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A non-additive fuzzy hybrid model for supplier evaluation and prioritization: A case study of automotive brake system manufacturer

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Abstract

Nowadays, due to the competitive conditions of global market, corporations try to outsource their extraneous processes to third-party suppliers. So, selecting a proper supplier play a significant role in organization success. The supplier selection problem can be viewed as a group decision-making problem with multiple criteria. Since in previous researches the inter relationship between criteria and sub-criteria lacks attention, this paper presents a new model which considers these relationship. Firstly, this model has determined interrelationships between criteria through Interpretive Structural Modeling(ISM), and then calculated the relative weights of each sub-criterion by considering their interactions and using the Fuzzy Analytic Network Process (FANP). Finally, the optimal supplier has been selected by applying obtained relative weights to calculate performance score of candidate suppliers in each sub-criterion and using fuzzy Choquet integral (a non-additive fuzzy integral) to remove the effects of sub-criteria interactions on performance score. A case study of an automotive brake system manufacturer in selecting its machining outsourcing suppliers is illustrated to demonstrate our model applicability in practical cases. The analytical results of this case study demonstrate the capability of the proposed model for solving group decision-making problems.

Keywords: Supplier, Multiple Criteria Decision Making (MCDM), Fuzzy Analytic Network Process (FANP), Interpretive Structural Modeling (ISM), Non-additive fuzzy integral.

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Introduction

Corporations need to work with different suppliers to continue their activities. In manufacturing industry the cost of raw materials and component parts constitutes the main cost of a product, so that in some cases it can account for up to 70%. In such circumstances the purchasing department can play a key role in cost reduction, and supplier selection is one of the important functions of purchasing management (Ghoudsypour & O'Brien, (1998)).As organizations become more dependent on suppliers the direct and indirect consequences of poor decision making become more important. The featured industrial companies invest more than half of their capital on purchasing required raw materials and parts. This investment share is increasing in automotive companies because of the current tendency toward company downsizing and outsourcing. (De Boer et al., (2001)). The supplier evaluation and performance measurement systems were developed and cut much waste and costs of corporations.

It is necessary to perform an evaluation process after identifying the potential suppliers, to obtain final supplier(s). Many experts believe that there is not a single method for evaluating final suppliers. Therefore, organizations can use different procedures to prioritize suppliers depending on their specialist's opinion and current situation.

This paper is organized as follows: Section 2 reviews corresponding literatures. Section 3 investigates the proposed model and goes over the key concepts of Interpretive Structural Modeling, Analytic Network Process, fuzzy measures and fuzzy integral. The implementation stages of proposed model are illustrated in Section 4 by a case study. The final section demonstrates results and conclusion.

Literature *Review*

During the half century that supplier selection issue has been considered, different methods have been developed and presented for it. The primary researches in this area return to early 1960s where Dickson (1966) sent questionnaires to 170 business managers throughout the United States and identified 23 different criteria for supplier selection problem. He ranked the criteria and assigned the highest weight to price and quality criteria. Weber et al. (1991) studied and classified the presented researches about supplier selection criteria and methods since 1966-1991. They reviewed 74 related papers and concluded that the considered criteria for supplier selection process are the same Dickson's criteria but, quality and price concepts are different from those proposed by him. They also concluded that supplier selection problem is a multiple criteria problem which addition to price and quality criteria, other criteria such as service rates and performance history should be also considered in it. De Boer et al. (2001) reviewed the decision methods reported in the literature and divided the supplier selection process into four phases: (1) defining problem; (2) defining the criteria; (3) pre-qualifying suitable suppliers; (4) making a final choice. The two last phases (3 and 4) are practically the major stages of supplier selection process. In the first phase of supplier selection an organization needs an outside supplier to meet its requirements. A list of desired criteria for supplier evaluation will be determined in the second phase.

The third phase consists of selecting of proper suppliers. Pre-qualification is the process of reducing the number of suppliers (De Boer et al., (2001)). The presented methods for pre-qualification of suitable suppliers can be classified into three major categories: (i) Data Envelopment Analysis (DEA), (ii) Cluster Analysis (CA), and (iii) Case Based Reasoning (CBR).

Finally, the fourth phase consists of evaluating the suppliers who are passed the pre-qualification phase and selecting the best ones as the main suppliers. Different methods and techniques have been proposed for final choice of a supplier which can be divided into four main groups: (i) Multi-Attribute Decision Making (MADM) methods, (ii) Multi-Objective Decision Making (MODM) and Mathematical programming models, (iii) Statistical methods, (iv) Artificial Intelligence (AI)-based models.

