Fuzzy DEMATEL for Determining the Importance of Criteria in Computer Vendor Selection

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Abstract

Vendor selection is a process of deciding the best supplier from a number of potential alternatives. However, criteria for each alternative are usually very much inconclusive. In this paper, fuzzy decision making trial and evaluation laboratory (DEMATEL) method is utilized in segmenting the importance of criteria in a case of computer vendor selection. Five managers of computer companies and thirteen criteria are considered in this experiment. The judgments for each criterion are made by the experts based on the linguistic variables and triangular fuzzy numbers. In fuzzy aggregation assessment process, converting fuzzy data into crisp scores (CFCS) method has been applied to aggregate and defuzzify those assessment as a crisp value. Degrees of influential criteria are then obtained and criteria are successfully divided into cause group and effect group. The results provide valuable suggestions to company on how to improve its performances by paying more attention to the key criteria that influenced computer vendor selection.

Keywords: *Decision Making Trial and Evaluation Laboratory (DEMATEL), vendor selection, fuzzy numbers, linguistic variable*

1. Introduction

In today's highly competitive environment, it is necessary for each company to consider the actual needs of a satisfactory vendor. It is just because a good vendor selection (VS) may improve the efficiency and increase productivity of company. Contrarily, selecting a wrong vendor may threaten the company's financial and operational position. As advocated by Howard [1] there is no more important than selection of appropriate vendor since a vendor with a good performance in one criterion may worse on some others. An appropriate vendor plays a significant role in order to improve the overall performances of company and enhance the customer satisfaction [2]. However, selecting the right vendor is not an easy task since VS problem is an unstructured and complicated. In another word, VS problem is a multi-criteria decision making (MCDM) problem in which the criteria need to be evaluated meticulously. Nowadays, various types of MCDM methods have been developed by researchers to solve VS problem.

Decision making trial and evaluation laboratory (DEMATEL) is one of the MCDM methods to solve VS problems and it has been proven as a useful method to solve complicated problems since it has many advantages in explaining the interconnected relationships among criteria. The DEMATEL method has been developed initially to visualize the causal relationship of sub-systems through a causal diagram [3]. The methodology, according to the characteristics of objective affairs, can verify the interdependence among the criteria and confirm the relation that reflects the characteristics with an essential system and evolution trend [4-6]. The degree importance of criteria can also be measured by this method. The DEMATEL method has been successfully applied to various circumstances, for example, developing global managers' competencies [7], evaluating intertwined effects in e-learning programs [8], airline safely measurement [9], innovation Policy Portfolios for SIP mall industry [5], choice of knowledge management strategy [10], causal analytic method for group decision making [11], and selection management systems of SMEs [12].

In the DEMATEL procedure, available information or evaluations of criteria by decision-makers (DMs) are often given as crisp values and expressed in linguistic terms. Generally, DMs usually tend to give assessments based on their knowledge and past experiences which are uncertain, vague and imprecise. Thus, a fuzzy set theory is a mathematical way to tackle the vagueness in information and the fuzziness of human judgment. Based on the definition of fuzzy sets, the concept of linguistic variables is introduced to represent a language typically adopted by a human expert. A linguistic variable is a variable whose values, namely linguistic values, have the form of phrases or sentences in a natural language [13-15]. The linguistic values are represented by fuzzy numbers and in this study, triangular fuzzy number is used in the DEMATEL method. This study aims to measure the degree importance of criteria, determine the relationship, and divide the criteria into cause group and effect group using the fuzzy DEMATEL method. The rest of the paper is organized as follows. The review of literature related to VS problem is mentioned in Section 2. In Section 3 we present the preliminaries. Section 4 details the solution algorithm. Section 5 displays our empirical analysis along with some discussions relating to a case study of computer vendor selection. Finally conclusions and remarks are given in section 6.

