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The Evaluation of Supplier Selection Criteria by Fuzzy DEMATEL Method

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ABSTRACT

Supply chain management can be considered as a key component of competitive strategy to enhance organisational productivity, performance and profitability (Askarany et al,2010). The aim of this paper is use the fuzzy DEMATEL method to find the intensity of influence of supplier selection criteria. This research designed questionnaire. Questionnaires sent to ten professional experts in different departments of automobile industry in Iran. From the fuzzy DEMATEL results, we can understand the Willingness and Attitude is the most influence and the strongest connection to other criteria.
KEYWORDS: Supply chain management, supplier selection criteria, Fuzzy set, DEMATEL.

1. INTRODUCTION

The success or failure of supply chain management depends upon a suitable SCM system and appropriate suppliers. Many firms apply collaborative commerce by establishing strategic partnerships with suppliers, and involve them in the early stages of product research and development (Araz & Ozkarahan, 2007). Experts agree that supplier selection is one of the most important functions of a purchasing department, helping businesses save material cost and increase competitive advantage (Saen, 2007).A supply chain is one of the most integral parts of new business management in the design of services from suppliers to customer (Christopher, 1998). Supply chain management is an important concept and discipline which enables business partners to integrate products and services effectively and to build long-term relationships. SCM can be extensively defined as effective coordination on material, product, delivery, payment, and information flows between enterprises and trading partners (Wu and Chuang , 2010). A supply chain is characterized by a forward flow of goods and a backward flow of information, and comprises seven main business processes: customer relationship management, customer service management, demand management, order fulfilment, manufacturing flow management, procurement, product development, and commercialization. SCM has been used extensively in the manufacture of products to improve efficiency across the value chain, including the efficiency of logistics and planning activities and material and information control, both internally, within companies, and externally, between companies (Zhang et al.,2009).

Effective supply chain management will lead to a lowering of the total amount of resources required to provide the necessary level of customer service to a specific segment and improving customer service through increased product availability and reduced order cycle time. Effective supplier decisions are significant components for productions and logistics management in many firms and a correct forecast is crucial for firms (Hsu, 2003).

DEMATEL has been widely used to extract a problem structure of a complex problematique (Fontela and Gabus, 1974; Tamura, 1986). By using DEMATEL we could quantitatively extract interrelationship among multiple factors contained in the problematique. In this case not only the direct influences but also the indirect influences among multiple factors are taken into account. Furthermore, we could find the dispatching factors that will rather affect the other factors, the receiving factors that will be rather affected by the other factors, the central factors that the intensity of sum of dispatching and receiving influences is big, and so forth. DEMATEL is an extended method for building and analyzing a structural model for analyzing the influence relation among complex criteria.

The remainder of this paper is organized as follows: Section 2 discusses the Background literature. Supplier selection criteria are presented in Section 3. Section 4 describes the methodologies of fuzzy DEMATEL. Section 5 outlines an empirical study to show the process of fuzzy DEMATEL method to determine the importance and influence of selection criteria of supplier. Section 6 carries our conclusions and suggestions.

2. Background literature

Traditional methodologies of the supplier selection process in the extant literature range from single objective techniques such as the cost-ratio method, linear or mixed integer programming to goal and multi-objective linear programming models (Yan et al., 2003; Oliveria and Lourenc¸o, 2002).Haq and Kannan (2006a) developed an integrated supplier selection and multi-echelon distribution inventory model for the original equipment manufacturing company in a built-to-order supply chain environment using fuzzy AHP and a genetic algorithm. Wang and Hu (2005) have developed a

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decision-based methodology for supply chain design that a plant manager can use to select suppliers. This methodology derived from the techniques of analytical hierarchy process (AHP) and pre-emptive goal programming. Meade and Sarkis (2002) developed amodel for selecting and evaluating 3PRLP using Analytic Network Process (ANP). Similarly, Chen et al. (2006) presented a fuzzy decision-making approach to deal with supplier selection problem in supply chain system. Haq and Kannan (2006b) proposed a structured model for evaluating vendor selection using AHP and fuzzy AHP. Yang and Hung (2007) proposed a technique for order preference by similarity to ideal solution (TOPSIS) and fuzzy TOPSIS as multiple criteria decision-making (MCDM) methods in solving a plant layout design problem. Chao et al. (1993) highlight six key criteria of supplier selection and describes the responses of a sample of Chinese purchasing managers. They segment the respondents into three clusters, based on similarities in their supplier evaluation processes and differentiate these clusters in terms of whether the managers emphasize reliable deliveries, price/cost considerations, or product quality.

