31.88	51.88	71.88	56.25	76.25	96.25
ALT7	3.75	23.75	43.75	75.63	95.63	98.13	35.00	55.00	73.75	35.00	55.00	73.75	56.25	76.25	96.25
ALT8	71.88	91.88	94.38	74.38	94.38	98.13	33.13	53.13	71.88	33.75	53.75	73.75	59.38	79.38	98.13
	C3			Q1			Q2			Q3			Q4		
ALT1	35.00	55.00	73.75	33.13	53.13	71.88	69.38	89.38	94.38	31.88	51.88	71.88	33.13	53.13	71.88
ALT2	31.25	51.25	70.00	36.25	56.25	73.75	71.25	91.25	96.25	33.13	53.13	71.88	35.63	55.63	75.63
ALT3	28.13	48.13	68.13	80.00	100.00	100.00	63.75	83.75	92.50	31.88	51.88	71.88	33.13	53.13	71.88
ALT4	31.25	51.25	70.00	39.38	59.38	75.63	71.25	91.25	96.25	17.50	37.50	55.00	33.13	53.13	71.88
ALT5	34.38	54.38	71.88	39.38	59.38	75.63	44.38	64.38	79.38	15.00	35.00	51.25	31.25	51.25	70.00
ALT6	1.88	21.88	41.88	8.75	28.75	47.50	52.50	72.50	88.75	13.75	33.75	51.25	58.13	78.13	98.13
ALT7	1.88	21.88	41.88	16.88	36.88	53.13	33.13	53.13	71.88	17.50	37.50	55.00	56.25	76.25	96.25
ALT8	75.63	95.63	98.13	5.63	25.63	45.63	58.13	78.13	98.13	52.50	72.50	92.50	61.25	81.25	100.00
	R1			R2			R3			R4					
ALT1	61.25	81.25	100.00	63.75	83.75	100.00	36.25	56.25	73.75	68.13	88.13	94.38			
ALT2	62.50	82.50	100.00	36.88	56.88	71.88	28.13	48.13	68.13	71.88	91.88	98.13			
ALT3	57.50	77.50	96.25	40.63	60.63	75.63	39.38	59.38	75.63	68.13	88.13	94.38			
ALT4	61.25	81.25	100.00	62.50	82.50	100.00	61.25	81.25	100.00	74.38	94.38	98.13			
ALT5	41.25	61.25	77.50	60.63	80.63	98.13	61.25	81.25	100.00	59.38	79.38	98.13			
ALT6	59.38	79.38	98.13	31.88	51.88	71.88	57.50	77.50	96.25	61.25	81.25	100.00			
ALT7	36.25	56.25	73.75	18.75	38.75	55.00	55.63	75.63	94.38	62.50	82.50	100.00			
ALT8	48.75	68.75	88.75	56.25	76.25	96.25	75.63	95.63	98.13	44.38	64.38	83.13			