2. Related Research

Around 1950s, National Bureau of Standards in the United States of America is the first to used vendor selection model to find the minimum cost way for awarding procurement contracts in the Department of Defense by applying linear programming and scientific computations [16][17]. Gaballa is the first author who applied mathematical programming to a supplier selection problem in a real case by using a mixed integer programming (MIP) model to minimize the total price of items allocated to the suppliers. Wind and Robinson [18] proposed a linear weighting method to the vendor selection problem for rating different vendors on the performance criteria for their quota allocations. Stevens [19] proposed a goal programming formulation for attaining goals pertaining to price, quality and lead-time under demand and budget constraints. Chaudhry et al. [20] have applied a mixed-integer programming model to determine the order quantities from vendors offering cumulative or non-cumulative price breaks, albeit ignoring net price, delivery, quality and capacity in their vendor evaluation criteria. Gheidar-Kheljani et al. [21] considered the issue of coordination between one buyer and multiple potential suppliers, and minimized the total cost of the supply chain rather than only the buyer's cost.

A number of subsequent studies used fuzzy set theory to deal with uncertainty in the vendor selection problem. Kumar et al. [22] developed a fuzzy goal programming and a fuzzy multi objective integer programming approach to handle the vagueness and imprecision in vendor selection model. Amid et al. [23] applied an asymmetric fuzzy-decision-making technique to assign different weights to various criteria in a fuzzy vendor selection problem, and formulated a weighted additive fuzzy multi-objective model for vendor selection problem under price breaks. Wang et al., [24] proposed a fuzzy vendor selection expected value model and a fuzzy vendor selection chance constrained programming model by characterizing quality, budget, and demand as fuzzy variables. Since vendor selection problem is usually a multi-criteria decision making (MCDM) problem, Mikhailov [25] proposed the fuzzy AHP method to determine the weight of each criterion and to score each alternative for each criterion. Besides, Shyur and Shih [26] developed a hybrid MCDM method for strategic vendor selection by using both the ANP and TOPSIS techniques.

3. Preliminaries

Some important definitions and notations of fuzzy set theory from Chen [27] and Cheng and Lin [28] are reviewed.

Definition 1. A fuzzy set $\tilde{A}$ is a subset of a universe of discourse X, which is a set of ordered pairs and is characterized by a membership function $\mu_{\tilde{A}}(X)$ representing a mapping $\mu_{\tilde{A}}(X): X \rightarrow [0,1]$.

Definition 2. A triangular fuzzy number $\tilde{N}$ can be defined as a triplet (l, m, r) and the membership function $\mu_{\tilde{N}}(x)$ is defined as:

$$\mu_{\tilde{N}}(x) = \begin{cases} 0, & x < 1, \\ \dfrac{(x-l)}{m-l}, & l \le x \le m, \\ \dfrac{(r-x)}{r-m}, & m \le x \le r, \\ 0, & x > r, \end{cases} \tag{1}$$

Where *l, m,* and *r* are real numbers and $l \le m \le r$.

Let $\tilde{A}$ and $\tilde{B}$ be two positive triangular fuzzy numbers parameterized by (a_1, a_2, a_3) and (b_1, b_2, b_3), then the operational laws of these two triangular fuzzy numbers are as follows:

$$\tilde{A} \oplus \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \tag{2}$$

$$\tilde{A} - \tilde{B} = (a_1 - b_1, a_2 - b_2, a_3 - b_3) \tag{3}$$

$$\tilde{A} \otimes \tilde{B} = (a_1 \times b_1, a_2 \times b_2, a_3 \otimes b_3) \tag{4}$$

$$\tilde{A} \div \tilde{B} = (a_1 / b_1, a_2 / b_2, a_3 / b_3) \tag{5}$$

where (a_1, a_2, a_3) and (b_1, b_2, b_3) are real numbers.

4. Fuzzy DEMATEL and Its Procedures

The DEMATEL method is a highly pragmatic way to form a structural model of evaluation for better decision making [29]. Analytical procedure of the fuzzy DEMATEL method is explained as follows:

Step 1: Identifying decision goal.

The relevant information is gathered to evaluate the advantages and disadvantages and monitoring the results to ensure the goals are achieved. This is necessary to form a committee for gathering group knowledge to achieve the goals.

Step 2: Developing evaluation criteria and survey instrument.

This is important to establish a set of criteria for evaluation. However, the criteria have the nature of complicated relationships within the cluster of criteria. To measure the degree importance of criteria, determine the relationship, and divide the criteria into cause group and effect group, the DAMATEL is appropriate to be applied in this study. Linguistic variable “influence” is used with five linguistic terms [30] as {Very high, High, Low, Very low, No} that are expressed in positive triangular fuzzy numbers (l_{ij}, m_{ij}, r_{ij}) as shown in Table 1.

