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Research Article

A Preference Ranking Method Based on Triangular Fuzzy Numbers for Green Supplier Selection

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Abstract. Green supplier selection is a process for establishing an effective supplier that fulfills environmental criteria in addition to economical criteria. However, the selection is not a straightforward process as it needs to consider multiple criteria with uncertain information. In order to overcome the uncertainty, we utilize a decision making method based on triangular fuzzy numbers in solving green supplier selection problems. Specifically, this paper aims to develop a preference of alternatives in the case of green supplier selection using fuzzy PROMETHEE method. Seven criteria, four alternatives and five decision makers were the main enterprises in this fuzzy decision making problem framework. Data was collected via personal communication with decision makers using five-point linguistic terms of triangular fuzzy numbers. The seven-step algorithm of fuzzy PROMETHEE with usual preference function and triangular fuzzy numbers was implemented to the case. The results of net flow values of alternatives indicate that supplier A1 is preferred over the other suppliers. More investigations about the fuzzy PROMETHEE method, particularly on the choice of preference functions and other applications are suggested in future research.

Keywords. Fuzzy number; Decision making; Green supplier selection; Preference function; PROMETHEE

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1. Introduction

The growing concern for sustainability has forced many organisation to integrate environmental criteria along with economic criteria in supply chains management. Organizations nowadays are putting more effort into environmental protection instead of just increase the profit [16]. It is the starting point where green supply chain begins to receive attention. Green supply chain is rapidly becoming a public attention because of its association with environmental protection and sustainable development. Supplier selection in the green supply chain applies environmental criteria to the selection of services and products [14]. Supplier selection is the process of deciding the success of the entire green supply chain. In order to protect our environment, the supplier selection processes have to integrate the considerations on environmental criteria such as energy monitoring system, carbon emissions, recycling initiatives and implementation of the environment management systems [17]. Suppliers are part of the organisation's networking and sustainable partnership that affect the performance of organisations. Green supplier selection can be explained as a decision process where a final decision among a set of potential suppliers is made. The decisions made are related to the determination of the optimal number of suppliers and the best supplier based on various criteria [10]. Green supplier selection can be considered as MCDM problems because of the existence of multi-criteria, multi-alternatives and decision makers [3]. In green supplier selection, economic and environmental criteria are considered concurrently [12]. In particular, green supplier selection is one example of decision making problems, where alternatives, criteria and decision makers are the main enterprises. Therefore, green supplier selection problem is germane to MCDM problems and could be solved using MCDM methods [2]. The methods may overcome traditional supplier selection problems where the requirements are so much focussing on single enterprises [18]. In addition, MCDM methods consider supplier selection problems as one interrelated problem of the entire supplier selection.

MCDM method is referred as a method used for scoring or ranking a finite number of alternatives with consideration of multiple criteria. In other words, MCDM concerns with evaluating and selecting alternatives that fit with the goals and necessity. There are many MCDM methods that available in literature, and the PROMETHEE is one of the MCDM methods where decisions are made based on outranking. The PROMETHEE is the abbreviation of preference ranking organization method for enrichment evaluation where it caters final decision of alternatives in the presence of criteria and decision makers. It is a ranking method which is considered as simple in conception and computation compared to many other MCDM methods. The biggest difference between other MCDMs and the PROMETHEE is the inner relationship of PROMETHEE during the decision making process [15]. It is well adapted to the decision problems where a finite number of alternatives are to be ranked subjected to multiple conflicting criteria [20]. The PROMETHEE method is based on pairwise comparisons of alternatives with respect to each criterion. According to Ulengin et al. [21] the PROMETHEE has at least three advantages. The first advantage is one of the user friendly outranking methods. The second advantage is the success of PROMETHEE in applications to real life planning problems. Another advantage of PROMETHEE lies on completeness of ranking.

The PROMETHEE I and PROMETHEE II allow partial and complete ranking of alternatives respectively. With all these in mind, the PROMETHEE has been widely adopted for numerous applications such as finance, water resources and chemistry [5].