Li and Wang use a grey-based decision-making method to deal with fuzziness in supplier selection (Li & Wang, 2007). Pi and Low propose a supplier selection method that uses Taguchi loss functions and the Analytic Hierarchy Process (AHP) to obtain weights of major criteria (Pi & Low, 2006). Liu et al. (2000) compare suppliers for supplier selection and performance improvement using data envelopment analysis (DEA). Weber, Current, and Benton (1991) for supplier selection identified price, delivery, quality, facilities and capacity, geographic location, and technology capability. Choy and Lee (2002) propose a case-based supplier management tool (CBSMT) using the case-based reasoning (CBR) technique in the areas of intelligent supplier selection and management that will enhance performance as compared to using the traditional approach. Masella and Rangone (2000) propose four different vendor selection systems (VSSs) depending on the time frame (short-term versus long term) and on the content (logistic versus strategic) of the co-operative customer/ supplier relationships. Dickson (1966) was one of the first ones in this field of study. He identified 23 different criteria for supplier selection based on a questionnaire sent to managers of companies of North America. These criteria include quality, delivery, performance, warrant and claim policy, production facilities and capacity, net price, and technical capabilities. De Boer, Labro, and Morlacchi (2001) identified four stages in supplier selection problem which consist of problem formulation, formulation of criteria, qualification and final selection.

3. Supplier selection criteria

SCM can apply an integrally systematic model to control information flow, material and service of enterprises to satisfy customer requirements. Managers have traditionally focused on managing internal operations to promote profits. SCM emphasizes integrating internal activities and decisions with external enterprise partners to promote competitive capability (Li & Wang, 2007). A firm uses supplier criteria to evaluate whether the supplier fits its supply and technology strategy. These considerations are largely independent of the product or service sought. Supplier differentiation refers to differences derived from supplier characteristics such as organizational culture, manufacturing procedure, technology capability and geographic location distribution (Chang et al. 2007). Adopting the proper supplier group to promote competitive capability and supplier performance is the greatest task.

Based on the previous literatures, we focus on twelve Criteria of supplier selection. The criteria used in relevant literatures are listed in Table 1.

Table 1.Criteria of supplier selection.

Criteria	Reference
Quality	Weber, Current, & Benton (1991),Dickson (1966), Gunasekaran et al. (2001), Prahinski & Benton (2004), Kreng & Wang (2005), Kannan and Haq (2007), Forme et al. (2007), Chang et al. (2007), Sevkli et al.(2008)
Delivery	Rushton and Oxley (1991), Weber, Current, & Benton (1991), Christopher (1992), Dickson (1966), Gunasekaran et al. (2001), Prahinski & Benton (2004), Kreng & Wang (2005), Chang et al. (2007), Forme et al. (2007), Sevkli et al.(2008)
Service	Weber, Current, & Benton (1991),Prahinski & Benton (2004), Chang et al. (2007)
Technical/Engineering Capability	Weber &Current(1993),Meade and Sarkis (2002), Noorul & Kannan(2006), Kannan and Haq (2007), Sevkli et al.(2008)
Rejection rate	Gunasekaran et al. (2001)
Lead-time	Prahinski & Benton (2004), Chang et al. (2007), Sevkli et al.(2008)
Reaction to demand change	Prahinski & Benton (2004), Chang et al. (2007)
Production capability	Noorul & Kannan(2006), Sevkli et al.(2008)
Price	Dickson (1966), Prahinski & Benton (2004), Kreng & Wang (2005), Noorul & Kannan(2006), Chang et al. (2007), Sevkli et al.(2008)
Up to Date	Sevkli et al.(2008)
Willingness and Attitude	Ravi and Shankar (2005)
Reputation	Sevkli et al.(2008)

4. The fuzzy DEMATEL method

4.1. DEMATEL method

The DEMATEL method assumes a system contains a set of components C= {C1, C2… Cn}, with pairwise relations that can be evaluated. The methodology, according to the properties of objective affairs, can confirm the interdependence among the variables/attributes and restrict the relation that reflects the properties with an essential system and development trend. The end product of the DEMATEL process is a visual representation an individual map of the mind by which the respondent organizes his or her own action in the world (Kamaike, 2001; Yuzawa, 2002).The procedures of the DEMATEL method (Fontela & Gabus, 1976) are discussed below.