Table 10. Normalized matrix

	D1			D2			D3			D4			F1		
ALT1	0.77	0.97	1.00	0.79	0.99	1.00	0.61	0.81	1.00	0.24	0.45	0.64	0.32	0.52	0.72
ALT2	0.33	0.54	0.75	0.59	0.79	0.98	0.59	0.80	1.00	0.24	0.45	0.64	0.48	0.68	0.83
ALT3	0.56	0.77	0.98	0.32	0.52	0.72	0.61	0.81	1.00	0.61	0.81	1.00	0.61	0.81	1.00
ALT4	0.38	0.58	0.77	0.33	0.53	0.72	0.73	0.94	0.96	0.19	0.39	0.60	0.13	0.33	0.51
ALT5	0.35	0.56	0.77	0.32	0.52	0.72	0.34	0.55	0.75	0.36	0.57	0.77	0.34	0.54	0.74
ALT6	0.60	0.81	1.00	0.09	0.29	0.48	0.34	0.54	0.73	0.25	0.45	0.66	0.58	0.78	0.98
ALT7	0.56	0.77	0.98	0.28	0.48	0.68	0.73	0.94	0.96	0.29	0.50	0.68	0.61	0.81	1.00
ALT8	0.58	0.79	1.00	0.32	0.52	0.72	0.39	0.59	0.77	0.69	0.90	0.96	0.74	0.94	0.96
	F2			F3			F4			C1			C2		
ALT1	0.57	0.77	0.92	0.58	0.78	0.92	0.74	0.94	0.98	0.08	0.09	0.12	0.04	0.05	0.06
ALT2	0.76	0.96	1.00	0.53	0.73	0.89	0.76	0.96	1.00	0.08	0.09	0.12	0.09	0.16	1.00
ALT3	0.61	0.81	1.00	0.54	0.74	0.90	0.71	0.91	0.94	0.14	0.21	0.48	0.09	0.16	1.00
ALT4	0.15	0.35	0.54	0.48	0.69	0.87	0.32	0.52	0.72	0.15	0.26	0.80	0.06	0.08	0.13
ALT5	0.34	0.54	0.73	0.45	0.65	0.83	0.30	0.50	0.70	0.16	0.27	1.00	0.08	0.12	0.32
ALT6	0.29	0.49	0.69	0.68	0.89	0.96	0.33	0.53	0.72	0.10	0.14	0.24	0.04	0.05	0.07
ALT7	0.04	0.24	0.45	0.77	0.97	1.00	0.35	0.55	0.74	0.10	0.14	0.21	0.04	0.05	0.07
ALT8	0.73	0.94	0.96	0.76	0.96	1.00	0.33	0.53	0.72	0.10	0.14	0.22	0.04	0.05	0.06
	C3			Q1			Q2			Q3			Q4		
ALT1	0.03	0.03	0.05	0.33	0.53	0.72	0.71	0.91	0.96	0.34	0.56	0.78	0.33	0.53	0.72
ALT2	0.03	0.04	0.06	0.36	0.56	0.74	0.73	0.93	0.98	0.36	0.57	0.78	0.36	0.56	0.76
ALT3	0.03	0.04	0.07	0.80	1.00	1.00	0.65	0.85	0.94	0.34	0.56	0.78	0.33	0.53	0.72
ALT4	0.03	0.04	0.06	0.39	0.59	0.76	0.73	0.93	0.98	0.19	0.41	0.59	0.33	0.53	0.72
ALT5	0.03	0.03	0.05	0.39	0.59	0.76	0.45	0.66	0.81	0.16	0.38	0.55	0.31	0.51	0.70
ALT6	0.04	0.09	1.00	0.09	0.29	0.48	0.54	0.74	0.90	0.15	0.36	0.55	0.58	0.78	0.98
ALT7	0.04	0.09	1.00	0.17	0.37	0.53	0.34	0.54	0.73	0.19	0.41	0.59	0.56	0.76	0.96
ALT8	0.02	0.02	0.02	0.06	0.26	0.46	0.59	0.80	1.00	0.57	0.78	1.00	0.61	0.81	1.00
	R1			R2			R3			R4					
ALT1	0.61	0.81	1.00	0.64	0.84	1.00	0.36	0.56	0.74	0.68	0.88	0.94			
ALT2	0.63	0.83	1.00	0.37	0.57	0.72	0.28	0.48	0.68	0.72	0.92	0.98			
ALT3	0.58	0.78	0.96	0.41	0.61	0.76	0.39	0.59	0.76	0.68	0.88	0.94			
ALT4	0.61	0.81	1.00	0.63	0.83	1.00	0.61	0.81	1.00	0.74	0.94	0.98			
ALT5	0.41	0.61	0.78	0.61	0.81	0.98	0.61	0.81	1.00	0.59	0.79	0.98			
ALT6	0.59	0.79	0.98	0.32	0.52	0.72	0.58	0.78	0.96	0.61	0.81	1.00			
ALT7	0.36	0.56	0.74	0.19	0.39	0.55	0.56	0.76	0.94	0.63	0.83	1.00			
ALT8	0.49	0.69	0.89	0.56	0.76	0.96	0.76	0.96	0.98	0.44	0.64	0.83			

$\tilde{x}_{ij}$ is a triangular fuzzy number which is shown by $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$.