In many decision making problems, it is very difficult to rank alternatives due to the uncertain information that attached to the decision making process. Therefore, fuzzy set theory is integrated with decision making methods. Reviews about numerous integrations and diffusion of the fuzzy sets into decision making methods can be found in literature [7], [1], [13]. Along the same lines, fuzzy set was also integrated with PROMETHEE and eventually called as fuzzy PROMETHEE. The main benefit of this method is user friendliness for the linguistic evaluations and the consideration of fuzziness to the decision making environment [6]. The fuzzy PROMETHEE has been utilised to solve many decision making problems. For example, Elevli [9] used the fuzzy PROMETHEE method to choose the potential logistic centre locations. Yuen and Ting [23] used the fuzzy PROMETHEE method for textbook selection problems. Analysis of the problem with welding machine selection was carried out by Yilmaz and Dagdeviren [22] using the fuzzy PROMETHEE method. In addition, a study conducted by Gupta et al. [11] used the fuzzy PROMETHEE method in a cement manufacturing company. Furthermore, a study proposed by Chen et al. [7] used the fuzzy PROMETHEE method for the outsourcing decision problem. Many researchers have investigated the applications of fuzzy PROMETHEE in business and manufacturing but very few literatures focus on business along with environment criteria. In contrast to the above applications, this study provides a decision model that considers both economic criteria and environmental criteria within green supplier selection framework. In particular, the study aims to develop preference of alternatives in green supplier selection problem using fuzzy PROMETHEE. This paper is organized as follows.Prerequisites definitions that required in the fuzzy PROMETHEE is presented in Section 2. Methodology of the research is described in Section 3. Section 4 comprehensively showcases the computational procedures of fuzzy PROMETHEE using data of the supplier selection problem. Section 5 concludes.

2. Prerequisites

This section provides several definitions that related to the fuzzy PROMETHEE. These definitions are required in implementing the computational procedures of fuzzy PROMETHEE, particularly in the case of green supplier selection. It is necessary to provide mathematics knowledge of fuzzy PROMETHEE underpinned by the following definitions.

Definition 1 (Fuzzy Sets [24])**.** A fuzzy set A in X is a class of objects with continuous grades of membership. The set is characterized by a membership function $\mu_A(x)$, whereas the range of the grade of membership is between 0 and 1.

$$A = \{(x, \mu_A(x)) \mid x \in X\}.$$

Definition 2 (Triangular Fuzzy Number [19])**.** The triangular fuzzy number$\mu_A(x)$ is represented as the notation $A = (\alpha, m, \beta)$. x is a variable that belongs to the fuzzy set and the membership function $\mu_A(x)$ is range between 0 and 1 whereas the constant α and β are the lower and upper bounds of the area data and it shows the fuzziness in the data. Figure 1 depicts the triangular fuzzy number in which the maximum membership of fuzzy number is 1 when symmetrical line $x = m$ divides a and b into two equal areas.

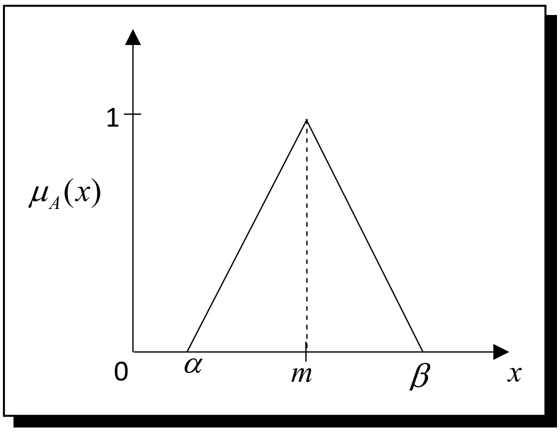

Figure 1. Membership Function of Triangular Fuzzy Number

For $x < \alpha$ or $x > \beta$, x does not belong to the set. For $\alpha \le x \le \beta$ the membership degree is indicated by membership function that range between 0 to 1.

Definition 3 (Membership function [12])**.** The fuzzy number $A = (\alpha, m, \beta)$ can be represented by membership functions as below:

$$\mu_A(x) = \begin{cases} 0, & \text{for } x < \alpha \\ \frac{x-\alpha}{m-\alpha}, & \text{for } \alpha \le x \le m \\ \frac{\beta-x}{\beta-m}, & \text{for } m \le x \le \beta \\ 0, & \text{for } x > \beta \end{cases}$$

(i) α to m is increasing function

(ii) m to β is decreasing function

(iii) $\alpha \le m \le \beta$

Definition 4 (Preference function [7])**.** Let $P_j(a,b) = F_j[d_j(a,b)]$ where $P_j(a,b)$ represents the function of the difference between the evaluations of alternative a regard alternative b on each criterion into a degree ranging from 0 to 1. The smaller number of the functions denotes the indifference of the decision maker. On the contrary, the closer to 1 indicates greater the preference.

