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Full Length Research Paper

A model for supplier selection based on fuzzy multi-criteria group decision making

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The great number of suppliers with different capabilities, decision about their numbers and combination, and the way of communication and other related relationships, makes their selection in trouble. Since human perception and judgment which have ambiguous natures govern decision making process, using fuzzy sets will be a suitable selection in these cases. In this paper, we proposed a multi-criteria group decision-making approach based on fuzzy sets which can solve supplier selection problems that have much vagueness. The majority of the existing supplier selection approaches focus on operational metrics. This study considers the strategic and operational factors simultaneously. Business process improvement (BPI) is employed as the strategic criteria, and product quality measurement indicators are operational criteria. In this method, at first, linguistic variables are used to assess the importance weights of strategic and operational criterion. Then the rating of suppliers in strategic criteria and scores of suppliers' product in operational criteria are assessed. Finally, suppliers are ranked in terms of their scores in each criterion and the top suppliers are selected. Also, an empirical case study is performed to clarify the procedure of the proposed method.

Key words: Supply chain management, supplier selection, fuzzy sets, multi-criteria group decision making, business process improvement.

INTRODUCTION

Nowadays, companies and organizations are exploring the ways by which they can meet several customer needs appropriately and timely by applying proper strategies. On the other hand, business environment is a network place and organizations have to survive with regard to supply chain and close cooperation between suppliers, producers and customers. All activities relating to product flow and conversion of materials, from supplying row materials to presenting final product to a customer, and also related information and financial flows lie inside supply chain. The management of supply chain means to integrate these activities through improving of chain relationships in order to obtain competitive advantages (Qazanfari and Fathollah, 2007). Goffin et al. (1997) have stated that management of suppliers is a key issue 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.

Hence, supplier selection is one of the most important decision making problems, since selecting the right suppliers lead to significant saves especially in those companies which spend most part of their sale's income for purchasing raw materials (Liu and Hai, 2005). In average, 70 to 80% of value of a product is related to raw material purchasing costs and payments to service providers (Ghobadian et al., 1993; Weber et al., 1991). Therefore, supplier selection is considered as one of the most important problems. Its object is to reduce purchase risk, maximize the total value to the purchaser, and make the closeness and long term relationships between buyers and suppliers (Chen et al., 2006). Meanwhile, the

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great number of suppliers with different capabilities, decision about their numbers and combination, the way of communication and other related relationships, makes their selection in trouble. Choosing a supplier is a process in which among existed potential suppliers, the best collection is chosen to meet the company's needs (Qazanfari and Fathollah, 2007).

Selecting top supplier with the aim of reducing the number of them can create a competitive advantage for manufacturers through reducing production costs, improving product quality and developing processes and products (Goffin et al., 1997). Indeed, the best advantage of decreasing the number of suppliers is that this frees more time for manufacturers enabling them to pay more attentions to relationships with the selected suppliers. Since human perception and judgment which have ambiguous natures govern decision making process, using Fuzzy sets instead of exact numerical (crisp) will be a suitable selection in these cases. In this paper, we solve supplier selection problem through developing a multi-criteria group decision making approach based on Fuzzy sets. In this regard, we used two groups of criteria. Strategic criteria, indicators of business process improvement (BPI), which is consistent with the company's strategies and operational criteria which are the indicators of suppliers' product quality measurement that have been considered simultaneously. For this, we formed a committee consisted of decision makers from various functional departments and assigned a weight to each member within this group.

Linguistic variables were used to assess the importance weights of strategic and operational criteria. Then the scores of suppliers in strategic criteria and suppliers' products in operational criteria were assessed. Finally, suppliers were ranked in terms of their scores in each criterion and the top suppliers were selected. In our model, all products are rated based on the assigned scores. In this way, we can encourage suppliers to supply high quality products as specified the requested ranks by manufacturers and suppliers are aware of this.

LITERATURE REVIEW

Nowadays, due to rapid growth of manufacturing industries, especially automobile making industries, and this fact that manufacturing of parts are being specialized, companies outsource some necessary parts. This causes the mother company to make relations with various suppliers, all which have their own suppliers with different qualities and efficiencies and usually the mother company is not able to select top suppliers. So, it seems necessary to define criteria by which suppliers are ranked and their places are specified. In this way, the manufacturer could select the most appropriate supplier based on its rank. This gives great advantage to the mother company. Since 1960, defining these criteria by which suppliers are selected and their efficiency are measured have attracted attentions of researchers. The most important matter is that these criteria should be defined in a manner that fit with organization's strategies and policies. Most of current models neglect this important issue and assume that the process of supplier selection is an operational process. Various models and methods have been suggested for supplier selection problem, but as they depend to a large extent on the situation of companies, there is no convergence about specifying whether or not one method is the most appropriate one for all fields. Thus, it would be a complex and critical decision to follow one of them (Liu and Hai, 2005). In this paper, we studied the criteria and techniques of supplier selection separately.