Step 1: *Generating the direct-relation matrix.* We use five scales for measuring the relationship among different criteria: 0 (no influence), 1 (very low influence), 2 (low influence), 3 (high influence), and 4 (very high influence). Next, decision makers prepare sets of the pair-wise comparisons in terms of effects and direction between criteria. Then the initial data can be obtained as the direct-relation matrix which is an $n \times n$ matrix T where each element of a_{ij} is denoted as the degree in which the criterion i affects the criterion j.

Step 2: *Normalizing the direct-relation matrix.* Normalization is performed using the following,

$$K = \frac{1}{max_{1\leq i\leq n} \sum_{j=1}^{n} a_{ij}} \quad i,j = 1,2,\dots,n \tag{1}$$

$$S = K.T \tag{2}$$

Step 3: *Attaining the total-relation matrix.* The total relation matrix M can be acquired by using Eq. (3), where I is denoted as the identity matrix

$$M = X(1 - X)^{-1} \tag{3}$$

Step 4: *Producing a causal diagram.* The sum of rows and the sum of columns are separately denoted as vector D and vector R through Eqs. (4-6). Then, the horizontal axis vector ($D + R$) named ''Prominence'' is made by adding D to R, which reveals the relative importance of each criterion. Similarly, the vertical axis (D - R) named ''Relation'' is made by subtracting R from D, which may divide criteria into a cause and effect groups. Generally, when (D - R) is positive, the criterion belongs to the cause group and when the (D - R) is negative, the criterion represents the effect group. Therefore, the causal diagram can be obtained by mapping the dataset of the (D + R, D - R), providing some insight for making decisions.

$$M = \left[m_{ij}\right]_{n\times n}, \quad i,j = 1,2,\dots,n \tag{4}$$

$$D = \left[\sum_{j=1}^{n} m_{ij}\right]_{n\times 1} = [t_{i.}]_{n\times 1} \tag{5}$$

$$R = \left[\sum_{i=1}^{n} m_{ij}\right]_{1\times n} = \left[t_{j.}\right]_{1\times n} \tag{6}$$

where D and R denote the sum of rows and the sum of columns, respectively. Finally, a causal and effect graph can be acquired by mapping the dataset of (D + R, D - R), where the horizontal axis (D + R) is made by adding D to R, and the vertical axis (D - R) is made by subtracting R from D.

4.2. Triangular fuzzy numbers

Zadeh proposed the fuzzy set theory and introduced the concept of membership function (Zadeh, 1965). The fuzzy set theory deals with linguistic variable problems in the real world.

A triangular fuzzy number $\tilde{A}$ is shown as a triplet (l, m, r) and a membership function $\mu_{\tilde{A}}$ is shown as Fig. 1.

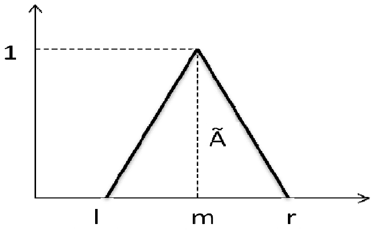

Fig. 1. A triangle fuzzy numbers Ã.

The membership function is defined as

$$\mu x(y) = \begin{cases} 0 & y < a \\ \dfrac{(y-a)}{(b-a)} & a \le y \le b \\ \dfrac{(c-y)}{(c-b)} & b \le y \le c \\ 0 & y > c \end{cases}$$

In assessing different projects, the satisfaction with different properties in the project is usually placed on a certain scale. If we signify it with a clear and precise number, it is less likely to reflect the reality. Therefore, in fuzzy multi-principle assessment, fuzzy numbers are used to show the degree of satisfaction. Fuzzy numbers refer to the fuzzy set on real line R and their membership function is μ_x(Y): R [0, 1], which has the following characteristics:

μ_x(Y) is piecewise continuous;

μ_x(Y) is convex fuzzy subset.

This study applies the triangular fuzzy number to obtain ideal solutions from group decision-making. Fuzzy aggregation processes must include a defuzzification step. In this paper we adopt a variation of the CFCS (Converting Fuzzy data into Crisp Scores) defuzzication method for our Fuzzy aggregation procedure. This approach has been deemed to be more effective by researchers for arriving at crisp values (e.g. when compared to the Centroid method) (Opricovic & Tzeng, 2003; Wu & Lee, 2007).