In recent years, many researchers have evaluated suppliers through Multi-Criteria Decision Making methods. Çebi and Bayraktar (2003) applied an integrated Lexicographic Goal Programming (LGP) and analytic hierarchy process (AHP) model to evaluate raw materials suppliers of a food company. In proposed model, firstly, suppliers were evaluated according to the 14 criteria by AHP method then, their scores entered into the LGP model and the purchase amount from each supplier were also calculated. Chan and Chan (2004) adopted AHP and quality management system principles in the development of the supplier selection model. In proposed model, suppliers have been evaluated based on the six primary criteria and twenty secondary sub-criteria in a hierarchical structure and suppliers performance is evaluated according to the customer requirements. Talluri et al. (2008) combined DEA and multi-objective programming for selecting buyer-supplier negotiations strategies. Wang et al. (2009) combined AHP and TOPSIS and through metric distance method proposed fuzzy hierarchical TOPSIS for selecting a set of suppliers.

Among the conducted researches only a few addressed supplier selection problem from viewpoint of criteria interdependence. Shyur and Shih (2006) developed a hybrid MCDM model which consideres criteria interdependence issue. First, they calculated the relative weights of multiple evaluation criteria by a five-step hybrid process, which incorporates the ANP with interdependence. Then, the modified TOPSIS is adopted to rank alternatives in terms of their overall performances. Yang et al. (2008) studied the effects of a non-additive model and criteria interrelationships influence on vendor selection process. In the presented method, first, they used ISM to map out the relationships among the sub-criteria. Then, the relative weights for each criterion are computed by the fuzzy analytical hierarchy process (FAHP) method. Then, a non-additive fuzzy integral is adopted to obtain the fuzzy synthetic performance of each common criterion and determine the best vendor according to the overall priority score of them. At the end, they concluded that the proposed non-additive method is more appropriate than the additive methods when sub-criteria are interdependent, and the results can provide a better estimation of vendor abilities. Lang et al. (2009) similar to Yang et al. (2008) presented a non-additive model. The proposed model computed the weights of criteria by ANP method and same as the Yang et al. (2008) method, evaluated performance of each supplier through a non-additive fuzzy integral.

Methodology

In this paper, a non-additive fuzzy hybrid MCDM model is presented for supplier evaluation and selection. First, we obtained the necessary evaluation criteria from the viewpoint of problem experts. Next, the relationships and interdependence type of criteria is determined by ISM method. Then, the fuzzy pair-wise comparisons matrix is formed according to the criteria relationships graph and ANP matrix is adopted for calculating the weights of criteria. Finally, the performance score of each supplier is computed by obtained fuzzy measures and supplier's fuzzy performance. Section 4 is illustrated a real case study to demonstrate the applicability of proposed model in real world problems.

In the past, many researches and methods were developed to identify the required criteria for supplier selection problem. The first study about this issue was done by Dickson (1966). He prepared a summarized list including at least 50 different factors that was presented by writers for investigation in supplier selection decisions. The subsequent researches were extremely influenced by Dickson's work and typically considered as an extension of it.

In this paper, the desired criteria are identified through literature review, library studies and interviews with experts of suppliers' evaluation department in under-studied company.

In a completely interdependent system, all components of the system are mutually related, directly or indirectly. Thus, any interference with one of the component affects all the others. Therefore, decision makers are looking for methods which could help them in identifying the structural relationships among criteria in a system. One of the proposed methods for this purpose is Interpretive Structural Modeling (Warfield, (1973)). The aim of ISM is to help decision makers for analyzing a complex structure and breaking it down to a simple hierarchical structure, and identifying the structural relationships among criteria in a system.

The general form of the judgment matrix of experts (evaluators) which is named adjacency matrix A can be expressed by:

$$A = \begin{array}{c} \\ C_{i1} \\ C_{i2} \\ \vdots \\ C_{it} \end{array} \begin{array}{c} \begin{array}{cccc} C_{i1} & C_{i2} & \dots & C_{it} \end{array} \\ \begin{bmatrix} 0 & e_{12}^{p} & \dots & e_{1t}^{p} \\ e_{21}^{p} & 0 & \dots & e_{2t}^{p} \\ \vdots & \vdots & \ddots & \vdots \\ e_{t1}^{p} & e_{t2}^{p} & \dots & 0 \end{bmatrix}_{t\times t} \end{array} \quad (1)$$

$$r = 1,\dots,t \,;\, p = 1,\dots,P$$

Where $e_{rr'}^{p}$ denotes the value of the relation between C_{ir} and $C_{ir'}$ sub-criteria given by p^{th} expert. If the answer given by expert p for sub-criterion C_{ir} inflecting the sub-criterion $C_{ir'}$ is ‘‘Yes”, then, $e_{rr'}^{p} = 1$; otherwise, the value of $e_{rr'}^{p} = 0$ is given.