In the next step, the decision matrix should be normalized to make its elements "unit free". For normalization, there are a number of methods that Chen *et al*. (1992) have applied linear normalization technique. In this method, the maximum and minimum values of each column, x_j^+ and x_j^-, are determined and r_{ij} is calculated according to following equations. r_{ij} represents the normalized value of x_{ij}. In case of triangular fuzzy numbers, equation (8) would be used:

$$\tilde{r}_{ij} = \begin{cases} (\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}) \quad ; \quad c_j^+ = \max_i c_{ij} \\ (\text{if } j \text{ has positive aspect}) \\ (\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}) \quad ; \quad a_j^- = \min_i a_{ij} \\ (\text{if } j \text{ has negative aspect}) \end{cases} \tag{8}$$

The normalized matrix D' is as follows:

$$D' = \begin{matrix} \\ A_1 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{matrix} \begin{matrix} X_1 & \dots & X_j & \dots & X_n \\ \left[\begin{matrix} \tilde{r}_{11} & \dots & \tilde{r}_{1j} & \dots & \tilde{r}_{1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{r}_{i1} & \dots & \tilde{r}_{ij} & \dots & \tilde{r}_{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{r}_{m1} & \dots & \tilde{r}_{mj} & \dots & \tilde{r}_{mn} \end{matrix}\right] \end{matrix} \tag{9}$$

It should be noted that in this problem, except sub-criteria selling cost, internal cost, ordering and billing cost, all other sub-criteria are profit. The normalized matrix is reflected in Table 10.

calculating the normalized weighted matrix (step 2)

The elements of the normalized weighted matrix $\tilde{v}_{ij}$ are calculated by equation (10):

$$\tilde{v}_{ij} = \begin{cases} \tilde{r}_{ij}.\tilde{w}_j = (\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}).(\alpha_j, \beta_j, \chi_j) \\ = (\frac{a_{ij}}{c_j^+}\alpha_j, \frac{b_{ij}}{c_j^+}\beta_j, \frac{c_{ij}}{c_j^+}\chi_j) \quad ; \quad \text{positive aspect} \\ \tilde{r}_{ij}.\tilde{w}_j = (\frac{a_j^-}{a_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{c_{ij}}).(\alpha_j, \beta_j, \chi_j) \\ = (\frac{a_j^-}{c_{ij}}\alpha_j, \frac{a_j^-}{b_{ij}}\beta_j, \frac{a_j^-}{a_{ij}}\chi_j) \quad ; \quad \text{negative aspect} \end{cases} \tag{10}$$

Finally, the normalized weighted matrix (V) is equation (11) and is shown in Table 11.

$$v = \begin{matrix} \\ A_1 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{matrix} \begin{matrix} X_1 & \dots & X_j & \dots & X_n \\ \left[\begin{matrix} \tilde{v}_{11} & \dots & \tilde{v}_{1j} & \dots & \tilde{v}_{1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{v}_{i1} & \dots & \tilde{v}_{ij} & \dots & \tilde{v}_{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{v}_{m1} & \dots & \tilde{v}_{mj} & \dots & \tilde{v}_{mn} \end{matrix}\right] \end{matrix} \tag{11}$$

4-3 Calculating negative and positive fuzzy ideal solutions (step 3)

So far, the normalized weighted decision matrix has been formed. In this step, negative and positive fuzzy ideal solutions (A^+ and A^-) are defined by equations (12) and (13) (Wang and Chang 2007):

$$A^+ = \left(\tilde{v}_1^+, \tilde{v}_2^+, \dots, \tilde{v}_n^+\right) = \left((1,1,1), (1,1,1), \dots, (1,1,1)\right) \tag{12}$$

$$A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-\right) = \left((0,0,0), (0,0,0), \dots, (0,0,0)\right) \tag{13}$$

Calculating distances of each criterion from the negative and positive fuzzy ideal solutions (step 5)

Distances of each criterion from A^+ and A^- $\left(d_i^-, d_i^+\right)$ are calculated by equations (14) and (15):

$$d_i^+ = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^+\right) \quad ; i = 1, 2, \dots, m \tag{14}$$

$$d_i^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right) \quad ; i = 1, 2, \dots, m \tag{15}$$

Where, $\tilde{v}_{ij} = \left(a, b, c\right)$, then, equations (16) and (17) would be resulted:

$$d\left(\tilde{v}_{ij}, \tilde{v}_j^+\right) = \sqrt{\frac{1}{3}\left((a-1)^2 + (b-1)^2 + (c-1)^2\right)} \tag{16}$$

$$d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right) = \sqrt{\frac{1}{3}\left(a^2 + b^2 + c^2\right)} \tag{17}$$

Calculation of relative distances of each alternative from ideal solutions C_i (step 5)