The CFCS method is based on determining the fuzzy maximum and minimum of the fuzzy number range. According to membership functions, the total score can be found out as a weighted average (Opricovic & Tzeng, 2003). Let $A_{ij} = (l_{ij}^n, m_{ij}^n, r_{ij}^n)$, mean the degree of criterion i that affects criterion j and fuzzy questionnaires n (n = 1, 2, 3 . . . p). The CFCS method involves a five-step algorithm as follows:

Step1. Normalization:

$$xr_{ij}^n = \left(r_{ij}^n - min l_{ij}^n\right)/\Delta_{min}^{max} \quad (7)$$

$$xm_{ij}^n = \left(m_{ij}^n - min l_{ij}^n\right)/\Delta_{min}^{max} \quad (8)$$

$$xl_{ij}^n = \left(l_{ij}^n - min l_{ij}^n\right)/\Delta_{min}^{max} \quad (9)$$

$$where\ \Delta_{min}^{max} = max r_{ij}^n - min l_{ij}^n \quad (10)$$

Step2. Compute right (rs) and left (ls) normalized values:

$$xrs_{ij}^n = xr_{ij}^n/\left(1 + xr_{ij}^n - xm_{ij}^n\right) \quad (11)$$

$$xls_{ij}^n = xm_{ij}^n/\left(1 + xm_{ij}^n - xl_{ij}^n\right) \quad (12)$$

Step3. Compute total normalized crisp values:

$$x_{ij}^n = \left[xls_{ij}^n\left(1 - xls_{ij}^n\right) + xrs_{ij}^n \times xrs_{ij}^n\right]/\left[1 - xls_{ij}^n + xrs_{ij}^n\right] \quad (13)$$

Step4. Compute crisp values:

$$z_{ij}^n = min l_{ij}^n + x_{ij}^n \times \Delta_{min}^{max} \quad (14)$$

Step5. Integrate crisp values:

$$z_{ij} = \frac{1}{p}\left(z_{ij}^1 + z_{ij}^2 + \cdots + z_{ij}^p\right) \quad (15)$$

5. Data analysis

Data analysis is divided into four sub-sections: (1) Fuzzy DEMATEL questionnaire design, (2) Application of the Fuzzy DEMATEL Process, (3) analyzing the degree of central role and relation, and (4) the causal diagram.

5.1. Fuzzy DEMATEL questionnaire design

The one questionnaire designed for fuzzy DEMATEL. This questionnaire designed for pairwise comparison to evaluate the influence of each score, where scores of 0, 1, 2, 3 and 4 represent: (no influence), (very low influence), (low influence), (high influence), and (very high influence), respectively.

5.2. Application of the DEMATEL Process

This study uses an expert interview method. The objects were professional experts in different departments of automobile industry in Iran (10 experts). The evaluation criteria symbols in this study are as follows: Price (A_1), Rejection rate (A_2), Up to Date (A_3), Technical Capability (A_4), Willingness and Attitude (A_5), Quality (A_6), Delivery (A_7), Reputation (A_8), Lead-time (A_9), Production capability (A_{10}), Reaction to demand change (A_{11}) and Service (A_{12}).
Data collected from the experts was analyzed with the fuzzy DEMATEL method. The major eight steps were conducted as the following.

Step1. Design the fuzzy linguistic variables

The study addresses response to the human logic variable, according to the linguistic variable (Li, 1999): no influence, very low influence, low influence, high influence and very high influence, and shows positive triangular fuzzy numbers$(l_{ij}^n, m_{ij}^n, r_{ij}^n)$ as Table 2.

Table 2. The fuzzy linguistic scale.

Linguistic terms	Influence score	Triangular fuzzy numbers
No influence (No)	0	(0, 0, 0.25)
Very low influence (VL)	1	(0, 0.25, 0.50)
Low influence (L)	2	(0.25, 0.50, 0.75)
High influence (H)	3	(0.50, 0.75, 1.00)
Very high influence (VH)	4	(0.75, 1.00, 1.00)

Ste 2. Set up Direct-Relation Matrix T

Separately, each expert was given a 12x12 linguistic/fuzzy scale direct-relation matrix T for comparison of Supplier selection criteria. For example, a completed direct-relation matrix for expert1 within a linguistic scale assessment among the Supplier selection criteria is shown in Table 5.there are nine matrix as table 3.

