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Green Suppliers' Evaluation and Selection Using a Fuzzy Analytic Hierarchy Process Approach

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Abstract

This study aims to evaluate environmentally friendly suppliers by employing a fuzzy Analytic Hierarchy Process (AHP) approach. The assessment of suppliers includes various criteria such as cost (C1), quality (C2), green design (C3), green technology (C4), and green image (C5). Data collection involved conducting interviews with managers directly overseeing the business's supply chain and materials. The fuzzy AHP method is applied in supplier evaluation. An application is utilized to illustrate the procedural steps of the approach.

Keywords: Green Supplier Selection, Fuzzy AHP, Fuzzy Numbers

1. Introduction

Green supplier evaluation is a crucial component of sustainable procurement, involving the selection of suppliers based on their environmental performance (Hajiaghaei-Keshteli *et al*., 2023) [6]. Choosing the right green suppliers not only brings economic benefits to businesses but also aligns with environmental goals and sustainable development. In recent years, many governments have implemented various policies and measures to promote green economies, including green supply chains.

To assess and select green suppliers, several studies have augmented environmental standards in the evaluation process (Ali and Zhang, 2023e) [1], alongside traditional economic criteria such as quality, service, and cost (Çalık, 2021) [2]. Environmental criteria have evolved to encompass aspects like green design (Çalık, 2021) [2], green product innovation (Sun *et al*., 2022) [10], green information systems (Esfahbodi *et al*., 2022) [5], pollution control (Çalık, 2021) [2], green technology (Sun *et al*., 2022) [10], green image (Çalık, 2021) [2], green transportation, and warehousing (Yildizbasi and Arioz, 2022) [12]. Various techniques have been employed in prior studies to address the SS&OA (supplier selection and order allocation) problem. Among these, multi-criteria decision-making (MCDM) techniques, such as the analytical hierarchy process (AHP) (Ikinci & Tipi, 2022) [8], best-worst method (BWM) (Darvazeh *et al*., 2022) [4], and the technique for order preference by similarity to ideal solution (TOPSIS) (Jiang *et al*., 2022) [9], are the most popular.

Presently, the fuzzy analytic hierarchy process (AHP) approach, initially proposed by Chang (1996) [3], stands out as one of the most widely used techniques for solving multi-criteria decision-making problems. This approach is frequently employed to determine factor impacts or criterion weights in uncertain information environments. However, some studies have criticized Chang's (1996) [3] fuzzy AHP approach, highlighting its potential for irrational weighting of decision criteria and sub-criteria, leading to incorrect decision-making (Wang *et al*., 2008; Hue *et al*., 2022) [11, 7]. In response, Hue *et al*. (2022) [7] introduced a revised generalized fuzzy AHP approach to address the limitations of Chang's (1996) [3] method. This study applies Hue *et al*.'s (2022) [7] fuzzy AHP approach to the evaluation and selection of green suppliers.

2. Generalized triangular fuzzy numbers

Definition 1: The membership function of TrFN $\tilde{A} = (\tilde{\varepsilon}_1, \tilde{\varepsilon}_2, \tilde{\varepsilon}_3; \tilde{\omega})$ is given by the following equation:

$$\mu_{\tilde{A}}(\tilde{x}) = \begin{cases} \mu_{\tilde{A}}^{L}(\tilde{x}), & \tilde{\varepsilon}_1 \le \tilde{x} \le \tilde{\varepsilon}_2, \\ \tilde{\omega}, & \tilde{\varepsilon}_2, \\ \mu_{\tilde{A}}^{R}(\tilde{x}), & \tilde{\varepsilon}_2 \le \tilde{x} \le \tilde{\varepsilon}_3, \\ 0, & \text{otherwise}, \end{cases} \quad (1)$$

where $\mu_{\tilde{A}}^{L}(\tilde{x})$ and $\mu_{\tilde{A}}^{R}(\tilde{x})$ are the left and right membership functions of $\tilde{A}$, respectively.