This indicator is defined to combine values of d_i^+ and d_i^- and also for comparison of alternatives than to each other. This indicator is calculated by equation (18):

$$C_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{18}$$

Indian Journal of Science and Technology Vol. 4 No. 10 (Oct 2011) ISSN: 0974- 6846

Table 11. Normalized weighted matrix

	D1			D2			D3			D4			F1		
ALT1	0.25	0.58	0.82	0.11	0.33	0.56	0.17	0.43	0.75	0.01	0.07	0.24	0.13	0.36	0.64
ALT2	0.11	0.32	0.61	0.09	0.26	0.55	0.17	0.42	0.75	0.01	0.07	0.24	0.19	0.47	0.74
ALT3	0.18	0.46	0.81	0.05	0.17	0.40	0.17	0.43	0.75	0.03	0.14	0.38	0.24	0.56	0.89
ALT4	0.12	0.35	0.63	0.05	0.18	0.40	0.21	0.50	0.72	0.01	0.07	0.23	0.05	0.22	0.46
ALT5	0.11	0.33	0.63	0.05	0.17	0.40	0.10	0.29	0.57	0.02	0.10	0.29	0.13	0.37	0.66
ALT6	0.19	0.48	0.82	0.01	0.10	0.27	0.09	0.29	0.55	0.01	0.08	0.25	0.23	0.54	0.87
ALT7	0.18	0.46	0.81	0.04	0.16	0.38	0.21	0.50	0.72	0.02	0.08	0.26	0.24	0.56	0.89
ALT8	0.19	0.47	0.82	0.05	0.17	0.40	0.11	0.32	0.58	0.04	0.15	0.36	0.29	0.65	0.86
	F2			F3			F4			C1			C2		
ALT1	0.22	0.52	0.81	0.23	0.54	0.81	0.31	0.68	0.93	0.03	0.07	0.11	0.01	0.02	0.04
ALT2	0.29	0.65	0.87	0.21	0.50	0.77	0.32	0.69	0.94	0.03	0.07	0.11	0.02	0.06	0.62
ALT3	0.23	0.54	0.87	0.21	0.51	0.79	0.29	0.65	0.89	0.06	0.15	0.42	0.02	0.06	0.62
ALT4	0.06	0.24	0.47	0.19	0.47	0.76	0.13	0.37	0.68	0.06	0.18	0.70	0.01	0.03	0.08
ALT5	0.13	0.36	0.64	0.17	0.44	0.72	0.13	0.36	0.66	0.06	0.19	0.87	0.01	0.05	0.19
ALT6	0.11	0.33	0.61	0.27	0.61	0.84	0.14	0.38	0.68	0.04	0.10	0.21	0.01	0.02	0.04
ALT7	0.01	0.16	0.39	0.30	0.67	0.87	0.15	0.39	0.70	0.04	0.10	0.19	0.01	0.02	0.04
ALT8	0.28	0.63	0.84	0.30	0.66	0.87	0.14	0.38	0.68	0.04	0.10	0.19	0.01	0.02	0.04
	C3			Q1			Q2			Q3			Q4		
ALT1	0.01	0.02	0.04	0.10	0.30	0.54	0.25	0.58	0.77	0.16	0.43	0.69	0.15	0.41	0.65
ALT2	0.01	0.02	0.05	0.11	0.32	0.55	0.26	0.59	0.78	0.17	0.45	0.69	0.16	0.43	0.69
ALT3	0.01	0.02	0.05	0.24	0.57	0.75	0.23	0.54	0.75	0.16	0.43	0.69	0.15	0.41	0.65
ALT4	0.01	0.02	0.05	0.12	0.34	0.56	0.26	0.59	0.78	0.09	0.31	0.53	0.15	0.41	0.65
ALT5	0.01	0.02	0.04	0.12	0.34	0.56	0.16	0.42	0.65	0.08	0.29	0.49	0.14	0.39	0.64
ALT6	0.01	0.05	0.77	0.03	0.16	0.35	0.19	0.47	0.72	0.07	0.28	0.49	0.27	0.60	0.89
ALT7	0.01	0.05	0.77	0.05	0.21	0.40	0.12	0.34	0.59	0.09	0.31	0.53	0.26	0.59	0.87
ALT8	0.01	0.01	0.02	0.02	0.15	0.34	0.21	0.50	0.80	0.26	0.61	0.89	0.28	0.63	0.91
	R1			R2			R3			R4					
ALT1	0.16	0.42	0.72	0.28	0.62	0.89	0.08	0.25	0.49	0.20	0.49	0.76			
ALT2	0.16	0.42	0.72	0.16	0.42	0.64	0.06	0.21	0.45	0.21	0.51	0.79			
ALT3	0.15	0.40	0.69	0.18	0.45	0.67	0.08	0.26	0.50	0.20	0.49	0.76			
ALT4	0.16	0.42	0.72	0.27	0.61	0.89	0.13	0.36	0.66	0.22	0.53	0.79			
ALT5	0.11	0.31	0.56	0.27	0.60	0.87	0.13	0.36	0.66	0.18	0.44	0.79			
ALT6	0.16	0.41	0.70	0.14	0.39	0.64	0.12	0.34	0.64	0.18	0.46	0.80			
ALT7	0.10	0.29	0.53	0.08	0.29	0.49	0.12	0.34	0.63	0.19	0.46	0.80			
ALT8	0.13	0.35	0.64	0.25	0.57	0.86	0.16	0.43	0.65	0.13	0.36	0.67			