Table 3. The Linguistic scale direct-relation matrix by expert1.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
A1	0	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0, 0, 0.25)
A2	(0.25, 0.50, 0.75)	0	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0, 0, 0.25)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)
A3	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	0	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)
A4	(0, 0.25, 0.50)	(0.75, 1.00, 1.00)	(0.75, 1.00, 1.00)	0	(0, 0, 0.25)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)
A5	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	0	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0, 0, 0.25)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)
A6	(0, 0, 0.25)	(0.75, 1.00, 1.00)	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	0	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)
A7	(0.75, 1.00, 1.00)	(0, 0, 0.25)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0, 0, 0.25)	(0.50, 0.75, 1.00)	0	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0, 0, 0.25)	(0.25, 0.50, 0.75)
A8	(0, 0.25, 0.50)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	0	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)
A9	(0.50, 0.75, 1.00)	(0, 0, 0.25)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0, 0, 0.25)	(0.50, 0.75, 1.00)	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	0	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0, 0, 0.25)
A10	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	0	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)
A11	(0, 0.25, 0.50)	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	(0.25, 0.50, 0.75)	0	(0.75, 1.00, 1.00)
A12	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0, 0, 0.25)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)	0

Note: Price (A_1), Rejection rate (A_2), Up to Date (A_3), Technical Capability (A_4), Willingness and Attitude (A_5), Quality (A_6), Delivery (A_7), Reputation (A_8), Lead-time (A_9), Production capability (A_{10}), Reaction to demand change (A_{11}) and Service (A_{12}).

Step3. Transform triangular fuzzy numbers into the initial direct-relation matrix F.

In this step we utilize the modified-CFCS method (Eqs (7)-(15) to develop a crisp value direct-relation matrix for each evaluator.

Utilizing Table 5 with the linguistic assessments by expert1, we will exemplify the normalization and crisping for factor A_1 to A_2. A fuzzy linguistic scale of (0, 0.25, 0.50) is currently assigned for this comparison by expert1. Essentially, it means that expert1 believes factor A_1 has a Very low influence on factor A_2.

Since the minimum value for each column j ($minl_{ij}^{n}$) is 0 for expert1 and the maximum value for each column j ($maxr_{ij}^{n}$) is 1 (from Table 5), our Δ_{min}^{max}= 1. For our example problem given that $l_{ij}^{n}=0$, $m_{ij}^{n}=0.25$ and $r_{ij}^{n}=0.5$ and using Eqs (7), (8), (9), (11), (12), and (13) we get the following normalized crisp value for the influence relationship between factor A_1 to A_2 by expert1 (x_{12}^{1}).

$$xr_{12}^{1}=\frac{0.5-0}{1}=0.5$$

$$xm_{12}^{1}=\frac{0.25-0}{1}=0.25$$

$$xl_{12}^{1}=\frac{0-0}{1}=0$$

$$xrs_{12}^{1}=\frac{0.5}{[1+0.5-0.25]}=0.4$$

$$xls_{12}^{1}=\frac{0.25}{[1+0.25-0]}=0.2$$

$$x_{12}^{1}=\frac{[0.2(1-0.2)+\ (0.4\times 0.4)]}{[1-0.2+0.4]}=0.26$$

To compute the final crisp value associated in the modified-CSCF approach, we utilize Eqs (14) for calculating z_{12}^{1} :

$$z_{12}^{1}=0+0.26(1)=0.26$$

Similarly, Calculation the normalization and crisping for factor A_1 to A_2, for the other experts are:
$z_{12}^{2}=0.43,\ z_{12}^{3}=0.5,\ z_{12}^{4}=0.66,\ z_{12}^{5}=0.43,\ z_{12}^{6}$=0.56, $z_{12}^{7}=0.96,\ z_{12}^{8}=0.5,\ z_{12}^{9}=0.23$, *and* $z_{12}^{10}=0.47$,
Step4. Integrate crisp values:
In this section compute the average value of influence of factor A_1 on factor A_2 (z_{12}), that obtain from all experts. These calculations obtain according to the Eqs (15) that is shown below:

$$z_{12}=\frac{(0.26+0.43+0.5+0.66+0.45+0.56+0.96+0.53+0.23+0.47+)}{10}=0.505$$

Other results of the comparisons between the Supplier selection criteria, such as the sample of solved (z_{12}), is obtained. Final results of these comparisons are shown in Table 4.

