A Decision making method with triangular fuzzy numbers for Unraveling the Criteria of E-Commerce

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Abstract: - The fuzzy decision-making trial and evaluation laboratory (fuzzy DEMATEL) provides a causal relationship among criteria and computationally feasible method for addressing uncertain and ambiguous information in decision making. This paper aims to unravel the relationships between criteria of e-commerce using the fuzzy DEMATEL, where triangular fuzzy numbers are used to represent uncertain and ambiguous information. One hundred and twelve undergraduate students of mixed gender at a public university in Malaysia were invited to evaluate the criteria of e-commerce using a six-construct questionnaire. Linguistic scales that defined using triangular fuzzy numbers were employed in data collection. Data were analyzed using the nine-step of the DEMATEL method. The main contribution of this paper is the development of the causal relationship among the criteria of e-commerce that obtained from a total relation matrix of the fuzzy DEMATEL. It is found that 'Ease of Use System' was the most influencing criterion and 'Information of Product or Services' was the most important criterion. Not only did the fuzzy DEMATEL unravel the relationship among criteria, but it also identified the degree of importance among the criteria. The findings contribute to a better understanding about the criteria of e-commerce, where retailers could develop effective strategies in marketing and reciprocally, consumers would receive products and services with higher quality.

Key-Words: - e-commerce, triangular fuzzy number, causal diagram, decision making

1 Introduction

A number of decision making tools have been developed over the last four decades to deal with qualitative information of multi-criteria decision making (MCDM) problems. One of the decision making tools that purposely used to unravel a relationship among criteria of decision problems is decision making trial and evaluation laboratory (DEMATEL). According to Govindan et al. [1], the DEMATEL is a comprehensive method that purposely used to design a structural model and analyzed it causal relationship among complex criteria. Previously, the DEMATEL method was proposed to establish integrated solutions by searching fragmented and antagonistic phenomena of world science. The DEMATEL method was used for researching and solving complicated and intertwined problems group in many issues such as race, hunger, environmental protection and energy [2]. Thus, it was able to project and to solve problems visually with digraphs and able to convert the interrelations among the cause group and effect group of factors into an intelligible structural model of a system [3]. The beauty of DEMATEL was described by Tzeng and Huang [4], where the related criteria of a decision problem can be divided into the cause group and effect group. Moreover, the DEMATEL method was particularly pragmatic to visualize the structure of complex causal influences with digraphs.

Like most of the MCDM methods, the DEMATEL depends on pairwise comparisons judged by a group of experts. Human judgments are always inherited some extent of uncertainty and subjective human perceptions. Incomplete information about criteria that under investigation is also may contribute to the uncertainty. To address these problems, fuzzy DEMATEL is used to solve decision problems because human's judgment and favoritism are difficult to convert into exact numbers [5]. Considering the vagueness in humans' judgments and incomplete information of criteria, the fuzzy DEMATEL was proposed. The concept of fuzzy numbers is embedded to the DEMATEL method. Humans' judgments are made in accordance with linguistic variables that defined by fuzzy numbers. There are many types of fuzzy numbers in literature and triangular fuzzy numbers are one of them. In many fuzzy DEMATEL methods, triangular fuzzy numbers are commonly used in defining linguistic variables. The fuzzy DEMATEL method is able to describe the causal interrelations of criteria and evaluate the strength of interactive influence between criteria based on linguistic judgment that defined using triangular fuzzy number.

Many cases of decision making problems have been solved using the fuzzy DEMATEL method. Samani and Shahbodaghlou [6] for example, used fuzzy DEMATEL to construct a risk assessment in Iranian oil and gas. Hiete et al. [7] conducted a research to apply the trapezoidal fuzzy DEMATEL method to indicator for disaster resilience. Chang et al. [8] applied the fuzzy DEMATEL approach to solar cell industry material selection process in Taiwan. In ensuring effective and accurate supplier selection decisions, fuzzy DEMATEL methods have been used in manufacturing industries [9], and electronic industries [10]. Patil and Kant [11] proposed a research to evaluate the critical success factor of knowledge management adoption in the supply chain using the fuzzy DEMATEL method. In another research related to supply chain, knowledge management criteria were evaluated using fuzzy DEMATEL. In addition, Rouhani et al. [12] introduced a research on fuzzy DEMATEL model for evaluation criteria of business intelligence where impact-relation map has been constructed.

