APPLYING FUZZY DEMATEL METHOD BASED ON SIMPLIFIED CENTROID DEFUZZIFICATION FOR SOLVING THE SUPPLIER SELECTION PROBLEM IN FERTIGATION SYSTEM

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Abstract

Fertigation is an innovative agricultural technique that can maximise crop yields. Since the fertigation system is widely used, deciding the best supplier selection becomes crucial. Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) method is a useful method for solving the Multicriteria Decision-Making (MCDM) in supplier selection problems. This study aims to identify the importance weights of criteria and the influence relationships among criteria in the fertigation system using the fuzzy DEMATEL method based on simplified centroid defuzzification. The fuzzy DEMATEL method consists of 6 steps whereby the simplified centroid defuzzification based on the pointwise operation was implemented in the procedure. This study also used secondary data from previous research, focusing on six supplier selection criteria relevant to the fertigation system: price, quality, delivery, public procurement policy, technical aspect, and managerial aspect. The results found that the technical aspect is the most influential criterion for supplier selection in the fertigation system. Further, this result can serve as a useful guide in determining the best selection of suppliers in the fertigation system using fuzzy DEMATEL based on the other defuzzification method.

Keyword: Centroid Defuzzification, Fertigation System, Fuzzy DEMATEL Method, Supplier Selection.

Introduction

DEMATEL method is a comprehensive and detailed method used to solve complex MCDM problems. This method can identify the importance weights among the evaluated criteria and it is generally used to visually analyse the influence relationships among the criteria based on the causal diagram (Mohd et al., 2020; Li et al., 2020; Si et al., 2018; Akyuz & Celik, 2015). Since human decisions are often uncertain, estimating the vague interdependency relationships among criteria using the exact numerical values are insufficient and problematic in real applications. In this regard, the DEMATEL method has been extended to improve decision-making in various environments as many real-world systems include inaccurate and uncertain information. Thus, the concept of fuzzy set theory is commonly applied in most studies to enhance the DEMATEL method to obtain the best solution to their problems (Liu et al., 2019).

A combination of fuzzy concept and the DEMATEL method, which deals with human sentiment can enhance strategic decision-making in organising the cause group barriers, consequently improving the impact of group barriers. Chang et al. (2011) is the pioneer study that applied the fuzzy DEMATEL method to find influential factors in selecting supplier selection criteria. They applied the Converting Fuzzy Crisp Scores (CFCS) defuzzification method in the fuzzy DEMATEL method with five steps algorithm: normalisation, calculation of the left and right normalised values, determination of the total normalised crisp values, calculation of the crisp value, and integration of the crisp value for all experts. In fuzzy DEMATEL studies, the defuzzification process is used to convert the fuzzy output into a single crisp value or the exact value that represents the fuzzy number (Panaihfar et al., 2015).

Numerous methods have also been applied by past researchers in the process of defuzzifiying fuzzy numbers into a crisp value in the fuzzy DEMATEL method (Si et al., 2018). The selection of the defuzzification method essentially affects the output value determined by the chosen method; hence, it is important to use the appropriate method to consider the need for human perception. In dealing with the ranking of fuzzy numbers in fuzzy MCDM models, centroid defuzzification methods are commonly used and often require membership functions to be identified. With regard to the fuzzy DEMATEL method, numerous studies have been proposed based on the centroid of fuzzy numbers (Liou et al., 2008; Akyuz & Celik, 2015; Panaihfar et al., 2015; Liu et al., 2019).

Akyuz & Celik (2015) and Panaihfar et al. (2015) applied centroid defuzzification at the final step in the fuzzy DEMATEL method to defuzzify the total relation fuzzy matrix into the total relation non-fuzzy matrix. Meanwhile, Liou et al. (2008) defuzzified the TFN using centroid defuzzification in the earlier step after averaging all the experts' TFN scores and continued with the classical fuzzy DEMATEL. Liu et al. (2019) also employed the simplified centroid defuzzification with an alpha level cut at the first step followed by the classical fuzzy DEMATEL method to obtain the result.