Table 1. The fuzzy linguistic scale.

Linguistic terms	Influence scores	Triangular fuzzy numbers
No influence	0	(0,0.1,0.3)
Very low influence	1	(0.1,0.3,0.5)
Low influence	2	(0.3,0.5,0.7)
High influence	3	(0.5,0.7,0.9)
Very high influence	4	(0.7,0.9,1.0)

Step 3: Acquiring and aggregating the assessments of decision makers.

To measure the relationship between evaluation criteria, it is usually necessary to ask DMs to make assessments in terms of influence and directions between the criteria. Then, using the Converting Fuzzy data into Crisp Scores (CFCS) method, those fuzzy assessments are defuzzified and aggregated as a crisp value to obtain initial direct-relation matrix, Z.

The five-step algorithms of CFCS method described as follows:

Let $z_{ij}^{k} = (l_{ij}^{k}, m_{ij}^{k}, r_{ij}^{k})$ indicate the fuzzy assessments of evaluator $k(k = 1,2,..., p)$ about the degree to which the criterion i affects the criterion j.

1. Normalization:

$$xl_{ij}^{k} = \frac{\left(l_{ij}^{k} - \min l_{ij}^{k}\right)}{\Delta_{\min}^{\max}} \tag{6}$$

$$xm_{ij}^{k} = \frac{\left(m_{ij}^{k} - \min l_{ij}^{k}\right)}{\Delta_{\min}^{\max}} \tag{7}$$

$$xr_{ij}^{k} = \frac{\left(r_{ij}^{k} - \min l_{ij}^{k}\right)}{\Delta_{\min}^{\max}} \tag{8}$$

where $\Delta_{\min}^{\max} = \max r_{ij}^{k} - \min l_{ij}^{k}$.

2. Compute left (*ls*) and right (*rs*) normalized value:

$$xls_{ij}^{k} = \frac{xm_{ij}^{k}}{\left(1 + xm_{ij}^{k} - xl_{ij}^{k}\right)} \tag{9}$$

$$xrs_{ij}^{k} = \frac{xr_{ij}^{k}}{\left(1 + xr_{ij}^{k} - xm_{ij}^{k}\right)} \tag{10}$$

3. Compute total normalized crisp value:

$$x_{ij}^{k} = \frac{\left[xls_{ij}^{k}\left(1 - xls_{ij}^{k}\right) + xrs_{ij}^{k} xrs_{ij}^{k}\right]}{\left[1 - xls_{ij}^{k} + xrs_{ij}^{k}\right]} \tag{11}$$

4. Compute crisp values:

$$z_{ij}^{k} = \min l_{ij}^{k} + x_{ij}^{k} \Delta_{\min}^{\max} \tag{12}$$

5. Integrate crisp value:

$$z_{ij} = \frac{1}{p}\left(z_{ij}^{1} + z_{ij}^{2} + \ldots + z_{ij}^{p}\right) \tag{13}$$

Step4: Establishing and analyzing the structural model.

On the base of the initial direct-relation matrix Z, the normalized direct relation matrix, *D* can be obtained through Eqs. (14) and (15).

$$X = \frac{Z}{s} \tag{14}$$

$$\text{where} \quad s = \max\left(\max_{1 \le i \le n} \sum_{j=1}^{n} z_{ij}, \max_{1 \le i \le n} \sum_{i=1}^{n} z_{ij} \right), \tag{15}$$

Then, the total-relation matrix, *T* can be acquired by using Eq. (16) in which *I* is denoted as the identity matrix.

$$T = X(I - X)^{-1} \tag{16}$$

The causal diagram can be acquired through Eqs. (17)–(19).

$$T = \left[t_{ij}\right]_{n \times n}, \qquad i, j = 1,2,\ldots,n \tag{17}$$

$$D = \left[\sum_{j=1}^{n} t_{ij} \right]_{n\times 1} = \left[t_i\right]_{n\times 1} \tag{18}$$

$$R = \left[\sum_{i=1}^{n} t_{ij} \right]_{1\times n} = \left[t_i\right]_{1\times n} \tag{19}$$

The sum of rows and the sum of columns are separately denotes as vector D and R through (17) to (19). Then, the horizontal axis vector ($D + R$) named "Prominence" shows the degree of importance that criterion i plays in the system while the vertical axis ($D – R$) named "Relation" shows the net effect the criterion i contributed to the system. When ($D – R$) is positive, criterion i is a net causer and when ($D – R$) is negative, criterion i is a net receiver [6][8].