Criteria selection

Dickson (1996) identified 23 different criteria. The most important ones were quality, delivery, performance history, warrant and claim policy, production facilities and capacity, net price, and technical capability. Ellram (1990) suggested a hierarchy framework including financial, performance, technology, organizational culture and strategy, and other factors. Weber et al. (1991) selected price, delivery, quality, facilities and capacity, geographic location, technology capability. Garvin (1993) provided performance factors in detail. In these studies, five factors have been suggested as: quality, cost, delivery, service, flexibility. In a research conducted by Choi and Hatly (1996) on America automobile industry, eight major criteria for supplier selection identified. These criteria include: financial resources, stability, relationships, flexibility, technological capability, customer service, reliability, and price. Ghodsypour and O'Brin (1998) stated that cost, quality and service are very effective in supplier selection parameters. Tracy and Tan (2001) concluded that there is no evidence that selecting suppliers based on price has a positive impact on firm performance. Kahraman et al. (2003) introduced four groups of criteria: supplier criteria, product performance criteria, service performance criteria and cost criteria. Garfamy (2004, 2005) concluded that the price criteria is not related to the company's performance on business processes improvement. In fact, only when there are two or more suppliers with the same capabilities and conditions, will price play a decisive role in the purchase decision. He concluded in his studies in 78 large firms of eight different industries in London, and proposed model to verify the accuracy and applicability. He proposed quality, service, organization, relationship and cycle time as important factors related within the performance of BPI (Table 1). BPI, a process-oriented and customer-oriented approach of improvement, is a comprehensive and effective means to improve a firm's performance (Bevilacqua et al., 2006) that can cause long-term

Table 1. Strategic criteria related with the performance of BPI (Garfamy, 2005).

Criteria	Sub-criteria
Quality	Durability Ergonomic quality Flexibility of operation Simplicity of operation Reliability (quality over period of time, consistency)
Service	Reaction to demand Ability to modify product/service Technical support After sales services (warranties and claim policies)
Organization	Quality performance (ISO9000 accreditation) Current technology of product and process Geography location Production facilities and capacity Technological capability Innovativeness
Relationship	EDI capability Compatibility with levels and functions of buyer firm Customer base Flexibility (payment, fright, price reduction, freight, order frequency and amount) Ability to identify need Ability to maintain commercial relation Availability
Cycle time	Delivery lead time Development speed

alliances with suppliers and customers (Mohammady, 2004). Shen and Yu (2009) used business process improvement criteria for supplier selection on initial stage of new product development. We also employed these factors and their associated criteria as the strategic criteria for supplier selection on modified re-buy situation.

Technique selection

There are dozens of methods for supplier selection problems including analytic hierarchy process (AHP), analytic network process (ANP), data envelopment analysis (DEA), fuzzy sets theory (FST), genetic algorithm (GA), goal programming (GP), simple multi-attribute rating technique (SMART), and other methods (Dahel, 2003). We gathered some of these techniques in four groups: mathematics, single, artificial intelligence and integrated methods (Table 2).

Most approaches of this field have not considered the inherent vagueness of supplier selection process. Fuzzy sets would be an effective tool for obtaining this object. We investigated some researches that consider fuzzy sets such as Sarkar and Mohapatra (2006) that used two factors for supplier assessment purposes: a) functionality and b) capability. Their object was to reduce the number of suppliers. Due to this fact that supplier's attributes are ambiguous factors, they used fuzzy sets in order to rank suppliers. Chen et al. (2006) proposed a hierarchy model based on fuzzy sets for supplier selection problem. They used linguistic variables in order to define the weight and rate of elements which could be in the form of triangular or trapezoidal fuzzy numbers. They used TOPSIS method for rating the obtained options. Flores - Lopez (2007) proposed a multiple fuzzy model for defining the capability of suppliers in creating customer value. Among 84 factors, which were based on the questionnaire response from purchasing managers in U.S., they used 14 important factors. Ghozheng (2009) proposed a multi-criteria decision making approach based on fuzzy sets. In his paper, he employed linguistic variables to assess the rating and weights for quantitative or qualitative factors.

Table 2. Supplier selection techniques.