Table 4. The initial direct-relation matrix F.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}
A_1	0	0.505	0.346	0.342	0.532	0.521	0.487	0.178	0.567	0.356	0.234	0.573
A_2	0.746	0	0.535	0.245	0.236	0.344	0.722	0.434	0.324	0.782	0.342	0.134
A_3	0.347	0.446	0	0.763	0.737	0.784	0.752	0.612	0.576	0.214	0.245	0.456
A_4	0.376	0.364	0.542	0	0.346	0.662	0.813	0.347	0.806	0.476	0.733	0.193
A_5	0.748	0.733	0.534	0.234	0	0.560	0.633	0.912	0.773	0.546	0.124	0.235
A_6	0.843	0.632	0.234	0.675	0.238	0	0.265	0.468	0.185	0.210	0.452	0.334
A_7	0.467	0.236	0.456	0.873	0.499	0.255	0	0.752	0.396	0.721	0.559	0.525
A_8	0.856	0.463	0.196	0.173	0.258	0.837	0.428	0	0.672	0.184	0.676	0.286
A_9	0.375	0.275	0.257	0.734	0.345	0.784	0.345	0.187	0	0.256	0.238	0.645
A_{10}	0.646	0.346	0.234	0.627	0.148	0.476	0.537	0.437	0.546	0	0.234	0.768
A_{11}	0.365	0.663	0.678	0.254	0.465	0.742	0.556	0.561	0.267	0.345	0	0.435
A_{12}	0.735	0.784	0.235	0.735	0.398	0.266	0.389	0.264	0.427	0.527	0.622	0

Note: Price (A_1), Rejection rate (A_2), Up to Date (A_3), Technical Capability (A_4), Willingness and Attitude (A_5), Quality (A_6), Delivery (A_7), Reputation (A_8), Lead-time (A_9), Production capability (A_{10}), Reaction to demand change (A_{11}) and Service (A_{12}).

Step5. Set up the generalized direct-relation matrix S.

The study obtains a generalized direct-relation matrix S through the Eqs (1) in which all principal diagonal elements are between 1 to zero. The generalized direct-relation matrix is shown as Table 5.

Table 5.The generalized direct-relation matrix S.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}
A_1	0	0.084	0.057	0.057	0.088	0.086	0.081	0.030	0.094	0.059	0.039	0.095
A_2	0.124	0	0.089	0.041	0.039	0.057	0.120	0.072	0.054	0.130	0.057	0.022
A_3	0.058	0.074	0	0.126	0.122	0.130	0.125	0.101	0.095	0.035	0.041	0.076
A_4	0.062	0.060	0.090	0	0.057	0.110	0.135	0.058	0.134	0.079	0.122	0.032
A_5	0.124	0.122	0.089	0.039	0	0.093	0.105	0.151	0.128	0.091	0.021	0.039
A_6	0.140	0.105	0.039	0.112	0.039	0	0.044	0.078	0.031	0.035	0.075	0.055
A_7	0.077	0.039	0.076	0.145	0.083	0.042	0	0.125	0.066	0.120	0.093	0.087
A_8	0.142	0.077	0.032	0.029	0.043	0.139	0.071	0	0.111	0.031	0.112	0.047
A_9	0.062	0.046	0.043	0.122	0.057	0.130	0.057	0.031	0	0.042	0.039	0.107
A_{10}	0.107	0.057	0.039	0.104	0.025	0.079	0.089	0.072	0.091	0	0.039	0.127
A_{11}	0.061	0.110	0.112	0.042	0.077	0.123	0.092	0.093	0.044	0.057	0	0.072
A_{12}	0.122	0.131	0.039	0.122	0.066	0.044	0.064	0.044	0.071	0.087	0.103	0

Note: Price (A_1), Rejection rate (A_2), Up to Date (A_3), Technical Capability (A_4), Willingness and Attitude (A_5), Quality (A_6), Delivery (A_7), Reputation (A_8), Lead-time (A_9), Production capability (A_{10}), Reaction to demand change (A_{11}) and Service (A_{12}).

Step6. Set up the total-relation matrix M.