5. Empirical Analysis

This study conducts an empirical analysis by gathering the feedbacks from five managers (experts) of computer companies in Malaysia. On the basis of guided interview, the experts use fuzzy linguistic scale in Table 1 for making assessments on influential criteria. Thirteen criteria are adopted as evaluation criteria in computer vendor selection (CVS). The criteria are management commitment (*C1*), warranties and claim policies (*C2*), quality assurance (*C3*), price performance value (*C4*), compliance with sectorial price behaviour (*C5*), transportation cost (*C6*), order fulfil rate (*C7*), lead time (*C8*), order frequency (*C9*), responsiveness (*C10*), stock management (*C11*), willingness (*C12*) and design capability (*C13*).

Once the criteria being measured by the DMs through the use of the fuzzy linguistic scale, the data from each individual assessment could be obtained. Then, the initial direct-relation matrix in Table 2 is constructed using the CFCS method. Eqs (6)-(13) is used to aggregate the assessment data.

Table 2. Initial direct-relation matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C1	0.00	0.57	0.75	0.62	0.58	0.43	0.62	0.66	0.72	0.65	0.70	0.54	0.58
C2	0.42	0.00	0.72	0.66	0.69	0.31	0.27	0.35	0.71	0.77	0.81	0.54	0.42
C3	0.70	0.74	0.00	0.84	0.74	0.45	0.58	0.50	0.79	0.69	0.54	0.42	0.69
C4	0.43	0.70	0.76	0.00	0.55	0.50	0.58	0.54	0.79	0.54	0.43	0.43	0.69
C5	0.58	0.46	0.67	0.77	0.00	0.43	0.57	0.31	0.67	0.70	0.43	0.58	0.65
C6	0.50	0.35	0.49	0.55	0.55	0.00	0.39	0.39	0.55	0.54	0.35	0.54	0.61
C7	0.73	0.58	0.60	0.61	0.65	0.38	0.00	0.46	0.79	0.77	0.77	0.58	0.50
C8	0.77	0.39	0.43	0.69	0.54	0.35	0.69	0.00	0.81	0.74	0.74	0.58	0.62
C9	0.73	0.58	0.70	0.81	0.73	0.43	0.66	0.66	0.00	0.57	0.76	0.50	0.77
C10	0.70	0.70	0.75	0.66	0.58	0.35	0.77	0.77	0.67	0.00	0.54	0.58	0.54
C11	0.65	0.61	0.45	0.57	0.61	0.26	0.81	0.81	0.71	0.50	0.00	0.50	0.46
C12	0.42	0.65	0.59	0.61	0.54	0.54	0.57	0.57	0.48	0.57	0.46	0.00	0.39
C13	0.73	0.66	0.80	0.81	0.76	0.50	0.46	0.50	0.78	0.50	0.58	0.46	0.00

Initial direct-relation matrix is normalized using Eqs (14) and (15). Result of the normalized initial direct-relation matrix is presented in Table 3.