Solving MCDM problems in supplier selection criteria is difficult because numerous factors and criteria need to be considered throughout the process. A preliminary study was done by Mohd et al. (2020) to analyse the supplier selection criteria in the fertigation system using the fuzzy DEMATEL method. They reported that public procurement policy is the most influential criteria among all criteria. Fertigation is an innovative agricultural technique that involves the application of water and fertilisers in a regulated manner to increase crop yield.

Since supplier selection is one of the most critical factors affecting an organisation's efficiency (Gharakhani, 2012), in this paper, the fuzzy DEMATEL method based on pointwise centroid defuzzification was applied to solve the supplier selection problem in the fertigation system. The simplified centroid defuzzification can be obtained directly based on the point of the fuzzy numbers without going through the integration process and this has shortened the lengthy calculation process. Thus, by using the secondary data, this study aims to identify the importance weights of criteria and the influence relationships among criteria in the fertigation system using the fuzzy DEMATEL method based on the simplified centroid defuzzification.

Preliminaries: Simplified Centroid Formula

In this section, the simplified centroid formula from the viewpoint of analytical geometry proposed by Wang et al. (2006) is presented. For a normal trapezoidal fuzzy number $F\left(f,g,m,l\right)$, the simplified centroid formula is given in (1).

$$\tilde{x}_F = \frac{1}{3}\left(f+g+m+l-\frac{\left(ml-fg\right)}{\left(m+l\right)-\left(f+g\right)}\right), \qquad \text{where } g \neq m \tag{1}$$

When $g = m$, the trapezoidal fuzzy number becomes a triangular fuzzy number with simplified centroid formula that can be written as shown in (2).

$$\tilde{x}_F = \frac{1}{3}(f + m + l) \quad (2)$$

Simplified Centroid Defuzzification on Fuzzy DEMATEL Method for Analysing the Supplier Selection Criteria

This study applies the simplified centroid formulae by Wang et al. (2006) in the fuzzy DEMATEL method to analyse the supplier selection criteria. The simplified method can be directly obtained from the pointwise form of the fuzzy numbers. The procedure of the fuzzy DEMATEL method used in this study is shown in **Figure 1**.

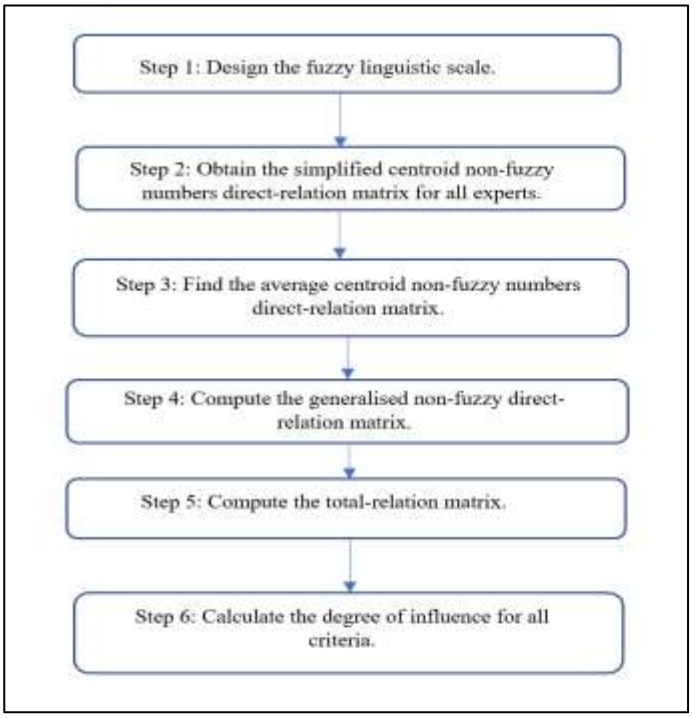

Figure 1 Procedure of Fuzzy DEMATEL Method

A group of k experts was selected to evaluate the significance of supplier selection criteria. They were required to answer a set of questionnaires on assessing the impact between criteria using pairwise comparison. The number of assessment criteria was set as A_1, A_2, … A_n where A_i is the i-th criteria ($i = 1,2,3,...,n$). The implementation of the simplified centroid formulae in the fuzzy DEMATEL method performed in this paper is shown in the following steps.