Techniques		Authors	Techniques		Authors
Mathematics Methods	AHP (Analytic Hierarchy Process)	Chan and Chan (2004) Liu and Hai (2005) Ho et al. (2010)	Integrated Methods	AHP, DEA	Ramanathan (2007)
	LP (Linear Programming)	Talluri and Narasimhan (2005)		AHP, GP	Kull and Talluri (2008)
	MOP (Multi-Objective Programming)	Dahel (2003) Narasimhan et al. (2006)		AHP, MOP	Xia and Wu (2007)
	GP (Goal Programming)	Karpak et al. (2001)		DEA, MOP DEA,SMART	Talluri et al. (2008) Seydel (2005)
	DEA (Data Envelopment Analysis)	Weber (1996) Forker and Mendez (2001) Talluri and Sarkis (2002) Garfamy (2006) Wu et al. (2007)		Fuzzy, AHP	Kahraman et al. (2003) Chan and Kumar (2007)
Single Methods	ClusterAnalysis	Hinkel et al. (1969)		Fuzzy, GA	Jain et al. (2004) Wang (2008)
	ConjointAnalysis	Mummalaneni et al. (1996)		Fuzzy, QFD	Bevilacqua et al. (2006) Hassanzadeh Amin and Razmi (2009)
Artificial Intelligence Methods	NN (Neural Network)	Wei et al. (1997)		Fuzzy, SMART	Kwong et al. (2002) Chou and Chang (2008)
	CBR (Case-Based Reasoning)	Cook (1992) Choy et al. (2002a) Choy et al. (2002b)		NN, AHP, DEA	Ha and Krishnan (2008)
	ES (Expert System)	Vokurka et al. (1996) Chen, Lin and Huang (2006)			
	FST (Fuzzy set Theory)	Chen et al. (2006) Sarkar and Mohapatra (2006) Florez-Lopez (2007) Guozheng (2009)			
	ANP (Analytic Network Process)	Sarkis and Talluri (2002)			
	GA (Genetic Algorithm)	Ding et al. (2005)			
	SMART (Simple Multi-Attribute Rating Technique)	Barla (2003) Huang and Keska (2007)			

Then, degree of similarity and probability of fuzzy sets are used to determine the ranking order of all alternatives. Kahraman (2003) applied a fuzzy AHP method for supplier selection problem in a Turkish white good manufacturing company. Decision makers used linguistic variables for rating of criteria. Chan and Kumar (2007) also employed a fuzzy AHP for supplier selection problem. Jain et al. (2004) suggested a combination model of Fuzzy and GA, for supplier selection problem. Bevilacqua et al. (2006) applied quality function development QFD technique for supplier selection problem. Amin and Razmi (2009) proposed a new framework on the basic of company's strategy for supplier management including supplier selection, evaluation, and development. This approach contained 3 phases: supplier selection, supplier assessment and supplier development. They used QFD technique for rating and defining the best Internet Service Provider (ISP). Due to the ambiguity of human perception, they also used Fuzzy logic and triangular fuzzy numbers. Kwong (2002) integrated fuzzy set theory into SMART to assess the performance of supplier. However, Chau and Chang (2008) used the same method for estimating an IT company's supplier.

According to our surveys in supplier selection field, there are just a few methods considering strategic and operational factors simultaneously. In our proposed approach, these factors were considered simultaneously on modified re-buy situation. Also in this paper, we used heterogeneous group decision making in which the weights of groups differ with each other. We assigned a weight to each decision maker. Then suppliers were ranked based on their points in each criteria using fuzzy multi criteria decision making model. We used MIT-STD 105d sampling method in order to define operational ranks of products. This method which was prepared in 1963 after 4 revisions is a common standard in U.S., U.K. and Canada applying in all industries (Ryan, 2000). We used this method in order to accept or reject a given product before calculating rate of product. This means that only after accepting a product we begin to rate it.

Fuzzy sets theory

For the first time, Professor Zadeh introduced fuzzy sets in the form of an article in the *information and control* magazine. In this paper, he gave fuzzy name to sets that had previously been known by Bertrand Russell, John Lucasiewich, Max Black and the others as ambiguous or multi valued sets (Azar, 2008). He believed that we need another kind of mathematic in order to empower ourselves to model ambiguities and uncertainties of events (Shavandi, 2007). Thus, FST is employed to express the existence of uncertainty in our accurate or mental definitions about preferences, constraints, and goals (Zadeh, 1995). This theory can mathematically formulate most non accurate and ambiguous concepts, variables and systems, such as the events of real world, and prepare a context for reasoning, deduction, control and decision making in uncertainty conditions. It should be noted that in this work uncertainty refers to the uncertainty of thoughts and words of human being and differs with the uncertainty of probability theory (Moraga, 2005).

Fuzzy set

A fuzzy set is a set of things in which there is no clear or pre-defined boarder between things which are or are not members of this set. Each thing to some extent may be or may not be a member of this set. Indeed, each member of this set is linked to a value expressing the degree of membership of that member. This value varies between [0, 1] in which 0 and 1 stand for the minimum and maximum value of the degree of membership respectively. All other values stand for relative degree of membership (Bevilacqua et al., 2006).