So far, however, there has been little discussion about the application of the fuzzy DEMATEL to consumers' behavior towards e-commerce. Recent developments in internet of things have heightened the need for efficient and trustworthy e-commerce transactions. In Malaysia alone, despite a small country, there are almost twenty million internet users in Malaysia, and approximately fifty per cent of it has online shopping experience buying or transacting online. However, Malaysian still does not regard the e-commerce platform as a medium for commerce [13]. Seventy one per cent of Malaysian regretted their online purchases due to mismatched expectation; forty eight per cent expressed their dissatisfaction with the product and twenty nine per cent of them regretted because of the poor product quality [14]. Apart from dissatisfaction over products, Valmohammadi and Dashti [15] also suggested that 'security and privacy' is another important factor in e-commerce transactions. These are among the factors that have been raised by several parties regarding e-commerce. This paper seeks to investigate these issues and how it would affect consumers' behavior toward e-commerce. Unlike the previous related research, this paper aims to develop a relationship among factors influencing e-commerce using fuzzy DEMATEL. The factors that attached to e-commerce are judged by respondents using triangular fuzzy numbers, where the relation among these factors can be unraveled. The word factors that normally used in describing e- commerce are now changed to criteria as to fulfil the word that normally used in the DEMATEL method and is being used in the subsequent text.

2 Preliminaries

One of the important concepts in fuzzy set theory is a linguistic variable. A linguistic variable is a variable that can be expressed in one or more words to portray information other than numbers. The linguistic variables are used by decision makers to express their assessments in a natural and effective way. It is a mathematical representation of semantic concepts that includes more than one term. Definitions of linguistic variables, triangular fuzzy numbers and its arithmetic operations are given as below.

Definition 1: Linguistic variables [16]
A linguistic variable characterized by the quintuples $(x, T(x), U, G, M)$ where

x - the name of the variable.

U - the universe of discourse that associated with the base variable u.

$T(x)$ - denotes the term set of x, that is the set of name for linguistic value of x. Each value of fuzzy variable is a generic of x and ranging over U.

G - is a syntactic rule for generating the name X, of the values x. A particular X, that is name generated by G, is called a term.

M - is a semantic rule for associating with each X and its meaning, $M(x)$, is a fuzzy subset U.

Linguistic value of variable $T(x)$ can be expressed by any fuzzy numbers, and the triangular fuzzy numbers are the commonly used due to its simplicity.

Definition 2: Triangular fuzzy number [17]
Triangular fuzzy number is to be used when some numbers cannot be specified precisely or accurately due to the vagueness of human judgments. A triangular fuzzy number can be defined as a triplet with the membership function. The membership function of triangular fuzzy number can be expressed as,

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

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

Similar to real numbers, triangular fuzzy numbers are also subjected to four basic arithmetic operations.

Definition 3: Operation of triangular fuzzy number [18],[19]
Operational laws of triangular fuzzy number are expressed as follows,

Suppose triangular fuzzy numbers $\tilde{A}_1, \tilde{A}_2$ are defined as

$\tilde{A}_1 = (l_1, m_1, r_1)$, $\tilde{A}_2 = (l_2, m_2, r_2)$

For $l_1, l_2 > 0$; $m_1, m_2 > 0$; $r_1, r_2 > 0$

i. Addition of the triangular fuzzy number
$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, r_1) \oplus (l_2, m_2, r_2) = (l_1 + l_2, m_1 + m_2, r_1 + r_2)$$
ii. Subtraction of the triangular fuzzy number
$$\tilde{A}_1 - \tilde{A}_2 = (l_1, m_1, r_1) - (l_2, m_2, r_2) = (l_1 - l_2, m_1 - m_2, r_1 - r_2)$$
iii. Multiplication of the triangular fuzzy number
$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1, m_1, r_1) \otimes (l_2, m_2, r_2) = (l_1 \times l_2, m_1 \times m_2, r_1 \times r_2)$$
iv. Division of the triangular fuzzy number
$$\tilde{A}_1 \div \tilde{A}_2 = (l_1, m_1, r_1) \div (l_2, m_2, r_2) = \left(\frac{l_1}{l_2}, \frac{m_1}{m_2}, \frac{r_1}{r_2}\right)$$

The concept of linguistic variables in Definition 1 provides a means for approximate characterization of phenomena that are complex or ill-defined to be amenable to description in conventional quantitative terms [20], [21]. Most of the linguistic definitions are bounded within the closed interval [0, 1]. Therefore, Definition 2 provides a triplet triangular fuzzy number that bounded in the closed interval [0,1]. Accordingly, the arithmetic operations of triangular fuzzy numbers are defined. These definitions are vehemently embedded in the algorithm of fuzzy DEMATEL method.