Step 1: Set up an $n \times n$ fuzzy linguistic scale direct-relation matrix for pairwise comparison of supplier selection criteria for each expert based on the fuzzy linguistic scale proposed by Li (1999). A five-level linguistic term of "influence" was used in the questionnaires as follows: no influence; very low influence; low influence; high influence; and very high influence. The triangular fuzzy numbers (TFN) for these linguistic terms are shown in **Table 1**.

Table 1 The fuzzy linguistic scale proposed by Li (1999)

Linguistic Term	**No influence (NO)**	**Very low influence (VL)**	**Low influence (L)**	**High influence (H)**	**Very high influence (VH)**
TFN	(0, 0, 0.25)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1, 1)

The $n \times n$ fuzzy initial direct-relation matrix for pairwise comparison of supplier selection criteria $T_k = \left[t_{ij}^k\right]_{n\times n} = \left[\left(f_{ij}^k, m_{ij}^k, l_{ij}^k\right)\right]_{n\times n}$ can be written as (3), where t_{ij}^k

denotes the influence degree of i^{th} criterion that affects j^{th} criterion evaluated by expert k.

$$T_k = \left[t_{ij}^k\right]_{n\times n} = \begin{bmatrix} 0 & t_{12}^k & \cdots & t_{1n}^k \\ t_{21}^k & 0 & \cdots & t_{1n}^k \\ \vdots & \vdots & \ddots & \vdots \\ t_{n1}^k & t_{n2}^k & \cdots & 0 \end{bmatrix}_{n\times n} \tag{3}$$

Step 2: Obtain the simplified centroid non-fuzzy numbers direct-relation matrix for all experts by considering a general TFN with a piecewise linear membership function. The centroid values can be determined from (2) in the preliminaries section.

Step 3: Find the average centroid non-fuzzy numbers of direct-relation matrix P for the influence relationships between all six criteria using (4) with k as the number of experts.

$$p_{ij} = \frac{1}{k}\left(p_{ij}^1 + p_{ij}^2 + \dots + p_{ij}^k\right) \tag{4}$$

Step 4: Compute the generalised non-fuzzy direct-relation matrix G as shown in (5) in relation to the overall non-fuzzy direct-relation matrix $P = \left(p_{ij}\right)$, where $i, j = 1,2,\dots,n$.

$$G = \left(G_{ij}\right) = \frac{p_{ij}}{\max_{1\le i\le n} \Sigma_{j=1}^{n} p_{ij}} \tag{5}$$

Step 5: Compute the total-relation matrix S using (6).

$$S = G\left(I - G\right)^{-1} \text{ , where } I \text{ is the identity matrix of } n\times n. \tag{6}$$

Step 6: Calculate the sum of rows (r_i) and the sum of columns (c_j) for each row i and column j from the matrix S by using (7). Then, calculate the values of $r_i + c_j$ and $r_i - c_j$.

$$r_i = \Sigma_{1\le j\le n}^{n} s_{ij}, \forall i$$
$$c_j = \Sigma_{1\le i\le n}^{n} s_{ij}, \forall j \tag{7}$$

The degree of influence in fuzzy DEMATEL represents the strength of influences for both the cause and impact factors and ranked based on the values of $r_i + c_j$ (Gharakhani, 2012). A causal diagram will be built with $r_i + c_j$ as the horizontal axis and $r_i - c_j$ as the vertical axis. The $r_i + c_j$ axis represents the importance degree of the criterion, while the $r_i - c_j$ axis indicates the extent of the influence. A criterion will be categorised into the cause group if the $r_i - c_j$ axis is positive. Otherwise, the criterion will be in the impact group if the $r_i - c_j$ axis is negative.