Membership function

A membership function is a function which assigns to each element x of X a number, $\mu_{\hat{A}}$(x), in the closed unit interval [0, 1] that characterizes the degree of membership of x in$\hat{A}$. The closer the value of $\mu_{\hat{A}}$(x) is to one, the greater the membership of x in $\widetilde{A}$. Thus, a fuzzy set $\hat{A}$ can be defined precisely by associating with each element x, a number between 0 and 1, which represents its grade of membership in $\tilde{A}$.

Triangular fuzzy number

If a triangular fuzzy number (TFN) $\hat{A}$ be defined as (a, b, c), its membership function is defined as follows (Ghodsypour and O'Brin, 1998):

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{(x-a)}{(b-a)} & ; a \le x \le b \\ \frac{(c-x)}{(c-b)} & ; b \le x \le c \\ 0 & \text{otherwise} \end{cases} \quad 1$$

In addition, the primary operations for two TFNs are shown in Appendix A.

Defuzzification

Fuzzy numbers must be transformed into crisp real numbers to obtain a ranking order of alternatives. There are many method have been developed for this purposes. This study adopts the signed distance method among defuzzification methods because of its simplicity and widespread use. The defuzzification of a TFN $\widetilde{A}$, by signed distance method, denoted as d($\hat{A}$), is therefore given by [7]:

$$d(\tilde{A}) = \frac{1}{4}(a+2b+c) \quad (1)$$

Linguistic variables

Sometimes it becomes a very difficult task to assess the characteristics of some events through numerical formats. A useful tool which is employed for this purpose is linguistic variables. They are variables which their values are sentences or words of natural or artificial languages (Bodjadziev and Bojadziev, 2003). Table 3 presents criteria importance weights and alternative ratings considered as linguistic variables. Figure 1 shows the respective linguistic variables membership functions of importance weights (Chen et al., 2006).

Fuzzy multi-criteria group decision making

Decision making is a problem solving process by which a method is selected among various methods in order to obtain an effective and applicable result (Bodjadziev and Bojadziev, 2003). In real world, we deal with decision

Table 3. The TFNs of linguistic variables for the importance weights and ratings.

Importance weight		Rating	
Linguistic variables	**TFNs**	**Linguistic variables**	**TFNs**
Very Low (VL)	(0,0,1)	Very poor (VP)	(0,0,10)
Low (L)	(0,1,3)	Poor (P)	(0,10,30)
Medium low (ML)	(1,3,5)	Medium poor (MP)	(10,30,50)
Medium (M)	(3,5,7)	Fair (F)	(30,50,70)
Medium high (MH)	(5,7,9)	Medium good (MG)	(50,70,90)
High (H)	(7,9,10)	Good (G)	(70,90,100)
Very high (VH)	(9,10,10)	Very good (VG)	(90,100,100)

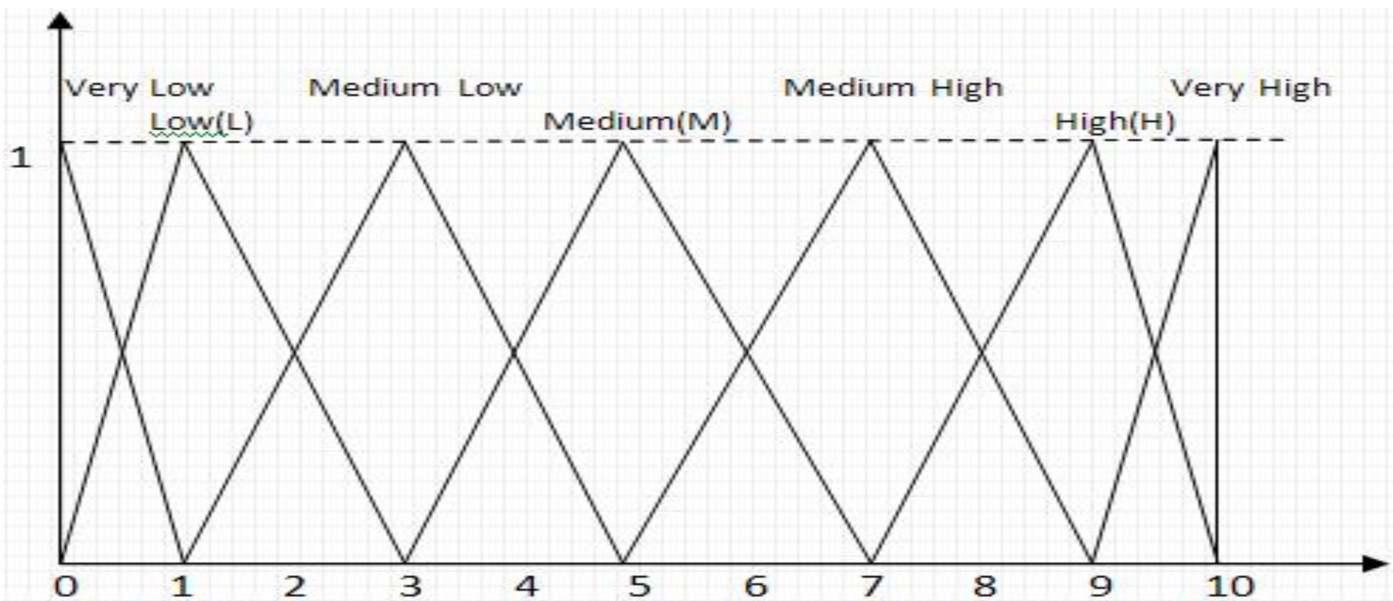

Figure 1. The memberships function of linguistic variables for importance weights.