3 Algorithm of Fuzzy Dmatel

The fuzzy DEMATEL has been proposed in substantial literature, where the method basically follows the seven-step computational procedure. In this paper, we adopted fuzzy DEMATEL proposed by Yeh and Huang [5], and Sangaiah et al.[22] . It is good to note that the relationship among criteria of e-commerce was developed using the DEMATEL that purposely used triangular fuzzy numbers instead of trapezoidal fuzzy numbers in defining linguistic scales. It is due to the fact that triangular fuzzy numbers are triplet of real numbers where more efficient of computations are expected. The second feature in this fuzzy DEMATEL is the defuzzification method, where Best Nonfuzzy Performance proposed by Chang and Wang [23] is adopted to transform triangular fuzzy numbers to crisp numbers. This method meant to locate the best value that extracted from triangular fuzzy numbers. The two features that attached to the fuzzy DEMATEL are fully manipulated in ensuring the method used is practical and simple in computation.

Computational procedure of the fuzzy DEMATEL method with two innovative features is described as follows.

Step 1: Determine the evaluation factor and designing the fuzzy linguistic scale.
The evaluation criteria based on respondents' opinion has been specified. The fuzzy linguistic scale is used with linguistic terms includes: Very high influence (VH), High influence (H), Low influence (L), Very low influence (VL) and No influence (No). These are displayed in positive triangular fuzzy numbers (l_{ij}, m_{ij}, u_{ij}), as shown in Table 1.

Table 1 The fuzzy linguistic scale

Linguistic terms	Crisp Value	Triangular fuzzy numbers
Very high influence (VH)	4	(0.75, 1.0, 1.0)
High influence (H)	3	(0.5, 0.75, 1.0)
Low influence (L)	2	(0.25, 0.5, 0.75)
Very low influence (VL)	1	(0, 0.25, 0.5)
No influence (No)	0	(0, 0, 0.25)

Step 2: Develop the initial fuzzy direct-relation matrix.
An initial fuzzy direct-relation matrix $\tilde{Z}$ is set up from the data gathered from the respondents. The evaluation criterion is expressed as

$\{C_i \mid i = 1,2,\ldots,n\}$. The initial fuzzy direct-relation matrix $\tilde{Z}$ by having the respondent's conduct in this research is as follows:

$$\tilde{Z} = \begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{bmatrix} 0 & \tilde{Z}_{12} & \cdots & \tilde{Z}_{1n} \\ \tilde{Z}_{21} & 0 & \cdots & \tilde{Z}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{Z}_{n1} & \tilde{Z}_{n2} & \cdots & 0 \end{bmatrix} \quad (1)$$

Note that $\tilde{Z}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, which represent lower bound (l), middle bound (m) and upper bound (u) of the triangular fuzzy number. Besides, $\tilde{Z}_{ij}, i = 1,2,\ldots,n$, on the diagonal is (0, 0, 0).

Step 3: Construct normalized fuzzy direct-relation matrix $\tilde{X}$.
The criteria scales transformed into comparable scales by using normalization formula. Fuzzy linguistic variable is converted into crisp scores. Having:

$$\tilde{a}_{ij} = \sum_{j=1}^{n} \tilde{Z}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \right)$$

$$and \quad r = \max_{1 \le i \le n} \left(\sum_{j=1}^{n} u_{ij} \right)$$

The normalized fuzzy direct-relation matrix is

$$\tilde{X} = \begin{bmatrix} \tilde{X}_{11} & \tilde{X}_{12} & \cdots & \tilde{X}_{1n} \\ \tilde{X}_{21} & \tilde{X}_{22} & \cdots & \tilde{X}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{X}_{m1} & \tilde{X}_{m2} & \cdots & \tilde{X}_{mn} \end{bmatrix} \quad \text{and}$$

$$\tilde{X}_{ij} = \frac{\tilde{Z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r} \right) \quad (2)$$

Step 4: Setting up the fuzzy total-relation matrix.
Once the normalized directed-relation matrix $\tilde{X}$ is produced, the fuzzy total-relation matrix $\tilde{T}$ can be constructed from the following formulae.

$$\begin{aligned} \tilde{T} &= \tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^k \\ &= \tilde{X}\left(I + \tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^{k-1}\right) \\ &= \tilde{X}\left(I + \tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^{k-1}\right)\left(I - \tilde{X}\right)\left(I - \tilde{X}\right)^{-1} \\ &= \tilde{X}\left(I \quad \tilde{X}\right)^{1} \quad , \quad when \lim_{k \to \infty} \tilde{X}^k = [0]_{n \times n} \end{aligned}$$

$$\left[l_{ij}^{"}\right] = X_l \times \left(I - X_l\right)^{-1}$$

$$\left[m_{ij}^{"}\right] = X_m \times \left(I - X_m\right)^{-1}$$

$$\left[u_{ij}^{"}\right] = X_u \times \left(I - X_u\right)^{-1}$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{m1} & \tilde{t}_{m2} & \cdots & \tilde{t}_{mn} \end{bmatrix} \quad \text{and} \quad \tilde{t}_{ij} = \left(l_{ij}^{"}, m_{ij}^{"}, \mathrm{u}_{ij}^{"}\right) \quad (3)$$

where X_l, X_m, X_u are crisp matrices from $\tilde{X}$, and I is identity matrix.