Numerical Calculation in Analysing the Supplier Selection Criteria based on Fuzzy DEMATEL with Simplified Centroid Defuzzification – Case Study in Fertigation System

In this section, the simplified centroid defuzzification method proposed by Wang (2006) has been applied to fuzzy DEMATEL to analyse the supplier selection criteria in fertigation system. This study used secondary data adopted from preliminary research by Mohd et al. (2020). There were six experts and six criteria of supplier selection relevant to the fertigation system involved in this study; price (A_1), quality (A_2), delivery (A_3), public procurement policy (A_4), technical (A_5), and managerial (A_6) (Etraj & Jayaprakash, 2017). The implementation of the simplified centroid in the fuzzy DEMATEL method performed in this paper is shown in the following steps.

Step 1: A 6x6 linguistic fuzzy scale direct-relation matrix T_k for the judgments of supplier selection criteria in linguistic scale for each expert was developed using (3). **Table 2** shows an example of a linguistic scale direct-relation matrix for Expert 1 (T_1).

Table 2 Linguistic Scale Direct-Relation Matrix for Expert 1 **(**T_1)

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	(0, 0, 0)	(0.75, 1.00, 1.00)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0, 0.25, 0.50)
A_2	(0.50, 0.75, 1.00)	(0, 0, 0)	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0.25, 0.50)	(0, 0.25, 0.50)
A_3	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0, 0, 0)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1.00)
A_4	(0.25, 0.50, 0.75)	(0, 0.25, 0.50)	(0, 0.25, 0.50)	(0, 0, 0)	(0.50, 0.75, 1.00)	(0.75, 1.00, 1.00)
A_5	(0.25, 0.50, 0.75)	(0.75, 1.00, 1.00)	(0.50, 0.75, 1.00)	(0, 0.25, 0.50)	(0, 0, 0)	(0.75, 1.00, 1.00)
A_6	(0, 0.25, 0.50)	(0.50, 0.75, 1.00)	(0.50, 0.75, 1.00)	(0, 0.25, 0.50)	(0.50, 0.75, 1.00)	(0, 0, 0)

Step 2: From **Table 2**, the comparison of criterion A_1 to A_2 was $t_{12}^1 = (0.75,\ 1.00,\ 1.00)$. By applying (2), the centroid value for t_{12}^1 was given as $\tilde{x}_F\left(t_{12}^1\right) = \frac{1}{3}\left(f_{12}^1 + m_{12}^1 + l_{12}^1\right) = \frac{1}{3}(0.75+1.00+1.00) = 0.917$. Thus, the centroid values for other membership functions for Expert 1 are shown in **Table 3**.

Table 3 Centroid Non-Fuzzy Number Direct-relation Matrix for Expert 1

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0.000	**0.917**	0.500	0.500	0.250	0.250
A_2	0.750	0.000	0.083	0.083	0.250	0.250
A_3	0.500	0.250	0.000	0.500	0.500	0.750
A_4	0.500	0.250	0.250	0.000	0.750	0.917
A_5	0.500	0.917	0.750	0.250	0.000	0.917
A_6	0.250	0.750	0.750	0.250	0.750	0.000

Step 3: The results derived for the centroid values of the same membership function for Experts 2, 3, 4, 5, and 6 are 0.917, 0.75, 0.75, 0.75 and 0.75, respectively. Thus, the average centroid number for the influence of criterion A_1 to A_2 was obtained using (4) with $p_{12} = \frac{0.917+0.917+0.75+0.75+0.75+0.75}{6} = 0.806$. The average centroid non-fuzzy numbers direct-relation matrix, P for the influence relationships among all six criteria are shown in **Table 4**.