To obtain the consensus opinion of all evaluators, a mode method is applied to calculate the value of the opinions of expert p for the relationships among sub-criteria in the adjacency matrix A. If the majority opinion is ‘‘1”, the value of the relationship for the sub-criterion is ‘‘1”, which represents the related sub-criteria. Likewise, if the majority opinion is ‘‘0”, the value of the relationship for the sub-criterion is ‘‘0”, which means the sub-criteria are not related; furthermore, if the majority evaluator answer is ‘‘1”, this represents the intensities of different dependencies among sub-criteria. Consequently, the most frequent value (i.e., 0 or 1) of the comparisons among sub-criteria is called the mode (Yang et al., (2008)). At this stage, the reachability matrix T is computed by:

$$T = T + I$$

$$T^{l} = T^{l+1}, \text{ when } l > 1 .$$

Where I is the identity matrix, l denotes the number of times we multiply T with itself and T^{l} is the stable reachability matrix. Note that the reachability matrix is calculated under the operators of the Boolean multiplication and addition law. (i.e., $1\times 1=1$, $1\times 0=0\times 1=0$, $0\times 0=0$, $1+1=1$, $1+0=0+1=1$, and $0+0=0$)

The ANP is an extension of the AHP. The networks are base structures of ANP and priorities are derived as well as the priority extraction method in AHP from the pair-wise comparison judgments. The feedback structure does not have the linear top-to-bottom form of a hierarchy but looks more like a network, with cycles connecting its components of elements, which we can no longer call levels, and with loops that connect a component to itself (Saaty & Vargas, (2006)) (Fig. 1).

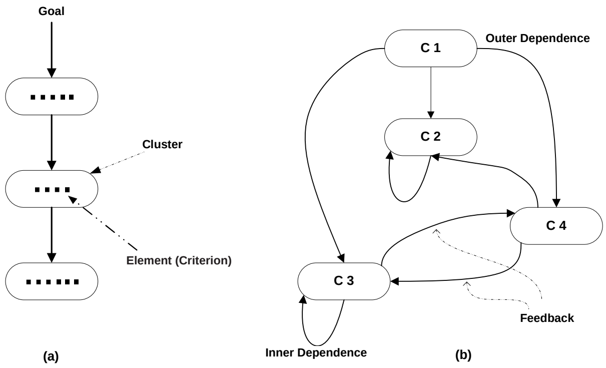

Fig.1. A sample of a hierarchy (a) and a network (b)

The ANP method consists of the following four steps (Saaty, 1996):

(1) Problem definition and building the model;

(2) Forming the pair-wise comparison matrices and priority vectors, and calculating the inconsistency rate of each matrix;

(3) Calculating the supermatrix;

(4) Extracting the priorities from supermatrix and conclusions.

Fuzzy set theory was first developed by Zadeh (1965) in 1965 as a mathematical approach to representing uncertain and imprecise measurements. Fuzzy set theory has provided an appropriate methodology to deal quantitatively with decision-making problems that are associated with imprecise parameters.

Many fuzzy AHP and fuzzy ANP methods are proposed to solve various types of problems. The EAM was first introduced by Chang (1996) for handling FAHP model. The proposed EAM by Chang (1996) has more application than many other FAHP and FANP approaches. In this study, we adopted the Chang's extent analysis method.

Triangular fuzzy numbers are used in EAM. The concepts and definitions of FAHP and FANP based on the EAM are briefly discussed here. Consider

$M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers (TFN) as shown in Fig. 2 (Lee (2009)). The fuzzy arithmetic operations of M_1 and M_2 can be expressed as follows (Hugos, (2003)):

$$M_1 \oplus M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$$

$$M_1 \otimes M_2 = (l_1.l_2, m_1.m_2, u_1.u_2)$$

$$M_1^{-1} = (\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1})$$

$$M_2^{-2} = (\frac{1}{u_2}, \frac{1}{m_2}, \frac{1}{l_2})$$

Note that the product of two multiplied TFNs or inverse of a TFN is no longer a triangular fuzzy number. These relationships give only an approximation of real product and inverse of TFNs (Lee(2009)).

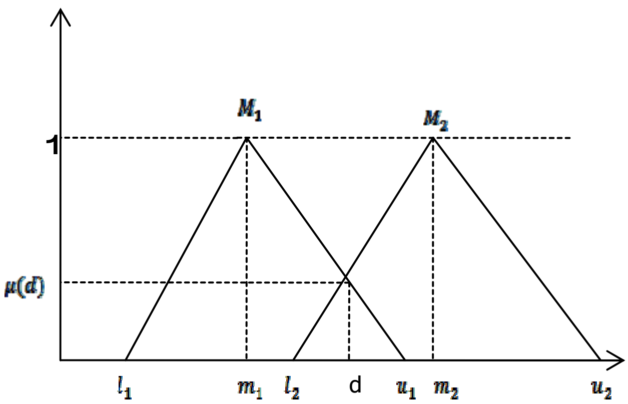

Fig. 2. Two triangular fuzzy numbers M_1 and M_2.

In EAM, the value of fuzzy synthetic extent for each row of pair-wise comparison matrix is calculated as:

$$S_k = \sum_{j=1}^{n} M_{kj} \otimes \left[\sum_{i=1}^{m} \sum_{j=1}^{n} M_{ij} \right]^{-1}$$

Where, S_k is a TFN and represents the value of fuzzy synthetic extent of row k and, i and j denote the alternatives and criteria, respectively.