Step 5: Conduct defuzzification.

The BNP method is used for defuzzification of values.
The fuzzy numbers can be defuzzified to obtain the total-relation matrix by using this formula,

$$\frac{\left[\left(u_{ij} - l_{ij}\right) + \left(m_i - l_{ij}\right)\right]}{3} + l_{ij}. \quad (4)$$

The matrix after deffuzification is denoted as T, where $t_{ij} \in$ T,

$$\mathrm{T} = \left[\mathrm{t}_{ij}\right], \quad \mathrm{i, j} \in \{1,2,\ldots,\mathrm{n}\} \quad (5)$$

Step 6: Calculate the row summation and the column summation.
The sum of row i is denoted as a vector R_i which indicates the influential levels of i factor on all other factors, whereas the sum of the column j is denoted as vector C_i, which indicates the influenced levels of j factor.

The symbol of summation

$$R_i = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1} \; ; C_i = \left[\sum_{i=1}^{n} t_{ij}\right]_{1 \times n} \quad (6)$$

denote the sum of row and sum of column respectively.

Step 7: Draw a cause-effect diagram.
In this step, the prominence $(R_i + C_i)$ and the relation $(R_i - C_i)$ are computed. A factor is considered in the cause group if $(R_i - C_i)$ is positive. However, the factors belong to the effect group if $(R_i - C_i)$ is negative. Thus, the causal diagram can visualize the complex causal relationship by mapping the data set of $(R_i + C_i, R_i - C_i)$.

Step 8: Compute the threshold value to obtain the digraph.
Threshold value, p is obtained by averaging the elements of T.

$$p = \sum_{i,j=1}^{n} t_{ij}/n \tag{7}$$

where t_{ij} is element of T, and n is the number of elements in T.

Step 9: Draw the cause and effect diagram.
Cause and effect diagram can be drawn based on the values of the prominence *(R+C)* and the relation *(R-C)* from Step 7.

The proposed nine-step of fuzzy DEMATEL is applied to a case of consumers' perception toward e-commerce.

3 A case study of e-commerce

The investigation into e-commerce and its criteria is not a straight forward decision-making process of a single participant owing to the fact that this case study involves many e-commerce consumers or participants. The participants of this study were undergraduate students of mixed gender at a public university in Malaysia. There were one hundred and sixty eight targeted students who have experienced in online shopping participated in this case study. All of these participants were chosen through purposeful sampling, where their age is between nineteen to twenty thirty years old. Participants were asked to respond to a six-construct questionnaire based on pair-wise comparison of influence of criteria of e-commerce. One hundred and twelve dataset were used in the computation due to the incomplete responses given by the participants. The six constructs are information of products or services, conveniences, incentives, security and privacy, ease of use, and website reputation. The subjective opinions of participants were collected and analyzed using the proposed DEMATEL method with triangular fuzzy numbers.

3.1 Computational Illustration and Results

In this sub-section, an illustrative computation of the fuzzy DEMATEL algorithm is presented.

Step 1: Determine the evaluation criteria and design the fuzzy linguistic scale.
Based on the literature, there are many key success factors for e-commerce. In order to make it compatible with the evaluation model, factors contributing to the success of e-commerce are now called as criteria and will be used in the subsequent text. There are six criteria evaluated in this study. The criteria are Information of Products or Services (A), Conveniences (B), Incentive Offers (C), Security and Privacy (D), Ease of Use System (E) and Website Reputation (F). The fuzzy linguistic scales in Table 1 are employed in this case study.

Step 2: Develop the initial fuzzy direct-relation matrix $\tilde{Z}$.
The initial fuzzy direct-relation matrix is computed by gathering one hundred and twelve participants who are requested to evaluate the criteria using pair-wise comparison. The initial fuzzy direct-relation matrix $\tilde{Z}$ is obtained using arithmetic mean of the collected data. Table 2 shows the initial fuzzy direct-relation matrix among the criteria.