Table 3. The normalized direct-relation matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C1	0.00	0.07	0.09	0.07	0.07	0.05	0.07	0.08	0.09	0.08	0.08	0.06	0.07
C2	0.05	0.00	0.09	0.08	0.09	0.04	0.03	0.04	0.09	0.10	0.10	0.07	0.05
C3	0.09	0.09	0.00	0.11	0.09	0.06	0.07	0.06	0.10	0.09	0.07	0.05	0.09
C4	0.05	0.09	0.10	0.00	0.07	0.06	0.07	0.07	0.10	0.07	0.05	0.05	0.09
C5	0.07	0.06	0.09	0.10	0.00	0.05	0.07	0.04	0.08	0.09	0.05	0.07	0.08
C6	0.06	0.04	0.06	0.07	0.07	0.00	0.05	0.05	0.07	0.07	0.04	0.07	0.08
C7	0.09	0.07	0.08	0.08	0.08	0.05	0.00	0.06	0.10	0.10	0.10	0.07	0.06
C8	0.10	0.05	0.05	0.09	0.07	0.04	0.09	0.00	0.10	0.09	0.09	0.07	0.08
C9	0.09	0.07	0.09	0.10	0.09	0.05	0.08	0.08	0.00	0.07	0.10	0.06	0.10
C10	0.09	0.09	0.10	0.09	0.08	0.05	0.10	0.10	0.09	0.00	0.07	0.08	0.07
C11	0.09	0.08	0.06	0.08	0.08	0.03	0.11	0.11	0.09	0.07	0.00	0.07	0.06
C12	0.06	0.09	0.08	0.08	0.07	0.07	0.08	0.08	0.06	0.08	0.06	0.00	0.05
C13	0.10	0.09	0.11	0.11	0.10	0.07	0.06	0.07	0.10	0.07	0.08	0.06	0.00

Next, the total-relation matrix in Table 4 is obtained using Eq (16).

Table 4. The total-relation matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13
C1	0.74	0.77	0.86	0.89	0.82	0.55	0.78	0.73	0.92	0.82	0.79	0.69	0.76
C2	0.77	0.69	0.83	0.87	0.81	0.52	0.72	0.68	0.90	0.81	0.78	0.67	0.72
C3	0.90	0.87	0.86	1.00	0.92	0.61	0.85	0.79	1.02	0.91	0.85	0.74	0.85
C4	0.80	0.80	0.87	0.82	0.82	0.56	0.78	0.73	0.94	0.82	0.77	0.68	0.78
C5	0.80	0.76	0.85	0.90	0.74	0.55	0.77	0.69	0.91	0.82	0.75	0.69	0.76
C6	0.68	0.64	0.71	0.76	0.70	0.42	0.64	0.60	0.78	0.69	0.64	0.59	0.66
C7	0.88	0.83	0.90	0.95	0.88	0.58	0.76	0.77	1.00	0.89	0.85	0.74	0.81
C8	0.88	0.80	0.88	0.95	0.86	0.58	0.83	0.71	0.99	0.88	0.84	0.73	0.81
C9	0.93	0.87	0.96	1.02	0.94	0.62	0.88	0.83	0.96	0.92	0.90	0.77	0.88
C10	0.93	0.89	0.97	1.01	0.92	0.61	0.89	0.84	1.04	0.85	0.88	0.78	0.86
C11	0.86	0.82	0.87	0.93	0.87	0.56	0.84	0.79	0.97	0.85	0.75	0.72	0.79
C12	0.77	0.77	0.82	0.87	0.79	0.55	0.75	0.71	0.87	0.79	0.75	0.60	0.72
C13	0.93	0.88	0.97	1.02	0.94	0.63	0.85	0.81	1.05	0.91	0.88	0.76	0.79

Then, structural correlation as presented in Table 5 is obtained using Eqs (17)–(19). Causal diagram in Figure 1 can be constructed by mapping a structural correlation analysis in Table 5.

Table 5. Structural correlation

Criteria	D+R	D-R
C1	20.9761	-0.740
C2	20.1819	-0.616
C3	22.4771	-0.181
C4	22.1295	-1.830
C5	21.0191	-1.020
C6	15.8772	1.174
C7	21.1805	0.509
C8	20.4397	1.074
C9	23.8086	-0.896
C10	22.4385	0.495
C11	21.0455	0.197
C12	18.9219	0.603
C13	21.6004	1.231