making cases which have different, antonym and multiple criteria. If we consider multiple qualitative and antonym elements in our decision making process, we call this a multi-criteria decision making (Azar, 2008). Multi-criteria decision making have two models: a) multiple objective decisions making (MODM) and b) multiple attribute decision making (MADM). The first model is applied for design purposes whereas the latter is used for selecting top options (Asqarpour, 2007). As nowadays systems benefit from expert employees in one hand and on the other hand managers of these systems are in the same level, so it would be better to make decisions with respect to the ideas of whole group and the basic body of system's decision makers. We call this kind of decision making; group decision making which can be applied to multi-criteria conditions (Rashidi, 2006). Decision making is a complex and difficult process due to various uncertainties and vagueness of information, mentalities and linguistics. So, when we deal with uncertainty conditions in various concepts and processes, we merge fuzzy sets with multi-criteria decision making (Wang and Elhag, 2006). In multi-criteria decision making method, the weight of elements and the estimated values are expressed by fuzzy numbers or linguistic variables.

RESEARCH METHOD

This study proposes a simple and practical fuzzy model for solving supplier selection problem on modified re-buy situation that considers strategic and operational criteria simultaneously. Our proposed model contains four phases which are discussed thus.

Determining the suppliers' scores in strategic criteria

Step 1: Forming decision maker group and defining the importance weights of them (Table 4). Assume that there is a committee of *t* decision makers (DMs), D_k, *k* = 1,2,…,*t*,. Let I_k be the importance

Table 4. The linguistic importance weighs of the DMs.

DMs	D_1	D_2	D_3	D_4
Weight	VH	H	MH	H

weight given to individual DMs.

Step 2: DMs identify strategic criteria based on firm's strategy and defines the importance weights of these criteria and relative sub-criteria. Assume that there is *m* numbers of criteria and *z* numbers of sub-criteria shown by *n* = 1,2,…,*m*, *y* = 1,2,…,*z*. Let $\widetilde{W}^s_{nyk}$= (a_{nyk} , b_{nyk} , c_{nyk}), be the linguistic weight given to sub-criteria C_{ny}, by DM D_k. The aggregated fuzzy sub-criterion weight with respect to it's criterion C^s_n, denoted as $\widetilde{W}^s_{ny}$= (a_{ny} ,b_{ny} ,c_{ny}), assessed by *t* DMs is defined as:

$$\widetilde{W}^s_{ny} = \sum_{k=1}^{t}(I_k \otimes \widetilde{W}^s_{nyk})/\sum_{k=1}^{t} I_k,$$
$$n = 1,2,\ldots,m,\ y = 1,2,\ldots,z. \quad (2)$$

The defuzzification of W^s_{ny}, denoted as d (W^s_{ny}), can be obtained by Equation 1. The crisp value of normalized weight for sub-criterion C^s_{ny}, denoted as W^s_{ny}, is given by:

$$W^s_{ny}= d(\widetilde{W}^s_{ny})/\sum_{y=1}^{z} d(\widetilde{W}^s_{ny}),$$
$$n = 1,2,\ldots,m,\ y = 1,2,\ldots,z, \quad (3)$$

where $\sum_{y=1}^{z} W^s_{ny}$= 1.

Let $\widetilde{W}^s_{nk}$= (a_{nk} ,b_{nk} ,c_{nk}) be the linguistic importance weight given to criteria C^s_n, by DMs. The aggregated fuzzy importance weight of criterion C^s_n, denoted as $\widetilde{W}^s_n$= (a_n ,b_n ,c_n), assessed by *t* DMs is defined as:

$$\widetilde{W}^s_n=\sum_{k=1}^{t}(I_k \otimes \widetilde{W}^s_{nk})/\sum_{k=1}^{t} I_k, \quad n=1,2,\ldots,m \quad (4)$$

The defuzzification of $\widetilde{W}_n$, denoted as d ($\widetilde{W}_n$), can be obtained by Equation (1). The crisp value of normalized weight for sub-criterion C_n, denoted as W_n, is given by:

$$W^s_n=d(\widetilde{W}^s_n)/\sum_{n=1}^{m} d(\widetilde{W}^s_n), \quad n = 1,2,\ldots,m, \quad (5)$$

where $\sum_{n=1}^{m} W^s_n$= 1.