Table 2 Initial fuzzy direct-relation matrix among criteria

	A	B	C	D	E	F
A	(0.00, 0.00, 0.00)	(0.43, 0.68, 0.86)	(0.33, 0.57, 0.78)	(0.33, 0.57, 0.79)	(0.38, 0.63, 0.83)	(0.41, 0.65, 0.84)
B	(0.39, 0.64, 0.83)	(0.00, 0.00, 0.00)	(0.29, 0.52, 0.74)	(0.28, 0.51, 0.73)	(0.38, 0.63, 0.82)	(0.33, 0.56, 0.78)
C	(0.35, 0.59, 0.79)	(0.34, 0.57, 0.79)	(0.00, 0.00, 0.00)	(0.28, 0.50, 0.73)	(0.32, 0.56, 0.78)	(0.36, 0.60, 0.81)
D	(0.34, 0.59, 0.80)	(0.34, 0.58, 0.79)	(0.31, 0.55, 0.76)	(0.00, 0.00, 0.00)	(0.34, 0.59, 0.80)	(0.35, 0.60, 0.81)
E	(0.40, 0.64, 0.85)	(0.40, 0.65, 0.85)	(0.32, 0.56, 0.78)	(0.34, 0.59, 0.79)	(0.00, 0.00, 0.00)	(0.38, 0.62, 0.83)
F	(0.41, 0.65, 0.84)	(0.38, 0.62, 0.81)	(0.34, 0.59, 0.79)	(0.38, 0.63, 0.83)	(0.39, 0.64, 0.84)	(0.00, 0.00, 0.00)

The initial fuzzy direct-relation matrix is written in $\tilde{Z}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ and conform to Eq (1).

Step 3: Find normalized fuzzy direct-relation matrix $\tilde{X}$.
The normalized fuzzy direct-relation matrix could be computed using eq (2). .

For row A, sum = 0 + 0.86 + 0.78 + 0.79 + 0.83 + 0.84 = 4.10
For row B, sum = 0.83 + 0 + 0.74 + 0.73 + 0.82 + 0.78 = 3.90
For row C, sum = 0.79 + 0.79 + 0 + 0.73 + 0.78 + 0.81 = 3.90
For row D, sum = 0.80 + 0.79 + 0.76 + 0 + 0.80 + 0.81 = 3.96

For row E, sum = 0.85 + 0.85 + 0.78 + 0.79 + 0 + 0.83 = 4.10
For row F, sum = 0.84 + 0.81 + 0.79 + 0.83 + 0.84 + 0 = 4.11

$$r = \max_{1\le i\le n}\left(\sum_{j=1}^{n} u_{ij}\right) = 4.11$$

The initial fuzzy direct-relation matrix is divided by 4.11, which is the maximum value of u_{ij}. Normalized fuzzy direct-relation matrix among criteria is computed. The elements of the matrix are shown in Table 3.

Table 3 Normalized fuzzy direct-relation matrix among criteria

	A	B	C	D	E	F
A	(0.00, 0.00, 0.00)	(0.10, 0.17, 0.21)	(0.08, 0.14, 0.19)	(0.08, 0.14, 0.19)	(0.09, 0.15, 0.20)	(0.10, 0.16, 0.20)
B	(0.09, 0.16, 0.20)	(0.00, 0.00, 0.00)	(0.07, 0.13, 0.18)	(0.07, 0.12, 0.18)	(0.09, 0.15, 0.20)	(0.08, 0.14, 0.19)
C	(0.09, 0.14, 0.19)	(0.08, 0.14, 0.19)	(0.00, 0.00, 0.00)	(0.07, 0.12, 0.18)	(0.08, 0.14, 0.19)	(0.09, 0.15, 0.20)
D	(0.08, 0.14, 0.19)	(0.08, 0.14, 0.19)	(0.08, 0.13, 0.18)	(0.00, 0.00, 0.00)	(0.08, 0.14, 0.19)	(0.09, 0.15, 0.20)
E	(0.10, 0.16, 0.21)	(0.10, 0.16, 0.21)	(0.08, 0.14, 0.19)	(0.08, 0.14, 0.19)	(0.00, 0.00, 0.00)	(0.09, 0.15, 0.20)
F	(0.10, 0.16, 0.20)	(0.09, 0.15, 0.20)	(0.08, 0.14, 0.19)	(0.09, 0.15, 0.20)	(0.09, 0.16, 0.20)	(0.00, 0.00, 0.00)

Step 4: Construct the fuzzy total-relation matrix $\tilde{T}$.
The fuzzy total-relation matrix is obtained using Eq (3).
The elements of the matrix $\tilde{T}$ are presented in Table 4.