Ranking of alternatives (step 6)

Alternatives can be ranked in the decreasing order. The results of steps 4 to 6 are shown in Table 12. As can be seen, results of hierarchical fuzzy TOPSIS indicate that Ali-abad cotton factory and Babolsar cotton factory are of the best and worst rank as the cotton suppliers.

Sensitivity analysis

Table 12. Results of hierarchical fuzzy TOPSIS

Cotton Supplier	d^+	d^-	C_i	Rank
Jito cotton factory	12.6183	7.8770	0.38433	4
Gonbad kavoos cotton factory	12.6371	8.0001	0.38765	3
Ali-abad cotton factory	12.2774	8.4978	0.40904	1
Sari cotton factory	13.1913	7.3346	0.35733	6
Babol cotton factory	13.3418	7.2873	0.35325	8
Kiakala cotton factory	13.1975	7.5188	0.36294	5
Babolsar cotton factory	13.3150	7.3421	0.35543	7
Broojerd cotton factory	12.5829	7.9838	0.38819	2

The sensitivity analysis aims to measure the precision of results and changes in final weights and ranks obtained from the applied hierarchical fuzzy TOPSIS method when weights of alternatives are substituted pair-wise. In other words, the final weights of sub-criteria are switched with each other for each sub-criterion. Then, different steps of hierarchical fuzzy TOPSIS method are re-applied to rank the suppliers. Table 13 shows the summary of sensitivity analysis.

Fig.3 and 4 show the changes of weights and ranking of alternatives. Ali-abad, Jito, and Kiakala cotton factories have kept their rank (the first, forth, and fifth) in all scenarios (pair-wise switch of weights) which stresses that these alternatives are not sensitive to switch of weights of their criteria. Bbaol and Sari cotton factories have one-time and two-time changes in their rank, respectively. The maximum change in rank belongs to Babolsar cotton factory in which with switch of weights of Q4 and R1, they have been fallen two ranks.

Indian Journal of Science and Technology Vol. 4 No. 10 (Oct 2011) ISSN: 0974- 6846

Table 13. Pair-wise switch of weights of sub-criteria to do the sensitivity analysis

Factory \ Switch	F1, D1	F3, D3	C3,F2	C2,Q2	C3,Q4	Q4,R1	D1,C1	F2,R3
Jito cotton factory	0.386	0.384	0.382	0.377	0.381	0.387	0.387	0.383
Gonbad kavoos cotton factory	0.387	0.388	0.385	0.384	0.384	0.390	0.389	0.384
Ali-abad cotton factory	0.409	0.409	0.406	0.406	0.406	0.411	0.411	0.407
Sari cotton factory	0.358	0.358	0.356	0.350	0.354	0.360	0.358	0.361
Babol cotton factory	0.353	0.353	0.351	0.349	0.350	0.354	0.354	0.356
Kiakala cotton factory	0.363	0.361	0.363	0.357	0.361	0.363	0.365	0.365
Babolsar cotton factory	0.355	0.355	0.356	0.351	0.353	0.354	0.358	0.360
Broojerd cotton factory	0.388	0.386	0.385	0.382	0.383	0.387	0.390	0.388