After calculating S_k, the magnitude degree of them must be compared toward each other. Generally, if M_1 and M_2 be two TFNs then, the magnitude degree of M_1 on M_2 is shown by $V(M_1 \geq M_2)$ and defined as:

$$\begin{cases} V(M_1 \geq M_2) = 1 & if\ m_1 \geq m_2 \\ V(M_1 \geq M_2) = hgt(M_1 \cap M_2) = \mu(d) & otherwise \end{cases}$$

where,

$$hgt(M_1 \cap M_2) = \frac{u_2 - l_2}{(u_2 - l_2) + (m_2 - m_2)}.$$

The magnitude rate of a TFN respect to k other TFNs is calculated by the below equation:

$$V(M_1 \geq M_2, \ldots, M_k) = V(M_1 \geq M_2), \ldots, V(M_1 \geq M_k)$$

The weights of criteria in pair-wise comparisons matrix can be computed as:

$$w'(x_i) = \min\{V(s_i \geq s_k)\} \qquad k = 1,2,\ldots,n,\ k \neq i$$

Therefore, the weight vector of criteria is:

$$w' = [w'(x_1), w'(x_2), \ldots, w'(x_n)]^n,$$

That is the non-normalized eigenvector in FAHP and FANP.

The fuzzy measure concept, first, is introduced by Sugeno (1977) and used widely in real world problems. This is applying to show the membership degree of an object in a set. Since the specification of general fuzzy measures is extremely cumbersome, Sugeno proposed a λ-fuzzy measure to facilitate the fuzzy measure calculations.

Definition 1. Function g in triple space of (β, g, X) is called a λ-fuzzy measure if and only if, it exists a $\lambda \in \left(\frac{-1}{\sup g}, \infty \right)$, where $\sup g = \sup_{A \in P(X)} g(A)$, so that:

$$g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B)$$

In general, for the set $\{x_1, x_2, \ldots, x_n\}$, the fuzzy measure $g_\lambda(X) = g_\lambda(\{x_1, x_2, \ldots, x_n\})$ can be formulated as follows:

$$g_\lambda(\{x_1, x_2, \ldots, x_n\}) = \sum_{i=1}^{n} g_i + \lambda \sum_{i_1=1}^{n-1} \sum_{i_2=i_1+1}^{n} g_{i_1} g_{i_2}$$

$$+ \cdots + \lambda^{n-1} g_1 g_2, \ldots, g_n$$

$$= \frac{1}{\lambda}\left| \prod_{i=1}^{n} (1 + \lambda g_i) - 1 \right|, \quad for\ -1 < \lambda < \infty$$

The λ parameter is a unique number which describes the degree of dependency between elements. In MCDM problems, x_i ($i = 1, 2, \ldots, n$) are considered as desired criteria.

According to the above definition it is proved that the unique number of λ has three below properties (Tzeng et al., (2005)):

i. If $\sum_{i=1}^{n} g_i > 1$, then $-1 < \lambda < 0$ and there are the substitutive effect between elements.

ii. If $\sum_{i=1}^{n} g_i = 1$, then $\lambda = 0$ and there are the aggregate effect between elements.

iii. If $\sum_{i=1}^{n} g_i < 1$, then $\lambda > 0$ and there are the additive effect between elements.

Unlike the additive methods where are considered the weights of criteria completely normal, in fuzzy measure method the weights of criteria are not necessarily normal. This feature causes the degree of dependency between criteria will be considered in evaluation process and makes the earned scores by alternatives to be more accurately than the additive methods.

In many MCDM models, the weighted average method is applied to calculate final scores of alternatives. This method assumes that the criteria are completely independent and non-interactive. However, due to some inherent interactions and inter dependencies among criteria, this assumption is not realistic in many real world applications.

The fuzzy integral method is a way that attempts to consider the criteria interdependencies. Applying it in decision making environments with criteria interactions will be resulted to consider the dependencies and more accurate calculation of alternatives scores. The Choquet integral (a non-additive fuzzy integral) is used for computing final score of suppliers.

Definition 2. Let h be a measurable function from X to [0, 1] and g be a fuzzy measure on X, then the Choquet integral of h is defined as following equation (Feng et al., (2010)):

$$\int h(x)dg$$

$$= h(x_n)g(H_n) + [h(x_{n-1}) - h(x_n)]g(H_{n-1})$$

$$+ \cdots + [h(x_1) - h(x_2)]g(H_1)$$

$$= h(x_n)[g(H_n) - g(H_{n-1})]$$

$$+ h(x_{n-1})[g(H_{n-1}) - g(H_{n-2})] + \cdots + h(x_1)g(H_1)$$

Where, $h(x_i)$ is a descending function and

$$H_1 = \{x_1\}, H_2 = \{x_1, x_2\}, \ldots, H_n = \{x_1, x_2, \ldots, x_n\}$$

In MCDM problems, h can be often considered as the performance of each alternatives respect to each criteria.