Table 4 Fuzzy total-relation matrix among criteria

	A	B	C	D	E	F
A	(0.07, 0.37, 5.82)	(0.16, 0.51, 6.04)	(0.13, 0.45, 5.68)	(0.13, 0.45, 5.73)	(0.15, 0.49, 5.93)	(0.16, 0.50, 5.98)
B	(0.14, 0.48, 5.79)	(0.06, 0.34, 5.67)	(0.12, 0.42, 5.48)	(0.12, 0.41, 5.53)	(0.14, 0.46, 5.74)	(0.13, 0.46, 5.78)
C	(0.14, 0.46, 5.78)	(0.13, 0.46, 5.83)	(0.05, 0.31, 5.33)	(0.12, 0.41, 5.53)	(0.13, 0.45, 5.73)	(0.14, 0.46, 5.78)
D	(0.14, 0.46, 5.78)	(0.13, 0.46, 5.83)	(0.13, 0.42, 5.48)	(0.05, 0.31, 5.38)	(0.13, 0.46, 5.73)	(0.14, 0.47, 5.78)
E	(0.16, 0.50, 6.04)	(0.16, 0.50, 6.09)	(0.13, 0.45, 5.72)	(0.13, 0.45, 5.77)	(0.06, 0.35, 5.82)	(0.15, 0.49, 6.03)
F	(0.16, 0.50, 5.98)	(0.15, 0.50, 6.03)	(0.13, 0.46, 5.68)	(0.14, 0.46, 5.73)	(0.14, 0.50, 5.93)	(0.07, 0.36, 5.81)

Step 5: Conduct defuzzification to obtain total-relation matrix.
The total-relation matrix is computed using defuzzification formula in Eq (4).
For example,

$$(\mathrm{A},\mathrm{A}) = \frac{(5.82-0.07)+(0.37-0.07)}{3} + 0.07 = 2.09$$

The rest of the defuzzification is calculated accordingly, and the elements of the matrix *T* is arranged as follows, (see eq (5)).

$$\tilde{T} = \begin{bmatrix} 2.09 & 2.24 & 2.09 & 2.10 & 2.19 & 2.21 \\ 2.14 & 2.02 & 2.01 & 2.02 & 2.11 & 2.12 \\ 2.13 & 2.14 & 1.90 & 2.02 & 2.10 & 2.13 \\ 2.13 & 2.14 & 2.01 & 1.91 & 2.11 & 2.13 \\ 2.23 & 2.25 & 2.10 & 2.12 & 2.08 & 2.22 \\ 2.21 & 2.23 & 2.09 & 2.11 & 2.19 & 2.08 \end{bmatrix}$$

Step 6: Calculate the row values and the column values.
The row values and column values are denoted as *R* and *C* respectively. It is calculated using Eq (6).

Row value (*R*) for example,
A = 2.09 + 2.24 + 2.09 + 2.10 + 2.19 + 2.21 = 12.92
Column value (*C*), for example,
A = 2.09 + 2.14 + 2.13 + 2.13 + 2.23 + 2.21 = 12.93

Table 5 shows the row values (*R*) and column values (*C*) for all criteria.

Table 5 Row values and column values according to criteria

Criteria	R	C
A	12.92	12.93
B	12.42	13.02
C	12.42	12.20
D	12.43	12.28
E	13.00	12.78
F	12.91	12.89

Step 7: Calculate the prominence and relation of total-relation matrix *T*.
The prominence is the sum of row values and column values, which indicate the importance of the criteria. Equally, the relation was the difference of row value and column value, which divided the criteria into a cause group and an effect group. Prominence and relation among criteria are presented in Table 6.

Table 6 Prominence and relation among criteria

Criteria	Prominence $(R+C)$	Relation $(R-C)$
A	25.85	-0.01
B	25.44	-0.60
C	24.62	0.21
D	24.71	0.15
E	25.78	0.22
F	25.80	0.02

Step 8: Compute the threshold value to obtain the digraph.

It is needed to calculate the average values of the total-relation matrix *T* before computing the threshold value. If the value in matrix *T* was less than the threshold value, the causal relation was not considered in the digraph. The threshold value is calculated using Eq (7).
Therefore, threshold value p = 2.11.
Table 7 shows the total-relation matrix, T and the t_{ij} * indicates that the element values that higher than the calculated threshold value.

Table 7 Total-relation matrix T

	A	B	C	D	E	F
A	2.09	2.24*	2.09	2.10	2.19*	2.21*
B	2.14*	2.02	2.01	2.02	2.11	2.12*
C	2.13*	2.14*	1.90	2.02	2.10	2.13*
D	2.13*	2.14*	2.01	1.91	2.11	2.13*
E	2.23*	2.25*	2.10	2.12*	2.08	2.22*
F	2.21*	2.23*	2.09	2.11	2.19*	2.08

t_{ij} * = higher than the threshold value (p) =2.11

Digraph is drawn to visualize the data after eliminating some values that below the threshold value. The diagraph depicts the causal relationship between the criteria more clearly after eliminating process. The calculated threshold value is taken as a benchmark value where it is useful to construct the digraph. The digraph among the six criteria is demonstrated in Fig 1.