The definitions are required to get insight of the algorithm of fuzzy PROMETHEE. The full algorithm is provided in Section 3.3.

3. Methodology

This section describes the details of the framework used in conducting this research. It is divided into three subsections.

3.1 Data Collection and Linguistic Variables

In this research, data were collected via personal communication with a group of senior managers at a country farm organics in Malaysia. This company offers a wide range of organic products and services to consumers through its outlets located around Malaysia. They were asked to provide a degree of importance to a set of criteria in green supplier selection and also four suppliers. They were requested to give their opinion about the criteria using a five-point Likert scale of linguistic variables of importance from 'unimportant' to 'very important'.

3.2 Suppliers, Criteria and Decision Makers

Four suppliers denoted by A_1, A_2, A_3 and A_4 were chosen in this study. Supplier A_1 is MVG Food Marketing Sdn Bhd. They supplied vegan organic frozen food. The wide variety of products are frozen dumpling and frozen meal box like lemongrass chicken rice. Supplier A_2 is CF org Noodle Sdn Bhd which is a noodle manufacturer company. The products they offer are whole wheat noodle, spinach noodle and spirulina stick noodle. Supplier A_3 is Hexa Food Sdn Bhd which is a spice, herb and seasoning manufacturer. They sell a variety of ground spice and seasoning to use in preparing dishes. SupplierA_4 SCS Food Manufacturing Sdn Bhd which is a sugar and salt manufacturer. They supply variety of salt such as organic salt, fine salt and coarse salt.

In personal communication, a group of five managers (D_1,D_2,D_3,D_4,D_5) were requested to rank and evaluate the four green supplier (A_1,A_2,A_3,A_4) based on the seven criteria viz. C_1: cost, C_2: quality of products, C_3: service, C_4: delivery, C_5: technology, C_6: environmental management system, C_7: green packaging. All these criteria are retrieved from Banaeian et al. [4].

3.3 Algorithm of PROMETHEE based on Triangular Fuzzy Numbers

The fuzzy PROMETHEE is one of the multi-criteria decision making methods that has an ability to provide outranking of alternatives. The eight-step procedure of fuzzy PROMEETHEE is presented as follows.

Step 1: *Identify alternatives, criteria and the number of decision makers*. Suppose m alternatives, k criteria and n decision maker exists.

Step 2: *Determine the criteria weight of each criteria responding to linguistic term*. Let w_j represent the weight of criterion c_j based on linguistic preference assigned by decision maker. The weight of criterion is expressed as a triangular fuzzy number and

$$\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \widetilde{3}_3], j = 1,2,\dots,n\,.$$

Step 3: *Aggregating decision maker valuation*. The fuzzy weights of the criteria are aggregated using the interval valued technique as follows:

$$\tilde{w}_j = \frac{1}{n}[\tilde{w}_j^1 + \tilde{w}_j^2 + \ldots + \tilde{w}_j^n]. \tag{1}$$

The ratings of alternatives are aggregated using the next equation

$$\tilde{x}_{ij} = \frac{1}{n}[\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + \ldots + \tilde{x}_{ij}^n]. \tag{2}$$

Step 4: *Constructing fuzzy preference function*. The preference function $\tilde{P}_j(m,n)$ represents the decision maker's preference between pairs of alternatives. Preference function $\tilde{P}_j(a,b)$ for a criterion can be defined as follows:

$$\tilde{P}_j(a,b)\tilde{P}_j(a,b) = \begin{cases} 0, & \tilde{x}_{aj} \le \tilde{x}_{bj}, \\ \tilde{x}_{aj} > \tilde{x}_{bj}, & \tilde{x}_{aj} > \tilde{x}_{bj}, \end{cases} \tag{3}$$

where $j = 1,2,\ldots,k$.