Case study

We have implemented our proposed model in a real case study to evaluate and prioritize a group of suppliers. The under-studied company activates include manufacturing different types of automotive brake systems. This company decided to outsource a part of the Peugeot brake system, called master cylinder to a qualified supplier. Therefore, the presented model in this paper is executed to help the company to select a supplier. The executive stages of our model are illustrated step-by step as follows:

Identifying desired criteria and sub-criteria for supplier evaluation

The first step of the model is identifying desired criteria and sub-criteria of the company for supplier selection. This criteria and related sub-criteria are identified through literature review, library studies and interviews with experts of suppliers' evaluation department in the company as presented in Table1.

Determining the alternatives

Considering the multiplicity and diversity of supplier's operations and productions in the under-studied company, four suppliers of S1, S2, S3 and S4 selected for the Peugeot master cylinder machining.

Determining interrelationships between criteria and sub-criteria by ISM method.

In this step, ISM method is adopted to clarify the relationship type and interactions between criteria and sub-criteria for supplier selection problem. The related results from the experts' opinions are presented in Table 2.

Table1. Criteria and sub-criteria for the company supplier evaluation

Criteria	Sub-criteria
Quality (Q)	Adherence to the obligations of quality (q_1)
	Percent of defective items in delivered batches (q_2)
	Average time of troubleshooting (q_3)
Cost (C)	Price stability (c_1)
	Ordering cost (c_2)
	Purchase cost per unit (c_3)
Supply chain support (D)	Reactivity to the purchase order (d_1)
	Timely delivery (d_2)
	After-sales service (d_3)
	Proper technical abilities(t_1)
	Production capacity (t_2)
	Modern technology (t_3)

Table 2.The calculations of relation matrix of criteria by ISM method

	Q	C	D	T
Q	0	1	0	0
C	1	0	1	0
D	1	0	0	0
T	1	0	1	0

A

	Q	C	D	T
Q	1	1	0	0
C	1	1	1	0
D	1	0	1	0
T	1	0	1	1

T=A + I

	Q	C	D	T
Q	1	1	1*	0
C	1	1	1	0
D	1	1*	1	0
T	1	1*	1	1

1=2

	Q	C	D	T
Q	1	1	1	0
C	1	1	1	0
D	1	1	1	0
T	1	1	1	1

1=3

Where the star (*) indicates the derivative relation which does not emerge in the original relation matrix (i.e., **A+I**).

The relationships graph of criteria respect to Table 2 is shown in Fig. 2.

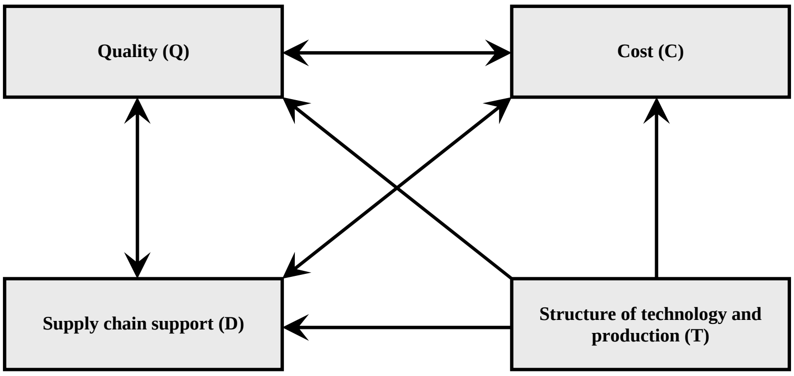

Fig. 2. The relationships diagram between criteria

Calculating the weights of criteria and sub-criteria by FANP method

In this step, a five-level linguistic variable scale is used to pair-wise comparisons of criteria. The fuzzy numbers corresponding to linguistic variables are represented by TFNs. The linguistic variables, ‘‘very good”, ‘‘good”, ‘‘fair”, ‘‘bad”, and ‘‘very bad” correspond to the fuzzy five-level scale used by the experts to score each criterion as ‘‘absolutely important”, ‘‘very strongly important”, ‘‘essentially important”, ‘‘weakly important”, and ‘‘equally important”, respectively (see Fig. 3).Table 3 shows the fuzzy numbers and inverse fuzzy numbers for transforming the five-level linguistic variable scale into triangular fuzzy numbers.

Therefore, the pair-wise comparison matrix can be constructed as TFNs by range 1/9 to 9 of Saaty's scale. Next, the weights of criteria and sub criteria are calculated by fuzzy pair-wise comparisons of supplier evaluation experts through FANP method. Table 4 summarized related calculations with pair-wise comparisons of quality sub-criteria respect to price stability, for instance. To calculate the overall priority in an interdependent system, the local priority vectors would be entered into corresponding columns of a matrix called "supermatrix". The obtained priorities from pair-wise comparison matrix considered as a part of supermatrix. Table 5 presented the supermatrix according to the obtained weights from pair-wise comparisons.