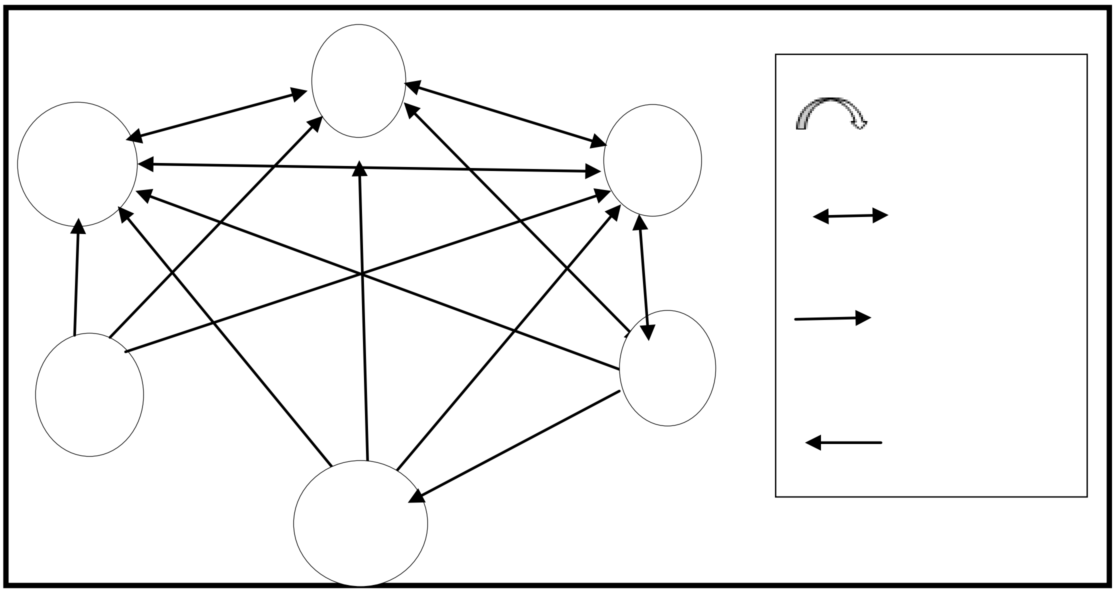

Fig 1 digraph of criteria

The arrows in the Figure 1 show the direction of influence on the criteria. For example, criterion A is influenced by criterion C and criterion D. The criterion A is also mutually influenced with criteria B, criteria E and criteria F.

Step 9: Draw the cause and effect diagram.
The cause and effect diagram was illustrated by the horizontal axis $(R+C)$ and vertical axis $(R-C)$. The value of $(R+C)$ represents the intensity of the effects among criteria, with a greater value meaning a bigger effect. If the $(R-C)$ is a positive value, the criteria are the cause of other criteria, whereas if the $(R-C)$ is a negative value, the criteria are affected by other criteria. The rank for prominence and causal effect are presented in Table 8.

Table 8 Prominence and cause-effect criteria

	Prominence $(R+C)$	Rank	Relation $(R-C)$	Cause/Effect Group	Rank
A	25.85	1	-0.01	Effect	(2)
B	25.44	4	-0.60	Effect	(1)
C	24.62	6	0.21	Cause	2
D	24.71	5	0.15	Cause	3
E	25.78	3	0.22	Cause	1
F	25.80	2	0.02	Cause	4

Based on the horizontal axis $(R+C)$ and the vertical axis $(R-C)$, the cause and effect diagram was built by mapping the data set $(R+C, R-C)$. The cause and effect diagram of criteria for fuzzy DEMATEL is presented in the Fig 2.