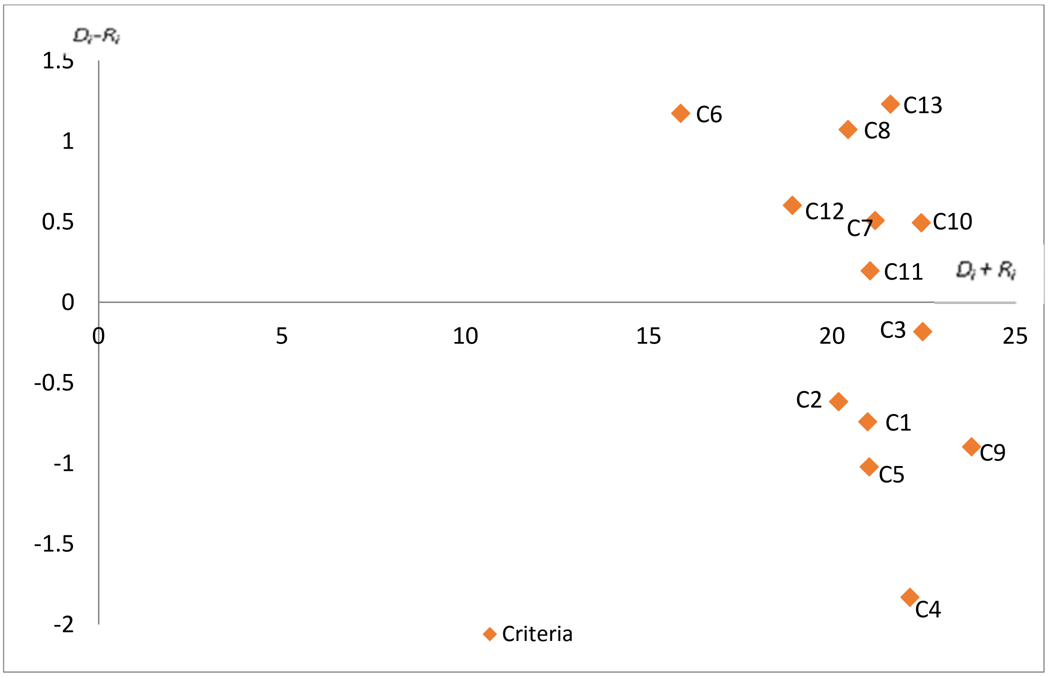

Figure 1. Causal diagram.

The evaluation criteria with positive *(D − R)* values; *C6, C7, C8, C10, C11, C12* and *C13* are divided into cause group also called as net causer, while negative value of *(D – R); C1, C2, C3, C4, C5* and *C9* are divided into effect group which are also called as net receiver. The cause criteria group imply the meaning of the influencing criteria, whereas the effect criteria group denote the meaning of the influenced criteria Fontela & Gabus [31]. Hori & Shimizu [32] define criteria in cause group difficult to move, while the effect criteria group are easily moved. Because the cause criteria have impact on the whole system, the performances can influence on the overall goal. Criteria in cause group should be paid a great more attention though the cause criteria group are difficult to move since they have significant impact on other criteria. Several valuable cues can be obviously obtained from Table 5 for making profound decisions. For example, among these thirteen criteria, *C9* is the most important criteria by the highest *(D + R)* priority of 23.8086 while *C13* is the most influencing criteria by the highest *(D − R)* priority of 1.231. As *C4* has the lowest (*D*−*R*) priority of -1.830, it is the most easily be influenced. Considering the significance of computer vendor selection, as presented in Table 5, the importance criteria is identified as *C9 > C3 > C10 > C4 > C13 > C7 > C11 > C5 > C1 > C8 > C2 > C12 > C6* according to the degree of importance *(D + R)*.

It can be seen that the criteria scattered in the causal diagram confirms that *C13* is the most influencing criteria. *C13* is the real source which affects the other criteria directly. Although *C13* is not considered as the priority criteria by the highest value of *(D + R)*, it can offer insights for company to understand the cause-effect relationship and to select appropriate computer vendor.

The results of fuzzy DEMATEL method are now compared with the findings of traditional DEMATEL method. Comparisons between these two methods are presented in Table 6.

Table 6. The results of CVS problem under different methods

Evaluation	Net-Group	Degree of importance
DEMATEL	Net causer: $C_1, C_3, C_6, C_7, C_8, C_{10}, C_{12}, C_{13}$ Net receiver: $C_2, C_4, C_5, C_9, C_{11}$	$C_9 > C_3 > C_{10} > C_4 > C_1 > C_{13} > C_7 > C_5 > C_{11} > C_8 > C_2 > C_{12} > C_6$
Fuzzy DEMATEL	Net causer: $C_6, C_7, C_8, C_{10}, C_{11}, C_{12}, C_{13}$ Net receiver: $C_1, C_2, C_3, C_4, C_5, C_9$	$C_9 > C_3 > C_{10} > C_4 > C_{13} > C_7 > C_{11} > C_5 > C_1 > C_8 > C_2 > C_{12} > C_6$

Based on Table 6, it can be seen that the two MCDM methods; DEMATEL and fuzzy DEMATEL method yield almost consistent result. They differ in four criteria; *C1, C7, C13* and *C11* with different position in term of degree importance of criteria. Also, three criteria; *C1, C3* and *C11* are not in the same net-group. However, it is better to note that the results of both methods reveal that *C9* is the most important criteria and *C6* is the least important criteria.