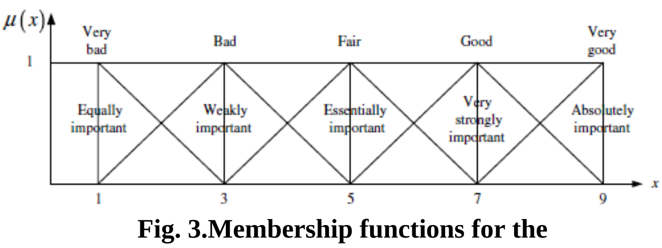

Fig. 3.Membership functions for the linguistic variable defined in this paper

Table 3.Triangular fuzzy numbers corresponding to linguistic variables

Fuzzy numbers		Inverse fuzzy numbers	
$\tilde{1}$	(1,1,3)	$\tilde{1}^{-1}$	(1/3,1,1)
$\tilde{3}$	(1,3,5)	$\tilde{3}^{-1}$	(1/5,1/3,5)
$\tilde{5}$	(3,5,7)	$\tilde{5}^{-1}$	(1/7,1/5,1/3)
$\tilde{7}$	(5,7,9)	$\tilde{7}^{-1}$	(1/9,1/7,1/5)
$\tilde{9}$	(7,9,9)	$\tilde{9}^{-1}$	(1/9,1/9,1/7)

Table 4.Pair-wise comparisons of quality sub criteria respect to price stability sub-criterion

Price stability	q_1	q_2	q_3
q_1	Equally important	Very strongly important	Absolutely important
q_2		Equally important	Weakly important
q_3			Equally important

Price stability	q_1	q_2	q_3
q_1	(1,1,3)	(5,7,9)	(7,9,9)
q_2	(0.1,0.1,0.2)	(1,1,3)	(1,3,5)
q_3	(0.1,0.1,0.1)	(0.2,0.3,1)	(1,1,3)

Normal weights	
W_{q_1}	0.4303
W_{q_2}	0.2931
W_{q_3}	0.2766

Inconsistency rate	0.0708

Table 5.The unweighted supermatrix from pair-wise comparisons

	q_1	q_2	q_3	c_1	c_2	c_3	d_1	d_2	d_3	t_1	t_2	t_3
q_1	1.0000	0.0000	0.0000	0.4303	0.3333	0.4114	0.3333	0.3019	0.2955	0.2905	0.3333	0.2746
q_2	0.0000	1.0000	0.0000	0.2931	0.3333	0.31141	0.3333	0.3042	0.3824	0.3144	0.3333	0.3141
q_3	0.0000	0.0000	1.0000	0.2766	0.3333	0.2746	0.3333	0.3939	0.3221	0.3951	0.3333	0.4114
c_1	0.3267	0.3267	0.3333	1.0000	0.0000	0.0000	0.2709	0.3069	0.3818	0.4062	0.2680	0.2847
c_2	0.2671	0.2671	0.3333	0.0000	1.0000	0.0000	0.4560	0.2869	0.2743	0.2869	0.4045	0.3361
c_3	0.4062	0.4062	0.3333	0.0000	0.0000	1.0000	0.2731	0.4062	0.3439	0.3069	0.3275	0.3792
d_1	0.2766	0.2766	0.4114	0.4303	0.2970	0.2970	1.0000	0.0000	0.0000	0.3943	0.2906	0.4062
d_2	0.2931	0.2931	0.3141	0.2931	0.4064	0.4064	0.0000	1.0000	0.0000	0.3478	0.2923	0.3267
d_3	0.4303	0.4303	0.2746	0.2766	0.2966	0.2966	0.0000	0.0000	1.0000	0.2579	0.4171	0.2671
t_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
t_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
t_3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

According to the ISM calculations and relationships diagram of criteria (Fig. 2), the cluster matrix is constructed and cluster weights are calculated to form weighted supermatrix. The weighted supermatrix is computed by multiplying the cluster weights to corresponding elements of unweighted supermatrix. Here, Matlab2009 is applied to power the matrices. After 25 times exponentiation of weighted matrix, the limited weighted supermatrix calculated as Table6.

Calculating the weights of sub-criteria by fuzzy pair-wise comparisons for non-interdependent criteria

If no interdependent relationship exists among the criteria, the obtained weight from its limited supermatrix would be 0. Regarding to this issue that none of criteria can be removed, the proposed Geometric Mean (GM) method by Lin et al. (2010) is adopted to calculate the final score of suppliers. For this purpose, we need to calculate the weights of corresponding sub-criteria with non-interdependent criteria by fuzzy pair-wise comparison. Because of lack of interaction between the "structure of technology and production" criterion with other criteria, the weights are calculated as in the table7.

Suppliers' performance determination for each sub-criterion and defuzzification.

To execute our model in under-studied company, four suppliers of S_1, S_2, S_3 and S_4 are selected for the Peugeot master cylinder machining. In this step, the performance of each supplier respect to each sub-criterion is measured by experts' judgments. The judgments of experts are expressed by corresponding TFN with linguistic variables. The defuzzified values of suppliers' performance would be considered as one of the fuzzy integral inputs. Since, the company has no an appropriate database contains of past purchase information and history of suppliers, the required information for supplier evaluation respect to the defined criteria were not available. Therefore, it is suitable to measure the performance of the suppliers in a fuzzy environment by the experts

A Likert-type five-point scale consists of corresponding linguistic variables with TFNs is applied to evaluate suppliers and the experts were asked to express their satisfaction level about performance of candidate suppliers according to subjective perceptions as a TFN such $E_{ij} = (L_{ij}, M_{ij}, U_{ij})$.