Step 3: Each decision maker defines the rate of options with respect to criteria and sub-criteria.

Assume that there is *l* numbers of supplier, A_i, *i* = 1,2,…,*l*. Let $\tilde{R}^s_{inyk}$=(a_{inyk} ,b_{inyk} , c_{inyk}), be the linguistic rating of each supplier A_i on sub-criteria C^s_{ny}, by DM D_k. The aggregated fuzzy rating of supplier A_i on sub-criteria C^s_{ny}, denoted as $\tilde{R}^s_{iny}$=(a_{iny} , b_{iny} , c_{iny}), assessed by *t* DMs is defined as:

$$\tilde{R}^s_{iny} = \sum_{k=1}^{t}(I_k \otimes \tilde{R}^s_{inyk})/\sum_{k=1}^{t} I_k,$$
$$n = 1,2,\ldots,m,\ y = 1,2,\ldots,z. \quad (6)$$

The total rate of supplier A_i on criterion C^s_n is given by:

$$\tilde{R}^s_{in}= \sum_{y=1}^{z}(W^s_{ny} \otimes \tilde{R}^s_{iny}),$$
$$i=1,2,\ldots,l,\ n=1,2,\ldots,m. \quad (7)$$

The subtotal fuzzy rating of each supplier on all criteria is given by:

$$\tilde{S}^s_i= \sum_{n=1}^{m} W^s_n \otimes \tilde{R}^s_{in},\ i = 1,2,\ldots,l. \quad (8)$$

The defuzzification of $\tilde{S}_i$, denoted as S_i, is therefore also given by Equation 1.

Determining the suppliers' product scores in operational criteria

Step 1: DMs identify product quality measurement criteria and recognize the importance weights for each of them with linguistic variables. Then by Equations 4 and 5, the importance weights of each operational criteria are calculated (instead of W^s_n , here we used W^o_n). Next, acceptable limitations are recognized for each of criterion.

Step 2: Using the sampling MIL_STD 105d, a product received from each supplier is analyzed and if accepted the next step is performed.

Step 3: Acceptable limitations of each criterion are valued. The minimum value is assigned to the farthest point from target; the target point gains the maximum point whereas points out of Acceptable limitations would gain zero value.

Step 4: The product score is calculated with respect to acceptable limitations' values and importance weights of criteria.

Assume that there is *q* number of product of A_i, shown by p = 1,2,...,q. If *m* is the number of operational criteria show by n = 1,2,...,m, then C^o_n represents operational criteria and the importance weight of this criterion shown by W^o_n. So that $\sum_{n=1}^{m} W^o_n$=1. The score of product is given by:

$$R^o_{in}= \frac{\sum_{p=1}^{q} R^o_{ip}}{q} \times W^o_n,\ p=1,2,\ldots,q. \quad (9)$$

The aggregated score of products in all operational criteria is calculated by Equation 10:

Table 5. The strategic criteria and sub-criteria.

Criteria	Sub-criteria
Quality (C_1^s)	(C_{11}^s) Reliability (quality over period of time, consistency)
Service (C_2^s)	(C_{21}^s) Reaction to demand
	(C_{22}^s) Technical support
Organization (C_3^s)	(C_{31}^s) Quality performance (ISO9000 accreditation)
	(C_{32}^s) Geography location
	(C_{33}^s) Production facilities & capacity
	(C_{34}^s) Technological capability
Relationship (C_4^s)	(C_{41}^s) Flexibility (payment, fright, price reduction, freight, order frequency and amount)
Cycle time (C_5^s)	(C_{51}^s) Delivery lead time

$$S_i^o=\sum_{n=1}^{m} R_{in}^o, \quad n=1,2,\ldots,m. \qquad (10)$$

Determining the suppliers' final scores in operational and strategic criteria

If we show suppliers score in strategic criteria with S_i^s, and the suppliers (product) scores in operational criteria with S_i^o, we will have this for final score:

$$TS_i = (1 + St_i) \times S_i^o, \qquad (11)$$

Where St_i is:

$$St_i = \begin{cases} \dfrac{S_i^s}{\sum_{i=1}^{l} S_i^s / l} - 1, & \text{if } S_i^s > \dfrac{\sum_{i=1}^{l} S_i^s}{l}, \\ 0, & \text{otherwise,} \end{cases}$$

i=1,2,…,l.