6. Conclusion

Fuzzy DEMATEL was introduced to handle uncertainty in linguistic evaluation of multi-criteria decision making problem. This study applied the fuzzy DEMATEL method in order to solve the problem of computer vendor selection in fuzzy environmental segmentation. We used both linguistic variables and a fuzzy aggregation method by CFCS method in fuzzy DEMATEL; hence it can effectively avoid vague and imprecise judgments. Besides, this method can successfully divide criteria into cause and effect groups through a causal diagram, thus the complexity of problem is easier to be deal and profound decisions can be made.

The results of this study indicate that order frequency *(C9)* is the most important criteria in VS followed by quality assurance *(C3),* responsiveness *(C10)*, price performance value *(C4).* This study finding is consistent with the past research where the top three weights ranking of criteria in VS are price, quality performance and purchase order reactiveness [33]. At the end of this finding, it can be concluded that design capability, *(C13)* is the key criteria influencing computer vendor selection.

Nonetheless, this study is subjected to some limitations. First, the shortage of DMs to ensure the validity of the research, future research should conduct with more DMs to achieve better exploration. Second, it is believed that setting a threshold value for fuzzy DEMATEL will give a better finding and network relationship map can be obtained successfully.

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8. References

[1] Howard, T.L. “Industrial Purchasing Principles and Practices.” Chicago: Richard D. Irwin, 1943.
[2] Kumar, M., Vrat P., Shankar, R. “A fuzzy goal programming approach for vendor selection problem in a supply chain.” Computers and Industrial Engineering, Vol. 46, pp. 69-85, 2004.
[3] Gabus, A., Fontela, E. “Perceptions of the world problematique: Communication procedure, communicating with those bearing collective responsibility (DEMATEL).” Battelle Geneva Research Centre, Switzerland Geneva, 1973.
[4] Chiu, Y.J., Chen, H.C., Tzeng, G.H., Shyu, J.Z. “Marketing strategy based on customer behaviour for the LCD-TV.” International Journal Management Decision Making, Vol. 7, pp.143–165, 2006.

[5] Huang, C.Y., Tzeng, G.H. “Reconfiguring the innovation policy portfolios for Taiwan’s SIP Mall industry.” Technovation, Vol. 27, No. 12, pp. 744–765, 2007.

[6] Tamura, M., Nagata, H., Akazawa, K. “Extraction and systems analysis of factors that prevent safety and security by structural models.” In 41st SICE annual conference, Osaka, Japan, 2002.

[7] Wu, W. W., Lee, Y. T. “Developing global managers’ competencies using the fuzzy DEMATEL method.” Expert Systems with Applications, Vol. 32, No. 2, pp. 499–507, 2007.

[8] Tzeng, G. H., Chiang, C. H., & Li, C. W. “Evaluating intertwined effects in elearning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL.” Expert Systems with Applications, Vol. 32, No. 4, pp. 1028–1044, 2007.

[9] Liou, J. J. H., Tzeng, G. H., & Chang, H. C. “Airline safety measurement using a hybrid model.” Journal of Air Transport Management, Vol. 13, No. 1, pp. 243–249, 2007.

[10] Wu, W. W. “Choosing knowledge management strategies by using a combined ANP and DEMATEL approach.” Expert Systems with Applications, Vol. 35, No. 2, pp. 828–835, 2008.

[11] Lin, C. J., & Wu, W. W. “A causal analytical method for group decision-making under fuzzy environment.” Expert Systems with Applications, Vol. 34, No. 1, pp. 205–213, 2008.

[12] Tsai, W. H., & Chou, W. C. “Selecting management systems for sustainable development in SMEs: A novel hybrid model based on DEMATEL, ANP, and ZOGP.” Expert Systems with Applications, Vol. 36, No. 2, pp. 1444–1458, 2009.