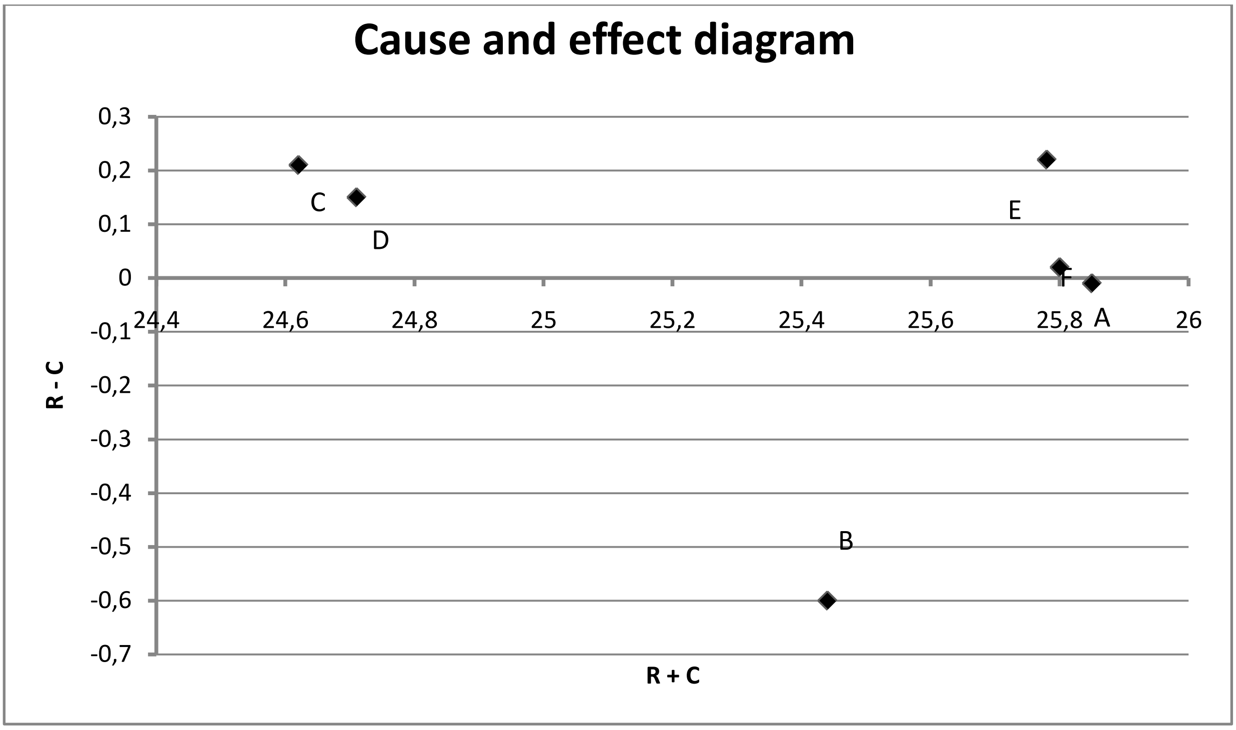

Fig 2 Cause and effect diagram

It is shown that the criterion C, criterion D, criterion E and criterion F are in the cause group because they showed the positive value of a relation $(R-C)$. For the criterion A and criterion B , they had a negative value of a relation $(R-C)$, meaning that they are being categorised under the effect group. Moreover, the Fig 2 also shows that the criterion A is the most important because it has the greatest $(R+C)$ value of 25.85 among the others criteria. Interestingly, the criterion A is categorised as the effect group which is affected by other criteria. The criterion C has the lowest $(R+C)$ value of 24.62 indicates that the least important criterion among other criteria in this study.

4 Conclusion

There are many MCDM methods that available in literature and each method basically proposes preference or ranking of alternatives or criteria of decision problems. However, the fuzzy DEMATEL provides more than preference or ranking. The method not only proposes the importance of criteria, but also identifies cause criteria and effect criteria. Moreover, the fuzzy DEMATEL also offer a digraph where the strength of influence among criteria can be visualized. Based on these advantages, this paper presented an evaluation to a case study of e-commerce using the fuzzy DEMATEL. Human's judgement and favoritism in consumers' behavior towards e-commerce have been dealt with triangular fuzzy numbers. The fuzzy DEMATEL method was preferred because it could be effectively avoided vague and imprecise judgments in consumers' behavior towards e-commerce. The results have confirmed the causal interrelations among the criteria for consumers' behavior towards e-commerce. It is revealed that the criterion 'Conveniences' is the most easily be influenced by others criteria such as 'Information of Products or Services', 'Security and Privacy', 'Ease of Use System' and 'Website Reputation'.

The most obvious finding to emerge from this study is that the most important criterion in e-commerce 'Information of Products or Services'. Accurate and up-to-date information about products are the utmost important criteria in e-commerce shopping environment. These results also support the findings of Jusoh and Goh [24], where the variable such as e-commerce experience, hours spent on internet, product perception, customers were positively correlated with attitude towards e-commerce. For future research, it would be interesting to assess at micro level on the effects of sub-criteria of e-commerce. The criteria could also be evaluated not only by consumers but also from the view of experts in e-commerce. The uniqueness of each decision method always opens to other MCDM methods such as PROMETHEE, VIKOR and ELECTRE to be considered as a future research direction.

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