Step 5: *Calculate the multi criteria preference index*. Multi criteria preference index is used to choose the rate in outranking relation.

$$\tilde{\pi}(a,b) = \sum_{j=1}^{k} [\tilde{w}_j \tilde{p}_j(a,b)] \Big/ \sum_{j=1}^{k} \tilde{w}_j \tag{4}$$

where $\tilde{w}_j$ denotes the important weight of the criteria.

$\tilde{\pi}(a,b) \approx 0$ implies a weak preference of a over b.

$\tilde{\pi}(a,b) \approx 1$ implies a strong preference of a over b.

Step 6: *Calculate the positive and negative outranking flows for partial ranking*. For PROMETHEE I (partial ranking) rank alternatives by calculating the positive and negative outranking flows:

$$\text{Positive outranking:} \quad \tilde{\phi}^+(m) = \frac{1}{n-1} \sum_{m \neq l} \tilde{\pi}(m,l), \quad \forall\, m,l \in A \tag{5}$$

$$\text{Negative outranking:} \quad \tilde{\phi}^-(m) = \frac{1}{n-1} \sum_{m \neq l} \tilde{\pi}(l,m), \quad \forall\, m,l \in A \tag{6}$$

where n denotes the number of alternatives.

Step 7: *Transformation and defuzzification*. The triangular fuzzy numbers are given as (L,M,R), and the transformation to L-R is written in (M,a,b).

$$a = M - L \quad \text{and} \quad b = R - M \tag{7}$$

Yager index method is chosen as the defuzzification method. The defuzzification equation in given as follows.

$$(M,a,b) = \frac{3M - a + b}{3} \tag{8}$$

Step 8: *Establishing complete ranking*. PROMETHEE II (complete or full ranking) rank alternatives by calculating the net flow. Eq. (9) is used to compute net flows.

$$\text{Net flow:} \quad \tilde{\phi}(m) = \tilde{\phi}^+(m) - \tilde{\phi}^-(m), \quad \forall\, m \in A \tag{9}$$

The seven steps algorithm of fuzzy PROMETHEE is implemented in the case of green supplier selection.

4. Supplier Selection

Using the collected linguistic terms and triangular fuzzy numbers as input data, the fuzzy PROMETHEE is implemented using the following steps.

Step 1: *Identify alternatives, criteria and the number of decision makers*. Suppose m alternatives, k criteria and n decision maker exists. There are four alternatives, seven criteria and five decision makers in this case study.

Step 2: *Determine the criteria weight of each criteria responding to linguistic variables*. Table 1 shows the weight of criteria and the rating scales defined in the respective triangular fuzzy numbers.

Table 1. Linguistic Variables and Their Corresponding Triangular Fuzzy Numbers

Weights of Criteria	Triangular Fuzzy Numbers	Rating Scales
Unimportant	(0.00, 0.00, 0.25)	Poor
Little important	(0.00, 0.25, 0.50)	Average
Moderately important	(0.25, 0.50, 0.75)	Good
Important	(0.50, 0.75, 1.00)	Very Good
Very important	(0.75, 1.00, 1.00)	Extremely Good

The collected data according to criteria and decision makers with respect to supplier A_1 for example, is presented in Table 2.

Table 2. Fuzzy Weight of Criteria and Decision Makers

	D_1	D_2	D_3	D_4	D_5
C_1	(0.5,0.75,1.0)	(0.75,1.0,1.0)	(0.75,1.0,1.0)	(0.75,1.0,1.0)	(0.75,1.0,1.0)
C_2	(0.75,1.0,1.0)	(0.75,1.0,1.0)	(0.75,1.0,1.0)	(0.75,1.0,1.0)	(0.5,0.75,1.0)
C_3	(0.25,0.5,0.75)	(0.5,0.75,1.0)	(0.75,1.0,1.0)	(0.25,0.5,0.75)	(0.25,0.5,0.75)
C_4	(0.5,0.75,1.0)	(0.5,0.75,1.0)	(0.75,1.0,1.0)	(0.5,0.75,1.0)	(0.75,1.0,1.0)
C_5	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1.0)
C_6	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.25,0.5,0.75)	(0.5,0.75,1.0)	(0.25,0.5,0.75)
C_7	(0.25,0.5,0.75)	(0.5,0.75,1.0)	(0.25,0.5,0.75)	(0.5,0.75,1.0)	(0.25,0.5,0.75)

Step 3: *Aggregate decision making evaluations*. Aggregation of the weight of each criterion from different decision makers is calculated using Eq. (1). The summary of aggregated fuzzy weights of each criterion is shown in Table 3.