Ranking the suppliers

We normalize all scores TS_i into a 1-0 scale by Equation 12 (Amin and Razmi, 2009; Chou and Chang, 2008):

$$\text{Score}(A_i) = \frac{TS_i - \min_{i=1,2,\ldots,m}\{TS_i\}}{\max_{i=1,2,\ldots,m}\{TS_i\} - \min_{i=1,2,\ldots,m}\{TS_i\}} \qquad (12)$$

EMPIRICAL CASE STUDY

Case company X has produced auto parts since 2002. In order to modify re-buy, this company wants to reduce the number of suppliers and select the best of them. In this case study, we chose one of the products that had variety supply, for further investigation.

Phase 1

Step 1: This Company appointed a special committee consisting of four managers from various functional departments, responsible for selecting the best suppliers; the production manager, the design and engineering managers, the marketing manager, and the quality manager. The importance weights for them were assigned. DMs then used linguistic importance weight variables (Table 4). DMs selected strategic criteria based on the company's strategy for this chosen product. Table 5 shows these criteria and relative sub-criteria.

Step 2: The decision makers investigated the weights of criteria and sub-criteria through Equations 2 to 5. Total weights were calculated in the forms of fuzzy numbers, defuzzified numbers and normalized numbers. Tables 6 and 7 show the results.

Step 3: The decision makers assessed the rating of suppliers through linguistic variables with respect to the sub-criteria. Total rate of each supplier on sub-criterion was calculated by Equation 6. For instance, Table 8 shows the calculations of 3 sub-criteria. Table 9 shows the rating of each supplier on all criteria which have been obtained by Equation 7. The subtotal fuzzy rating of each supplier on all criteria was calculated by Equation 8 and the corresponded defuzzified numbers obtained through Equation 1.

Phase 2

Step 1: Each decision maker identifies product quality measurement criteria and determined acceptable limitations for each of these criteria and then defines the importance weights of them (Table 10).

Step 2: Each received consignment from suppliers was analyzed by MIL_STD 105d method, and the

Table 6. The linguistic and aggregated importance weights of the strategic sub-criteria.

Sub-criteria	DMs' linguistic weights				Aggregated weights		
	DM_1	DM_2	DM_3	DM_4	Fuzzy	Defuzzified	Normalized
C^s_{11}	VH	VH	VH	VH	(9,10,10)	9.75	1
C^s_{21}	VH	VH	H	VH	(8.6,9.8,10)	9.55	0.59
C^s_{22}	MH	H	L	H	(5.11,6.63,8.13)	6.72	0.41
C^s_{31}	MH	H	ML	MH	(3.8,5.7,7.3)	5.6	0.21
C^s_{31}	VH	VH	H	MH	(7.6,0.1,9.7)	4.4	0.17
C^s_{33}	MH	H	VH	VH	(7.2,8.9,9.7)	8.68	0.33
C^s_{34}	MH	MH	H	H	(5.8,7.9,9.2)	7.7	0.29
C^s_{41}	MH	VH	H	VH	(7.36,8.94,9.7)	8.7	1
C^s_{51}	H	H	VH	VH	(7.86,9.46,10)	9.2	1

Table 7. The linguistic and aggregated importance weights of the strategic criteria.

Criteria	DMs' linguistic weights				Aggregated weights		
	DM_1	DM_2	DM_3	DM_4	Fuzzy	Defuzzified	Normalized
C^s_1	VH	VH	H	MH	(7.6,9.1,9.7)	8.8	0.21
C^s_2	H	VH	VH	H	(7.86,9.46,10)	9.2	0.23
C^s_3	ML	VH	VH	H	(5.9,7.7,8.7)	7.5	0.18
C^s_4	ML	ML	H	VH	(4.8,6,7.4)	6.1	0.15
C^s_5	H	H	VH	VH	(7.86,9.46,10)	9.2	0.23

Table 8. The linguistic and aggregated fuzzy ratings of sub-criteria.

Sub-criteria	Suppliers	DMs' linguistic ratings				Aggregated fuzzy ratings
		DM_1	DM_2	DM_3	DM_4	
C^s_{11}	A_1	G	MG	MG	G	(61.43,80.86,95.13)
	A_2	MG	F	MG	F	(40,59.7,79.74)
	A_3	G	MG	MG	MG	(56.43,75.71,92.56)
C^s_{21}	A_1	F	G	G	F	(47.14,68.3,61.54)
	A_2	G	G	F	G	(62.86,82,93.1)
	A_3	MG	G	G	MG	(58.6,79.1,94.9)
C^s_{22}	A_1	MG	G	F	MG	(51.43,71.1,87.9)
	A_2	G	F	MG	MG	(51.43,70.6,87.44)
	A_3	MG	G	G	G	(63.6,84.3,97.44)

consignment is accepted with respect to this method.

Step 3: Acceptable limitations were valued according to table 11. For example, the maximum point of C_1^o is obtained through multiplying its weight, that is, 0.19 by 100 which would be 19. Also the minimum point would be 1 such that 19 is assigned to the target point which is 60 and 1 is assigned to the 55 and 65 which are the farthest points from target point.