The three most common defuzzification methods are mean of maximal, Center of Area (COA), and the $\alpha-$cut methods (Zhao & Govind (1991); Yager(1994); Opricovic & Tzeng(2003)). But the COA methodis simple and does not need to introduce the preferences of any experts. Hence, we choose the COA method to defuzzify experts' opinion.

Table 6.The limited weighted supermatrix and sub-criteria weights

q_1	0.1431	0.1431	0.1431	0.1431	0.1431	0.1431	0.1431	0.1431	0.1431	0.1431	0.1431	0.1431
q_2	0.1330	0.1330	0.1330	0.1330	0.1330	0.1330	0.1330	0.1330	0.1330	0.1330	0.1330	0.1330
q_3	0.1308	0.1308	0.1308	0.1308	0.1308	0.1308	0.1308	0.1308	0.1308	0.1308	0.1308	0.1308
c_1	0.0961	0.0961	0.0961	0.0961	0.0961	0.0961	0.0961	0.0961	0.0961	0.0961	0.0961	0.0961
c_2	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914	0.0914
c_3	0.1079	0.1079	0.1079	0.1079	0.1079	0.1079	0.1079	0.1079	0.1079	0.1079	0.1079	0.1079
d_1	0.0974	0.0974	0.0974	0.0974	0.0974	0.0974	0.0974	0.0974	0.0974	0.0974	0.0974	0.0974
d_2	0.0976	0.0976	0.0976	0.0976	0.0976	0.0976	0.0976	0.0976	0.0976	0.0976	0.0976	0.0976
d_3	0.1015	0.1015	0.1015	0.1015	0.1015	0.1015	0.1015	0.1015	0.1015	0.1015	0.1015	0.1015
t_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
t_3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

To accomplish this part of model, first, the experts were asked to express the expected interval for each linguistic variable. The results are shown in Table 8. Then, all experts judged about the performance of each supplier and the fuzzy numbers and corresponding defuzzied values were calculated for each sub-criterion. For instance, Table 9 summarized the expert's opinion about performance of each supplier for quality sub-criterion. The performance score of each supplier is presented in Table 10.

Obtaining the fuzzy measures for interdependent sub-criteria

Fuzzy measures are one of the fuzzy integral inputs where calculated in this step in respect to presented relations and concepts.

Table 7.Pair-wise comparisons for structure of technology and production sub-criteria in respect to corresponding criterion

structure of technology and production	t_1	t_2	t_3
t_1	Equally important	Equally important	Essentially important
t_2		Equally important	Very strongly important
t_3			Equally important

structure of technology and production	t_1	t_2	t_3
t_1	(1,1,3)	(1,1,3)	(3,5,7)
t_2	(0.3,1,1)	(1,1,3)	(5,7,9)
t_3	(0.1,0.2,0.3)	(0.1,0.1,0.2)	(1,1,3)

Normal weights	
W_{t_1}	0.3428
W_{t_2}	0.3885
W_{t_3}	0.2687

Inconsistency rate	0.0109

Calculating the score of suppliers by fuzzy integral method for interdependent criteria

The performance score of interdependent criteria are calculated through Choquet integral by means of fuzzy measures according to Table 11.

Table 8.The expected interval of expert for each linguistic variable

	Minimum	Medium	Maximum
Very poor	0	15	30
Poor	25	35	50
Medium	40	50	70
Good	65	70	85
Very Good	80	90	100

Calculating the score of suppliers by weighted average method for non-interdependent criteria

Structure of technology and production criterion has no interaction with other criteria. Here, the simple additive weighted (SAW) method is applied to calculate hybrid score of this criterion. So, the score of each supplier according to the obtained weights are:

Score of supplier $S_1 =$

$$= 53.33 \times 0.3428 + 53.33 \times 0.3885 + 53.33 \times 0.0.2687 = 53.33$$

Score of supplier $S_2 =$

$$= 90 \times 0.3428 + 73.33 \times 0.3885 + 90 \times 0.0.2687 = 83.52$$

Score of supplier $S_3 =$

$$= 73.33 \times 0.3428 + 36.67 \times 0.3885 + 15 \times 0.0.2687 = 43.41$$

Score of supplier $S_4 =$

$$= 73.33 \times 0.3428 + 90 \times 0.3885 + 90 \times 0.0.2687 = 84.29$$

Table 9.The expert's opinion about the performance of suppliers for quality sub-criteria

Quality	q_1	q_2	q_3
S_1	Medium	Medium	Good
S_2	Good	Good	Very good
S_3	Poor	Very poor	Very poor
S_4	Medium	Good	Very good