Table 3. Aggregated Fuzzy Weights of Criteria

Criteria, C_i	Fuzzy Weight, $\widetilde{w}_j$
C_1	(0.70, 0.95, 1.00)
C_2	(0.70, 0.95, 1.00)
C_3	(0.40, 0.65, 0.85)
C_4	(0.60, 0.85, 1.00)
C_5	(0.30, 0.55, 0.80)
C_6	(0.30, 0.55, 0.80)
C_7	(0.35, 0.60, 0.85)

Then, aggregation of the rating of each supplier by different decision makers can be calculated using Eq. (2). Aggregation of rating is summarized in Table 4.

Table 4. Aggregated Fuzzy Rating of Each Supplier with respect to Criteria

Criteria	Suppliers	Aggregated Rating
C_1	A_1	(0.55, 0.80, 1.00)
	A_2	(0.15, 0.40, 0.65)
	A_3	(0.25,0.50,0.75)
	A_4	(0.25,0.50,0.75)
C_2	A_1	(0.35,0.60,0.85)
	A_2	(0.15,0.40,0.65)
	A_3	(0.15,0.40,0.65)
	A_4	(0.20,0.45,0.70)
C_3	A_1	(0.60,0.85,1.00)
	A_2	(0.50,0.75,0.95)
	A_3	(0.35,0.60,0.85)
	A_4	(0.40,0.65,0.90)
C_4	A_1	(0.45,0.70,0.90)
	A_2	(0.25,0.50,0.75)
	A_3	(0.30,0.55,0.80)
	A_4	(0.35,0.60,0.85)
C_5	A_1	(0.55,0.80,0.90)
	A_2	(0.25,0.50,0.75)
	A_3	(0.35,0.60,0.85)
	A_4	(0.40,0.65,0.90)
C_6	A_1	(0.40,0.65,0.90)
	A_2	(0.25,0.50,0.75)
	A_3	(0.30,0.55,0.80)
	A_4	(0.25,0.50,0.75)
C_7	A_1	(0.35,0.60,0.85)
	A_2	(0.25,0.50,0.75)
	A_3	(0.45,0.70,0.90)
	A_4	(0.30,0.55,0.80)

Step 4: *Construct the fuzzy preference function*. Preference function $\widetilde{P}_j(a,b)$ is used in this step (see Eq. (3)). The fuzzy preference function of A_1, A_2, A_3, A_4 are shown in Table 5, Table 6, Table 7 and Table 8.

Table 5. Fuzzy Preference Function, $\widetilde{P}_j(A_1,A_i)$

Criteria, C_i	$\widetilde{P}_j(A_1,A_2)$	$\widetilde{P}_j(A_1,A_3)$	$\widetilde{P}_j(A_1,A_4)$
C_1	(–0.10,0.40,0.85)	(–0.20,0.30,0.75)	(–0.20,0.30,0.75)
C_2	(–0.30,0.20,0.70)	(–0.30,0.20,0.70)	(–0.35,0.15,0.65)
C_3	(–0.35,0.10,0.50)	(–0.25,0.25,0.65)	(–0.30,0.20,0.60)
C_4	(–0.30,0.20,0.65)	(–0.35,0.15,0.60)	(–0.40,0.10,0.55)
C_5	(–0.20,0.30,0.65)	(–0.30,0.20,0.55)	(–0.35,0.15,0.50)
C_6	(–0.35,0.15,0.65)	(–0.40,0.10,0.60)	(–0.35,0.15,0.65)
C_7	(–0.40,0.10,0.60)	(0,0,0)	(–0.45,0.05,0.55)

Table 6. Fuzzy Preference Function, $\widetilde{P}_j(A_2,A_i)$

Criteria, C_i	$\widetilde{P}_j(A_2,A_1)$	$\widetilde{P}_j(A_2,A_3)$	$\widetilde{P}_j(A_2,A_4)$
C_1	(0,0,0)	(0,0,0)	(0,0,0)
C_2	(0,0,0)	(–0.50,0,0.50)	(0,0,0)
C_3	(0,0,0)	(–0.35,0.15,0.60)	(–0.40,0.10,0.55)
C_4	(0,0,0)	(0,0,0)	(0,0,0)
C_5	(0,0,0)	(0,0,0)	(0,0,0)
C_6	(0,0,0)	(0,0,0)	(–0.50,0,0.50)
C_7	(0,0,0)	(0,0,0)	(0,0,0)