Table 4 Average Centroid Non-Fuzzy Numbers Direct-Relation Matrix for All Experts (*P*)

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0.000	**0.806**	0.542	0.653	0.542	0.528
A_2	0.792	0.000	0.472	0.625	0.611	0.681
A_3	0.500	0.542	0.000	0.500	0.583	0.583
A_4	0.667	0.681	0.681	0.000	0.708	0.681
A_5	0.750	0.806	0.694	0.569	0.000	0.778
A_6	0.653	0.625	0.611	0.389	0.667	0.000

Step 4: The generalisation for the comparison of criterion A_1 to A_2 obtained using (5) was $G_{12} = \frac{p_{12}}{\max_{1 \le i \le n} \Sigma_{j=1}^{6} p_{ij}} = \frac{0.806}{3.597} = 0.224$ where the sum of rows, $\Sigma_{j=1}^{6} p_{ij} = \{3.069, 3.181, 2.708, 3.417, 3.597, 2.944\}$ and the maximum sum of rows, $\max_{1 \le i \le n} \Sigma_{j=1}^{6} p_{ij} = 3.597$. **Table 5** shows the generalised non-fuzzy direct-relation matrix *G* for the influence relationships among all six supplier selection criteria.

Table 5 Generalised Non-Fuzzy Direct-relation Matrix G

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	0.000	0.224	0.151	0.181	0.151	0.147
A_2	0.220	0.000	0.131	0.174	0.170	0.189
A_3	0.139	0.151	0.000	0.139	0.162	0.162
A_4	0.185	0.189	0.189	0.000	0.197	0.189
A_5	0.208	0.224	0.193	0.158	0.000	0.216
A_6	0.181	0.174	0.170	0.108	0.185	0.000

Step 5: The total-relation matrix *S* was obtained from (6) as shown in **Table 6**.

Table 6 Total-Relation Matrix *S*

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1.089	1.299	1.109	1.067	1.144	1.181
A_2	1.302	1.150	1.125	1.088	1.188	1.242
A_3	1.096	1.129	0.876	0.938	1.046	1.081
A_4	1.343	1.376	1.228	0.995	1.270	1.308
A_5	1.408	1.450	1.272	1.172	1.150	1.373
A_6	1.197	1.218	1.083	0.974	1.127	1.009

Step 6: The sum of rows and columns for each row *i*, r_i and column *j*, c_j for total relation matrix S in **Table 6** was calculated using (7). The values of r_i, c_j, $r_i + c_j$, and $r_i - c_j$ obtained for each criterion are shown in **Table 7** where the values of $r_i + c_j$ represent the degree of influence of the criteria.

Table 7 Degree of Influence for Each Criterion

	A_1	A_2	A_3	A_4	A_5	A_6
r_i	6.888	7.095	6.165	7.520	7.826	6.607
c_j	7.435	7.621	6.693	6.234	6.926	7.194
$r_i + c_{\mathrm{j}}$	14.323	14.716	12.858	13.754	**14.752**	13.801
r_i - c_j	-0.547	-0.526	-0.528	1.286	0.900	-0.587

The importance weights of criteria were ranked based on the values of $r_i + c_j$. From **Table 7**, the highest value of $r_i + c_j$ is 14.752 for the A_5, followed by 14.716 for A_2, 14.323 for A_1, 13.801 for A_6, 13.754 for A_4, and 12.858 for A_3. Thus, the rank of the strength of the criteria in this study is $A_5 \succ A_2 \succ A_1 \succ A_6 \succ A_4 \succ A_3$. The technical aspect is the most important criteria to be considered in selecting supplier selection for the fertigation system, followed by quality, price, managerial aspect, public procurement policy, and delivery of goods.