[13] Chen, M.F., Tzeng, G.H., Ding, C.G. “Combining fuzzy AHP with MDS in identifying the preference similarity of alternatives.” Applied Soft Computing Journal, Vol. 8, No. 1, pp. 110–117, 2008.

[14] Hu, Y.C., Chen, R.S., Tzeng, G.H. “Discovering fuzzy association rules using fuzzy partition methods.” Knowledge-Based Systems, Vol. 16, No. 3, pp. 137–147, 2003.

[15] Von Altrock, C.V. “Fuzzy Set Theory & Neurofuzzy Applications in Business and Finance.” Prentice Hall, New Jersey, 1996.

[16] Stanley, E.D., Honig, D.P., Gainen, L. “Linear programming in bid evaluation.” Naval Research Logistics Quarterly, Vol. 1, pp. 48-54, 1954.

[17] Gainen, L. “Linear programming in bid evaluation.” Proceedings of the Second Symposium of Linear Programming DC/Scomptroller, 1, USAF, Washington DC, pp.19–38, 1955.

[18] Wind, Y., Robinson, P.J. “The determinants of vendor selection: The evaluation function approach.” Journal of Purchasing and Materials Management Fall, pp. 29-41, 1965.

[19] Stevens, G.C. “Integrating the supply chain.” International Journal of Physical Distribution and Materials Management, Vol. 19, No. 8, pp. 3–8, 1989.

[20] Chaudhry, S.S., Forst, F.G., Zydiak, J.L. “Vendor selection with price breaks.” European Journal of Operational Research, Vol. 70, pp. 52–66, 1993.

[21] Gheidar-Kheljani, J., Ghodsypour, S.H., Brien, C.O. “Optimizing whole supply chain benefit versus buyer’s benefit through supplier selection.” International Journal of Production Economics, Vol. 121, No. 2, pp. 482–493, 2009.

[22] Kumar, M., Vrat, P., Shankar, R. “A fuzzy goal programming approach for vendor selection problem in a supply chain.” Computers and Industrial Engineering, Vol. 46, pp. 69-85, 2004.

[23] Amid, A., Ghodsypour, S.H., O’Brien, C. “Fuzzy multi-objective linear model for supplier selection in a supply chain.” International Journal of Production Economics, Vol. 104, pp. 394–407, 2006.

[24] Wang, J., Zhao, R., Tang, W. “Fuzzy programming models for vendor selection problem in a supply chain.” Tsinghua Science and Technology, Vol. 13, pp. 106-111, 2008.

[25] Mikhailov, L. “Fuzzy analytical approach of partnership selection in formation of virtual enterprises.” Omega, Vol. 30, No. 2, pp. 393–401, 2002.

[26] Shyur, H.J., Shih, H.S. “A hybrid MCDM model for strategic vendor selection.” Mathematical and Computer Modelling, Vol. 44, No. 8, pp. 749–761, 2006.

[27] Chen, C.H. Fuzzy logic and neural network handbook. McGraw-Hill, Inc., New York, 1996.
[28] Cheng, C. H., & Lin, Y. (2002). Evaluating the best main battle tank using fuzzy decision theory with linguistic criteria evaluation. European Journal of Operational Research, 142(1), 174–186.
[29] Wu, W.W. "Segmenting critical factors for successful knowledge management implementation using the fuzzy DEMATEL method." Applied Soft Computing, Vol. 12, pp. 527–535, 2012.
[30] Lin, R.J. "Using fuzzy DEMATEL to evaluate the green supply chain management practices." Journal of Cleaner Production, Vol. 40, pp. 32-39, 2013.
[31] Fontela, E., & Gabus, A. (1976). The DEMATEL observer, DEMATEL 1976 report. Switzerland Geneva: Battelle Geneva Research Center.
[32] Hori, S., Shimizu, Y. "Designing methods of human interface for supervisory control systems." Control Engineering Practice, Vol. 7, No.11, pp. 1413–1419, 1999.
[33] Yang, J.L., Chiu, H.N., Tzeng, G.H., Yeh, R.H. "Vendor selection by integrated fuzzy MCDM techniques with independent and interdependent relationships". Information Sciences, Vol. 178, pp. 4166-4183, 2008.