Table 7. Fuzzy Preference Function, $\widetilde{P}_j(A_3,A_i)$

Criteria,C_i	$\widetilde{P}_j(A_3,A_1)$	$\widetilde{P}_j(A_3,A_2)$	$\widetilde{P}_j(A_3,A_4)$
C_1	(0,0,0)	(0.40,0.10,0.60)	(–0.50,0,0.50)
C_2	(0,0,0)	(–0.50,0,0.50)	(0,0,0)
C_3	(0,0,0)	(0,0,0)	(0,0,0)
C_4	(0,0,0)	(–0.45,0.05,0.55)	(0,0,0)
C_5	(0,0,0)	(–0.40,0.10,0.60)	(0,0,0)
C_6	(0,0,0)	(–0.45,0.05,0.55)	(–0.45,–0.05,0.55)
C_7	(–0.40,0.10,0.55)	(–0.30,0.20,0.65)	(–0.35,0.15,0.60)

Table 8. Fuzzy Preference Function, $\widetilde{P}_j(A_4,A_i)$

Criteria, C_i	$\widetilde{P}_j(A_4,A_1)$	$\widetilde{P}_j(A_4,A_2)$	$\widetilde{P}_j(A_4,A_3)$
C_1	(0,0,0)	(–0.40,0.10,0.60)	(–0.5,0,0.5)
C_2	(0,0,0)	(–0.45,0.05,0.55)	(–0.45,0.05,0.55)
C_3	(0,0,0)	(0,0,0)	(–0.45,0.05,0.55)
C_4	(0,0,0)	(–0.40,0.10,0.60)	(–0.45,0.05,0.55)
C_5	(0,0,0)	(–0.35,0.15,0.65)	(–0.45,0.05,0.55)
C_6	(0,0,0)	(–0.50,0,0.50)	(0,0,0)
C_7	(0,0,0)	(–0.45,0.05,0.55)	(0,0,0)

Step 5: *Generate the multi-criteria preference index*. The multi-criteria preference index can be obtained using eq. (4). The indices are given in Table 9.

Table 9. Preference Index of alternatives

Suppliers	A_1	A_2	A_3	A_4
A_1		(–0.27015, 0.218137, 0.662698)	(–0.29, 0.206667, 0.64633)	(–0.33209, 0.164216, 0.610714)
A_2	(0, 0, 0)		(–0.44545, .0.060938, 0.545946)	(–0.44286, 0.054167, 0.525758)
A_3	(–0.4, 0.1, 0.55)	(–0.42712, 0.076404, 0.572936)		(–0.45, 0.055952, 0.54717)
A_4	(0, 0, 0)	(–0.42288, 0.076404, 0.575688)	(–0.46296, 0.037975, 0.539247)	

Step 6: *Determine the positive and negative outranking flows of each supplier (PROMETHEE I partial ranking)*. Positive outranking flow (leaving flow) and negative outranking flow (entering flow) can be calculated using eq. (5) and eq. (6), respectively. Outranking flows are presented in Table 10.

Table 10. Fuzzy PROMETHEE I Flow

Suppliers	Leaving flow, $\phi^+(A_i)$	Entering flow, $\phi^-(A_i)$
A_1	(–0.8922, 0.5890, 1.9197)	(–0.4000, 0.1000, 0.5500)
A_2	(–0.8883, 0.1151, 1.0717)	(–1.1202, 0.3709, 1.8113)
A_3	(–1.2771, 0.2324, 1.6701)	(–1.1984, 0.3056, 1.7315)
A_4	(–0.8858, 0.1144, 1.1149)	(–1.2250, 0.2743, 1.6836)

Step 7: *Transformation and defuzzification*. The fuzzy numbers are given as (L,M,R), and the transformation to L-R is made using eq. (8)

Table 11 shows the outflows given in the form (M,a,b).