The total-relation matrix M is acquired using Eq. (3) from the generalized direct-relation matrix. The total-relation matrix is shown as Table 6.

Table 6.The generalized direct-relation matrix M.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}
A_1	0.493	0.490	0.382	0.493	0.406	0.544	0.520	0.417	0.505	0.417	0.388	0.443
A_2	0.622	0.423	0.422	0.496	0.377	0.540	0.573	0.470	0.488	0.491	0.417	0.400
A_3	0.680	0.590	0.416	0.667	0.522	0.711	0.678	0.586	0.621	0.490	0.489	0.517
A_4	0.645	0.548	0.480	0.529	0.446	0.666	0.657	0.523	0.622	0.503	0.533	0.463
A_5	0.734	0.624	0.490	0.586	0.407	0.676	0.654	0.620	0.644	0.533	0.462	0.488
A_6	0.603	0.496	0.359	0.518	0.354	0.454	0.478	0.444	0.439	0.384	0.413	0.394
A_7	0.677	0.545	0.476	0.666	0.477	0.623	0.553	0.590	0.586	0.550	0.523	0.520
A_8	0.643	0.504	0.375	0.483	0.382	0.616	0.527	0.401	0.533	0.403	0.468	0.419
A_9	0.530	0.441	0.356	0.532	0.364	0.563	0.480	0.399	0.401	0.384	0.379	0.436
A_{10}	0.619	0.490	0.384	0.562	0.370	0.567	0.553	0.471	0.529	0.382	0.416	0.495
A_{11}	0.622	0.571	0.477	0.538	0.443	0.644	0.593	0.531	0.518	0.463	0.401	0.470
A_{12}	0.671	0.589	0.419	0.605	0.433	0.577	0.575	0.483	0.547	0.496	0.496	0.407

Note: Price (A_1), Rejection rate (A_2), Up to Date (A_3), Technical Capability (A_4), Willingness and Attitude (A_5), Quality (A_6), Delivery (A_7), Reputation (A_8), Lead-time (A_9), Production capability (A_{10}), Reaction to demand change (A_{11}) and Service (A_{12}).

Step7. Obtain the sum of rows and columns.

The sum of rows and the sum of columns are separately denoted as D and R within the total relation matrix M as below:

Sum of rows = 5.498 5.719 6.967 6.615 6.918 5.336 6.786 5.754 5.265 5.838 6.271 6.298.

Sum of columns = 7.539 6.311 5.036 6.675 4.981 7.181 6.841 5.935 6.433 5.496 5.385 5.452.

Ste 8. Set up degrees of central role and relation.

Using Eqs (5)-(6), we obtain the degree of the influence for each Supplier selection criteria (Table 7).

Table 7. The degree of central role (D + R).

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}
D	5.498	5.719	6.967	6.615	6.918	5.336	6.786	5.754	5.265	5.838	6.271	6.298
R	7.539	6.311	5.036	6.675	4.981	7.181	6.841	5.935	6.433	5.496	5.385	5.452
D + R	13.037	12.03	12.003	13.29	11.899	12.517	13.627	11.689	11.698	11.334	11.656	11.75
D - R	-2.041	- 0.592	1.931	-0.06	1.937	-1.845	-0.055	-0.181	-1.168	0.342	0.886	0.846

Note: Price (A_1), Rejection rate (A_2), Up to Date (A_3), Technical Capability (A_4), Willingness and Attitude (A_5), Quality (A_6), Delivery (A_7), Reputation (A_8), Lead-time (A_9), Production capability (A_{10}), Reaction to demand change (A_{11}) and Service (A_{12}).

5.3. Analyzing the degree of central role and relation

The degree of central role ($D_x + R_x$) in DEMATEL represents the strength of influences both dispatched and received. On the other hand, if ($D_x - R_x$) is positive, then the evaluation criterion x dispatches the influence to other evaluation criteria more than it receives. If ($D_x - R_x$) is negative, the evaluation criterion x receives the influence from other evaluation criteria more than it dispatched. The ($D_x - R_x$) values are reported in Table 9.

5.4. Causal diagram

The graphical representation (the prominence-causal diagram) and digraphical relationships are now constructed. This step will allow a clearer visualization of the structure and relationships amongst the supplier selection criteria. One of the first activities of this sub-step is to plot the various supplier selection criteria on a two-axes the prominence horizontal axis (R+D) and the net cause/effect vertical axis (R-D). We do this to help us observe general patterns and relationships amongst all the programs simultaneously and in pairs. For example, we see that A_9 have very little influence/effect on the other programs, and is more of an effect or influenced by others.