Table 8 Comparison of the Weights of Criteria ($r_i + c_j$) for Fertigation System

Defuzzfication Method	A_1	A_2	A_3	A_4	A_5	A_6
CFCS (Mohd et al., 2020)	14.282	**14.481**	12.558	13.475	14.460	13.670
Simplified centroid	14.323	14.716	12.858	13.754	**14.752**	13.801

Table 8 compares the weights of criteria based on the values of $r_i + c_j$ for fertigation system from this study and the result by Mohd et al. (2020) which applied the CFCS defuzzification method in the fuzzy DEMATEL. From the results by Mohd et al. (2020), the importance weights of criteria in the fertigation system were ranked as $A_2 \succ A_5 \succ A_1 \succ A_6 \succ A_4 \succ A_3$ which differs from the result of this study with ranking $A_5 \succ A_2 \succ A_1 \succ A_6 \succ A_4 \succ A_3$. The result showed that the implementation of the simplified centroid defuzzification method has slightly changed the ranking results of the weights of criteria. Thus, the results from this study can be used as a guide in obtaining the best selection of suppliers in the fertigation system.

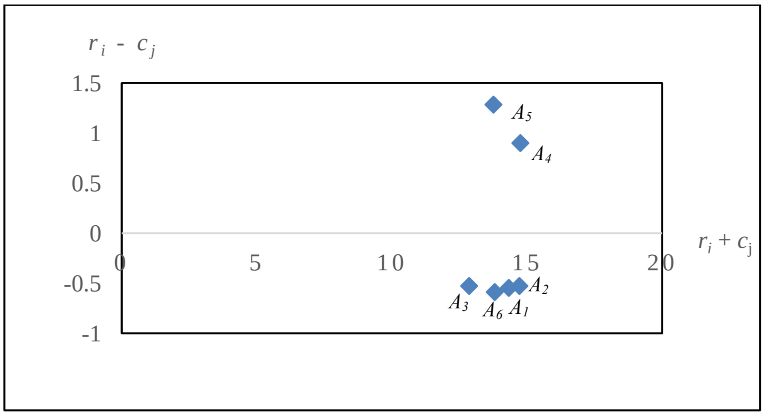

Figure 2 Causal Diagram

Further analysis has been done to analyse the influence relationships among the evaluated criteria using a causal diagram of $r_i + c_j$ (horizontal axis) versus $r_i - c_j$ (vertical axis) as shown in **Figure 2**. Based on the causal diagram, the public procurement policy (A_4) and technical aspect (A_5) are categorised into the cause group, while price (A_1), quality (A_2), delivery (A_3), and managerial aspect (A_6) are categorised into the impact group. The results obtained from this study are parallel to the results reported by Mohd et al. (2020). The public procurement policy and technical aspect can directly or indirectly influence the other criteria and require more consideration. From the comparison of the result of this study and Mohd et al. (2020), the simplified centroid defuzzification on the fuzzy DEMATEL method affects the criteria's ranking but did not affect the influence relationships among the criteria. Since CFCS needs a longer step in the defuzzification process, the simplified centroid defuzzification method can shorten the procedure in analysing the supplier selection problems.

Conclusion

This paper employed simplified centroid defuzzification to solve the fertigation supplier selection problem based on the fuzzy DEMATEL method. As per the results of this study, the technical aspect is the most important criterion for selecting supplier selection for the fertigation system, followed by quality, price, managerial aspect, public procurement policy, and delivery of goods. The findings also showed that the ranking of the strength of criteria is slightly affected by the types of defuzzification method used; however, the influence relationships between them remain the same. The public procurement policy and technical aspect are categorised into the cause group and require more consideration compared to the price, quality, delivery, and managerial aspect in the impact group. The simplified centroid defuzzification can also be directly calculated based on the pointwise of the fuzzy numbers compared to the five steps algorithm in the CFCS method. Thus, the proposed method can be a preferable alternative solution in selecting suppliers in fertigation systems based on fuzzy DEMATEL. In the future, it is recommended to apply fuzzy DEMATEL based on another defuzzification method to get the best result in solving the supplier selection problems in the fertigation system.

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Conflict of interests

The authors hereby declare that there is no conflict of interest with any organisation or financial body in supporting this study.

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