Step 4: the product score was calculated by Equations 9 and 10. Table 12 shows the results.

Phase 3

In this phase, the suppliers' final score in two sets of criteria was calculated by Equation 11. The results are given in Table 13.

Phase 4

In this phase, the suppliers were ranked by Equation 12. The results are given in Table 13.

Table 9. The aggregated fuzzy and defuzzified (crisp) ratings of strategic criteria for each supplier.

Criteria	Fuzzy and defuzzified ratings of suppliers					
	A_1		A_2		A_3	
	Fuzzy	Defuzzified	Fuzzy	Defuzzified	Fuzzy	Defuzzified
C_1^s	(61.43, 80.86, 95.13)		(40,59.7,79.74)		(56.43,75.71,92.56)	
C_2^s	(48.9,69.5,72.35)		(58.2,77.35,90.83)		(60.7,81.3,95.95)	
C_3^s	(70.56,89.7,98.67)		(49.77,70.11,88.1)		(55.38,74.95,91.03)	
C_4^s	(66.43,88.6,97.7)		(69.43,87.7,95.6)		(87.9,95.43,100)	
C_5^s	(81.43,92.6,100)		(68.6,90,98.31)		(61.43,80.86,95.13)	
Aggregated	(64.54,83.71,92.04)	81	(57.07,77.26,90.45)	75.5	(63.11,81.01,94.83)	79.99

Table 10. The linguistic and aggregated importance weights of the operation criteria.

Criteria	Acceptable limitation	DMs' linguistic weights				Aggregated weights		
		DM_1	DM_2	DM_3	DM_4	Fuzzy	Defuzzified	Normalized
Hardness (C_1^o)	60±5	VH	VH	H	VH	(8.64,9.8,10)	9.56	0.19
Tensile (C_2^o)	≤7	H	VH	VH	H	(7.86,9.46,10)	9.2	0.18
Elongation (C_3^o)	≤250	ML	VH	VH	H	(5.93,7.74,8.72)	7.53	0.15
Tear (C_4^o)	≤10	ML	ML	H	VH	(4.1,6,7.44)	5.9	0.12
Internal diameter (C_5^o)	29±0/2	H	H	VH	VH	(7.9,9.5,10)	4.5	0.1
External diameter (C_6^o)	40±0/5	MH	MH	ML	MH	(4.3,6.2,8.1)	6.2	0.11
Tick edge (C_7^o)	3±0/30	MH	H	MH	H	(6,8.03,9.5)	7.9	0.15

Table 11. The scores of operation criteria.

Criteria		
C_1^o	Acceptable limitation	55 ← 60 → 65
	Score	1 ← 19 → 1
C_2^o	Acceptable limitation	7 → 18
	Score	1 → 18

As can be seen, supplier A_1 was selected as top supplier and supplier A_3 was ranked in second place.

Conclusion

Dimensionality reduction in a proper manner will lead to increasing the efficiency of decision making process. In this paper, we used fuzzy multi-criteria decision making model for solving supplier selection problem in modified re-buy situation. While most of current methods consider just operational criteria our simple method considers strategic and operational criteria simultaneously. We employed business process improvement as strategic criteria and the product quality measurement indicators as operational criteria. This method can increase the quality of products and enhance supplier's levels because it ranks supplier's products and causes them to compete for producing high quality products. Therefore, in this paper we employed linguistic variables to give importance to the weights of criteria and the rates of suppliers.

We also tried to coordinate our attempts about obtaining an optimized result in this field with organizational objects through assigning weights to each decision maker and also by contribution of all levels of the organization in assessment process.

LIMITATIONS AND FUTURE RESEARCH

We applied this method in a raw material supplier belonging to one of automobile parts manufacturing

Table 12. The product score in operation criteria.

Criteria	A_1 (Product)	A_2 (Product)	A_3 (Product)
C_1^o	3.42	3.42	3.42
C_2^o	2.16	1.8	1.98
C_3^o	1.65	1.2	1.5
C_4^o	0.96	0.96	0.96
C_5^o	0.6	0.5	0.6
C_6^o	0.77	0.77	0.77
C_7^o	1.05	1.2	1.05
Aggregated	10.61	9.76	10.28

Table 13. The final rates, scores and ranks of suppliers.

Suppliers	TS_i	Score(A_i)	Rank
A_1	10.91	1	1
A_2	9.76	0	3
A_3	10.42	0.6	2

company in corrected repurchase condition. Since conditions of companies differ with each other so we could not conclude that the results of this study are applicable in other companies too. This is one of the restrictions of our study. For future studies, we suggest applying this method in other industries and other purchase conditions. We also suggest carrying out more studies on the influences of product ranking on supplier's development which will lead to more clarifying of advantages of this method.

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