The development of the digraphs in Figure 2 shows the interrelationships amongst each of the individual supplier selection criteria. We can also observe general clusters into cause and effect groups. Generally the supplier selection criteria that are part of the effect cluster include A4, A2, A7, A9, A8, A6 and A1; the cause cluster includes A5, A3, A11, A12 and A10.The causal relationships among supplier selection criteria can be depicted as the causal diagram (Fig. 2).this figure is shown that Willingness and Attitude is the most influence and the strongest connection to other criteria.

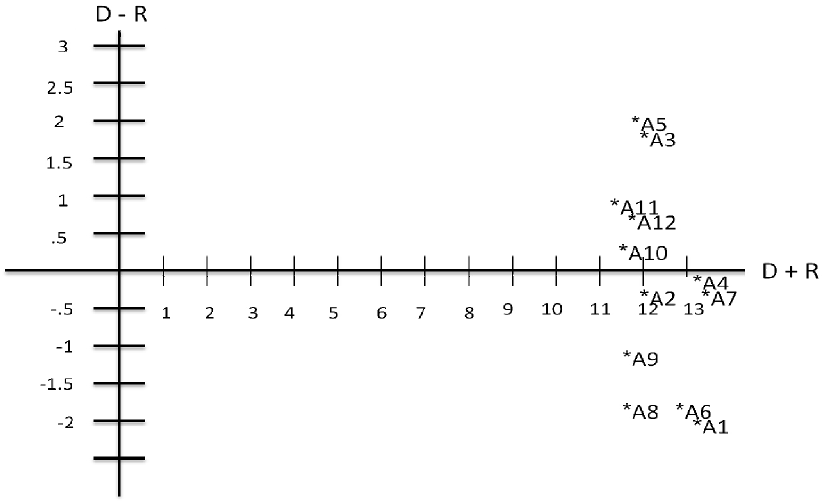

Fig 2. The causal diagram. Using * as the symbol for evaluation criteria: Price (A_1), Rejection rate (A_2), Up to Date (A_3), Technical Capability (A_4), Willingness and Attitude (A_5), Quality (A_6), Delivery (A_7), Reputation (A_8), Lead-time (A_9), Production capability (A_{10}), Reaction to demand change (A_{11}) and Service (A_{12}).

6. Conclusion and future study

Supplier selection decisions have long become an important component of production and logistics management. As purchases from outside suppliers may constitute a large proportion of a product's costs, suppliers should be carefully compared with each other to determine their relative strengths and weaknesses. Most supplier selection decisions are made today in increasingly complex environments where the theory of fuzzy decision making can be of significant use. In many of such decision-making settings the theory of fuzzy decision-making can be of use. Fuzzy group decision-making can overcome this difficulty. This study uses the fuzzy DEMATEL method to analyze and forecast supplier selection criteria. The results of this study can hopefully help enterprises precisely forecast which suppliers are suitable by focusing on crucial factors found in this study. From the fuzzy DEMATEL results, we can understand the Willingness and Attitude is the most influence and the strongest connection to other criteria. According to DEMATEL analysis results, Willingness and Attitude could directly or indirectly influence many other characteristics such as Up to Date, Reaction to demand change, Service, Production capability, Technical Capability, Rejection rate , Delivery, Lead-time, Reputation, Quality and Price.

One major limitation is the evaluation effort required with these techniques. For this study evaluators to each method had to each complete over 132 comparisons. Fatigue is easily a possibility which may cause some reliability problems. The fuzzy DEMATEL method of this paper could be used for other problems in other industry. There are other multiple attribute decision-making methods such as ELECTRE, TOPSIS and VIKOUR, which could be applied for ranking the supplier selection criteria.

Further research may be the application of these methods to the supplier selection problem and the comparison of the results. Finally, adding more alternative suppliers which encompass both domestic and international suppliers may serve another avenue for future research, though it may increase computational difficulties.

In a decision-making process, the use of linguistic variables in decision problems is highly beneficial when performance values cannot be expressed by means of crisp values. In this paper, we present DEMATEL as a generalized method to solve supplier selection problem under a fuzzy environment.

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