Table 11. Fuzzy PROMETHEE Flow in the Form of L-R triangular fuzzy numbers

Suppliers	Leaving flow, $\phi^{+}(A_i)$	Entering flow, $\phi^{-}(A_i)$
A_1	(0.5890, 1.4812, 1.3307)	(0.1000, 0.5000, 0.4500)
A_2	(0.1151, 1.0034, 0.9566)	(0.3709, 1.4911, 1.4404)
A_3	(0.2324, 1.5095, 1.4377)	(0.3056, 1.5040, 1.4259)
A_4	(0.1144, 1.0002, 1.0005)	(0.2743, 1.4993, 1.4093)

The defuzzification method is calculated using Eq. (8).

Table 12 shows the defuzified fuzzy PROMETHEE flows.

Table 12. Defuzzified Fuzzy PROMETHEE Flow

Suppliers	Leaving flow, $\phi^{+}(A_i)$	Entering flow, $\phi^{-}(A_i)$
A_1	0.5389	0.0833
A_2	0.0995	0.3540
A_3	0.2085	0.2796
A_4	0.1145	0.2443

In fuzzy PROMETHEE I, the alternative partial pre-order of $aP^{(I)}b$ are $A_1P^{(I)}A_2$, $A_1P^{(I)}A_3$, $A_1P^{(I)}A_4$, $A_3P^{(I)}A_4$, $A_3P^{(I)}A_2$ and $A_4P^{(I)}A_2$. The inner relationships among alternatives are presented in Figure 2.

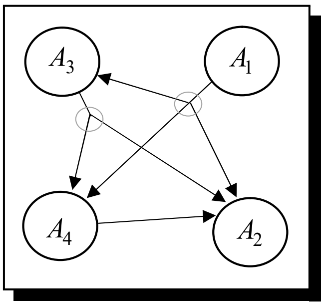

Figure 2. Partial Pre-Order Value Outranking Graph

Step 8: *Compare and rank all the suppliers using the net flow (PROMETHEE II)*. The net flows can be obtained using eq. (9). Table 13 shows the final net flows and ranking for each supplier.

Table 13. The Net Flow Value and Ranking of Suppliers

Suppliers	Net flow	Ranking
A_1	0.4556	1
A_2	-0.2545	4
A_3	-0.0711	2
A_4	-0.1298	3

Moreover, in fuzzy PROMETHEE II, the complete pre-order ranking of $aP^{(II)}b$ are $A_1P^{(II)}A_3$, $A_3P^{(II)}A_4$ and $A_4P^{(II)}A_2$. The outranking graph is shown in Figure 3.

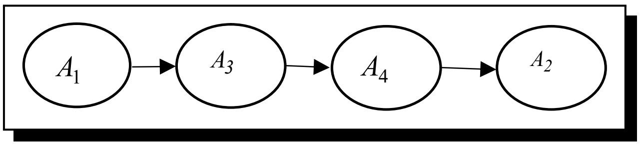

Figure 3. Complete Pre-Order Value Outranking Graph

The ranking results show that the best supplier is supplier A_1-MVG Food Marketing Sdn Bhd. It is a result after considering all the economic and environmental criteria using the fuzzy PROMETHEE outranking model.

5. Conclusions

Green supplier selection can enhance company competitiveness and contribute to sustainability and environment protection. Besides, the success of a company is depending heavily on selecting the right suppliers. However, selecting a suitable supplier is not a trivial task as many criteria need to be wisely prioritized. In addition, the evaluations of the supplier are abundant and those that concern environmental issues are rather limited. This paper developed a preference of suppliers for the case green supplier selection using fuzzy PROMETHEE method. The fuzzy PROMETHEE method is suitable for fuzzy input value which consists of a range of value in evaluation. The decision making method based on fuzzy sets was chosen due to substantial uncertainty and vagueness in the process of developing decision. In the process of developing decision, seven criteria and four suppliers were the main components in fuzzy PROMETHEE. Five decision makers were invited to provide opinions on weight of criteria and the performance rating of each supplier. The preference of suppliers was made after considering all economic and green or environment criteria. This study has shown that the supplierA_1-MVG Food Marketing Sdn Bhd is the best choice of supplier. The proposed decision method can be extended to any types of decision making problems with the fuzzy input value. Sensitivity of the input data toward the preference could be further investigated in future research.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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