Quality	q_1	q_2	q_3
S_1	(40,50,70)	(40,50,70)	(65,70,85)
S_2	(65,70,85)	(65,70,85)	(80,90,100)
S_3	(25,35,50)	(0,15,30)	(0,15,30)
S_4	(40,50,70)	(65,70,85)	(80,90,100)

Quality	q_1	q_2	q_3
S_1	53.33	53.33	73.33
S_2	73.33	73.33	90.00
S_3	36.67	15.00	15.00
S_4	53.33	73.33	90.00

Table 10.The performance score of suppliers

	q_1	q_2	q_3	c_1	c_2	c_3	d_1	d_2	d_3	t_1	t_2	t_3
S_1	53.33	53.33	73.33	53.33	53.33	90.00	73.33	53.33	53.33	53.33	53.33	53.33
S_2	73.33	73.33	90.00	36.67	53.33	90.00	90.00	53.33	90.00	90.00	73.33	90.00
S_3	36.67	15.00	15.00	73.33	36.67	73.33	53.33	53.33	73.33	73.33	36.67	15.00
S_4	53.33	73.33	90.00	73.33	36.67	73.33	73.33	73.33	90.00	73.33	90.00	90.00

Table 11.The score of suppliers by Choquet Integral for interdependent criteria

	q_1	q_2	q_3	c_1	c_2	c_3	d_1	d_2	d_3	Choquet Integral
S_1	53.33	53.33	73.33	53.33	53.33	90.00	73.33	53.33	53.33	60.6703
S_2	73.33	73.33	90.00	36.67	53.33	90.00	90.00	53.33	90.00	71.3416
S_3	36.67	15.00	15.00	73.33	36.67	73.33	53.33	53.33	73.33	42.8561
S_4	53.33	73.33	90.00	73.33	36.67	73.33	73.33	73.33	90.00	69.3583

Table12.The final score of suppliers

Supplier	Performance score for Q,C and D criteria by Choquet integral	Performance score for criterion T by SAW method	Final score by GM method
S_1	60.67	53.33	56.88
S_2	71.34	83.52	77.19
S_3	42.86	43.41	43.13
S_4	69.36	84.29	76.46

Determining the final score of suppliers by GM method and ranking them

The GM method is applied in this step to determine final score of suppliers according to proposed method by Lin et al. (2010). Therefore, the final score of suppliers is determined based on the obtained data in stages 8-4 and 9-4, and According to it, supplies were ranked and the best one was selected as the proper source for Peugeot master cylinder machining. Table 12 summarizes performance score of supplier for each group of criteria (interdependent or non-interdependent) and the final scores of them. As the "structure of technology and production" is a non-interdependent criterion and has no interrelationship with other criteria, it is not necessary to use the fuzzy integral method to calculate performance score of suppliers. So, the SAW method (i.e. multiplying the weight in performance) is applied.

According to the obtained scores, the final ranking of suppliers is: $S_2>S_4>S_1>S_3$.

Results and conclusion

The obtained weights of criteria indicate that the quality criterion has the more importance for the company in purchase process. Price and supply chain support criteria have the equal priority and structure of technology and production located in the next priority for the company. Because of the production type which is the automotive brake system and its significant role in human safety, the government rules and standards are monitoring the products, regularly. Therefore, as expected, the quality criterion is more important for the company than other criteria in the supplier selection process.

The properties of interdependent criteria were an emphasized issue in this paper. These properties divided into the three groups of substitutive, aggregate and additive effects.

The obtained $\lambda = 0.499997$ (which is a value greater than 0) indicate that the sub-criteria have additive effect and as a result the calculated score from fuzzy integral is less than those obtained by weighted average method.

There is no doubt that the purpose of any supplier evaluation is discovering the strengths and weaknesses of them. Obviously, whatever decision makers have a better estimation from suppliers, so, they can make more accurate decisions in the next stages. Therefore, when criteria are interacting with each other, using the non-additive methods will be more suitable than additive methods. In other words, when criteria are affecting each other, applying the additive methods will be leaded to ignore available properties among criteria and their interdependencies and, the obtained scores will not reflect capabilities of suppliers, correctly. Moreover, the dependence values of sub-criteria are obtained relatively low. According to this fact that the dependency value can be change from -1 to $+\infty$, it can be indicated that there are still many improvement potential for each supplier to develop themselves.

The obtained performance score of suppliers can help the company to identify strengths and weaknesses of suppliers. According to the final scores, suppliers are ranked as: $S_2>S_4>S_1>S_3$. So, purchasing from supplier S_2 in the short term and now is recommended and purchasing from S_3 is subject to improve their overall situation and not recommended.

Also in respect to performance score of suppliers for sub-criteria, it can be mentioned that the performance of supplier S_2 for price stability sub-criterion, performance of supplier S_3 for sub-criteria of adherence to the obligations of quality, percent of defective items in delivered batches, average time of troubleshooting, ordering cost and production capacity, and performance of supplier S_4 for ordering cost sub-criterion is lower than the expected value (less than the half of acquirable scores).

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