Fig. 4. Changes in weights of alternatives after sensitivity analysis

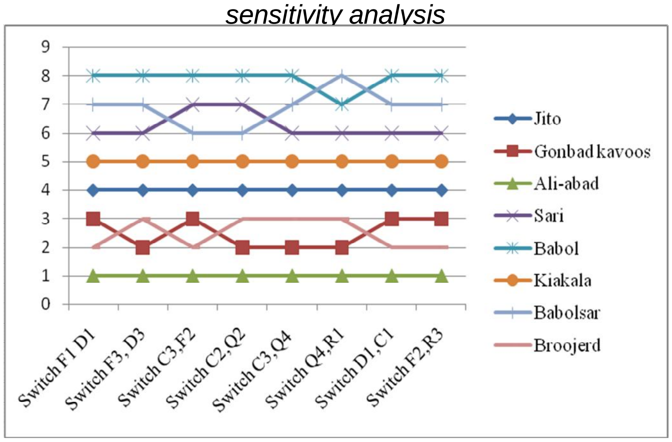


Fig. 4. Changes in weights of alternatives after sensitivity analysis

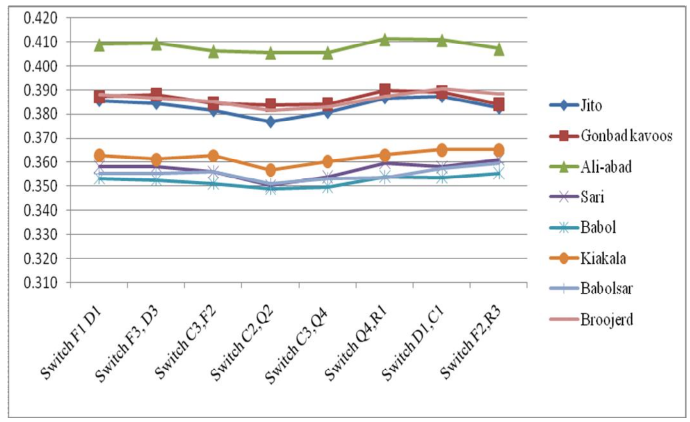


Table 14. Weights and rank of criteria

Criterion	Weight	Rank	Sub-criterion	Weight	Rank
Delivery	4	5	Geographical Location	4	1
			Shipment Conditions	2.75	3
			Lead Time	3.75	2
			Trade Restriction	1.9375	4
Flexibility	4.4375	2	Capacity	4.0625	2
			Inventory Availability	4	4
			Meeting The Unexpected Needs	4.0625	2
			Make To Order	4.125	1
Cost	4.1875	4	Selling Cost	4.4375	1
			Internal Cost	3	3
			Billing And Ordering	3.9375	2
Quality	4.625	1	Continuous Improvement Plans	3.5	4
			Customers' Services	3.75	3
			Standards And Certificates	4.375	1
			Defect Rate	4.3125	2
Reliability	4.3125	3	Feeling of Trust	3.4375	3
			Financial Strength	4.5	1
			Pricing And Payment Policies	3.125	4
			Warranty Policies	3.5625	2

Table 15. The most important sub-criterion of each main criterion

Main criterion	The most important sub-criterion
Delivery	Geographical position
Flexibility	Make to order
Cost	Selling cost
Quality	Standards and certificates
Reliability	Financial strength

Conclusion

In this paper, the supplier selection problem in the textile industry in Iran was considered. The result of this research is the ranking of effective criteria in selection of suppliers in the textile industry in Iran. 19 criteria were grouped into five classes. Table 14 shows the rank of criteria. The main criteria in selection of suppliers of cotton, from the most important to the lease important, are quality, flexibility, reliability, cost, and delivery. In addition, the most important criterion in each class of main criteria is summarized in Table 15. Quality is the most important criterion in evaluation of cotton suppliers. Also, among different provinces, cotton produced in Golestan is of the best quality in the region. Ali-abad cotton factory located in Golestan was assigned the first rank which matched with the quality-oriented strategy of Mazandaran textile factory. That a supplier has enough storage to meet the customers' regular and emergency needs is another important criterion which indicates the ability of suppliers. The results of research indicate that next to quality, flexibility is the most important criterion showing the ability of suppliers. Also, financial stability and strength and pricing and payment policies of a supplier can be evaluated in the purchaser's decision making. The results of this paper show that financial stability and strength and pricing and payment policies play critical roles in the performance of suppliers.

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