Definition 2: Arithmetic operations on generalized TrFNs
$\tilde{F}=(\tilde{\varsigma}_1,\tilde{\varsigma}_2,\tilde{\varsigma}_3;\tilde{\omega}_{\tilde{F}})$ and $\tilde{T}=(\tilde{\tau}_1,\tilde{\tau}_2,\tilde{\tau}_3;\tilde{\omega}_T)$ are two generalized TrFNs, where $\tilde{\varsigma}_1,\tilde{\varsigma}_2,\tilde{\varsigma}_3,\tilde{\tau}_1,\tilde{\tau}_2,$ and $\tilde{\tau}_3$ are real values, $\tilde{\omega}_F,\tilde{\omega}_T\in[0,1]$. The following arithmetic operators are defined for the generalized TrFNs $\tilde{F}$ and $\tilde{T}$ by the following equations:

(i). Addition $(+)$:

$$\tilde{F}(+)\tilde{T}=\left\{\tilde{\varsigma}_1+\tilde{\tau}_1,\tilde{\varsigma}_2+\tilde{\tau}_2,\tilde{\varsigma}_3+\tilde{\tau}_3;\min(\tilde{\omega}_{\tilde{F}},\tilde{\omega}_T)\right\}, \tag{2}$$

(ii). Subtraction $(-)$:

$$\tilde{F}(-)\tilde{T}=\left\{\tilde{\varsigma}_1-\tilde{\tau}_3,\tilde{\varsigma}_2-\tilde{\tau}_2,\tilde{\varsigma}_3-\tilde{\tau}_1;\min(\tilde{\omega}_{\tilde{F}},\tilde{\omega}_T)\right\}, \tag{3}$$

(iii). Multiplication (x):

$$\tilde{F}(\mathrm{x})\tilde{T}=\left\{\tilde{\varsigma}_1\mathrm{x}\,\tilde{\tau}_1,\tilde{\varsigma}_2\mathrm{x}\,\tilde{\tau}_2,\tilde{\varsigma}_3\mathrm{x}\,\tilde{\tau}_3;\min(\tilde{\omega}_{\tilde{F}},\tilde{\omega}_T)\right\}, \tag{4}$$

(iv). Division $(/)$:

$$\tilde{F}(/)\tilde{T}=\left\{\tilde{\varsigma}_1/\tilde{\tau}_3,\tilde{\varsigma}_2/\tilde{\tau}_3,\tilde{\varsigma}_3/\tilde{\tau}_1;\min(\tilde{\omega}_{\tilde{F}},\tilde{\omega}_T)\right\}, \tag{5}$$

Where $\tilde{\varsigma}_1,\tilde{\varsigma}_2,\tilde{\varsigma}_3,,\tilde{\tau}_1,\tilde{\tau}_2,$ and $\tilde{\tau}_3$ are non-zero positive real numbers.

3. Methodology

Hue *et al*. (2022) [7] proposed an improved fuzzy AHP approach that uses generalized fuzzy numbers to overcome the shortcomings of Chang's (1996) [3] fuzzy AHP approach. The procedures of Hue *et al*.'s (2022) [7] approach are as follows:

- Developing the fuzzy comparison matrix:

$$\tilde{T}=(\tilde{x}_{ij})_{nxn}=\begin{bmatrix}(1,1,1;w_{11}) & (a_{12},b_{12},c_{12};w_{12}) & \cdots & (a_{1n},b_{1n},c_{1n};w_{1n})\\(a_{21},b_{21},c_{21};w_{21}) & (1,1,1;w_{22}) & \cdots & (a_{2n},b_{2n},c_{2n};w_{2n})\\ \vdots & \vdots & \vdots & \vdots\\(a_{n1},b_{n1},c_{n1};w_{n1}) & (a_{n2},b_{n2},c_{n2};w_{n2}) & \cdots & (1,1,1;w_{nn})\end{bmatrix}$$

Where $\tilde{x}_{ij}=(a_{ij},b_{ij},c_{ij};w_{ij})$, $\tilde{x}_{ij}^{-1}=(1/c_{ij},1/b_{ij},1/a_{ij};w_{ij})$ for $i,j=1,\ldots,n$ and $i\neq j$.

- Defining the values of the fuzzy synthetic extents:

The values of fuzzy synthetic extents, S_i are defined in Equation (1).

$$S_i=\left(g_i,h_i,k_i;\min(w_{ij})\right)=\sum_{j=1}^{n}M_{g_i}^{j}\otimes\left[\sum_{i=1}^{n}\sum_{j=1}^{n}M_{g_i}^{j}\right]^{-1}$$
$$=\left(\frac{\sum_{j=1}^{n}a_{ij}}{\sum_{j=1}^{n}a_{ij}+\sum_{k=1,k\neq i}^{n}\sum_{j=1}^{n}c_{kj}},\frac{\sum_{j=1}^{n}b_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}b_{ij}},\frac{\sum_{j=1}^{n}c_{ij}}{\sum_{j=1}^{n}c_{ij}+\sum_{k=1,k\neq i}^{n}\sum_{j=1}^{n}a_{kj}};\min(w_{ij})\right) \tag{6}$$

Where $\sum_{j=1}^{n}M_{g_i}^{j}=\left(\sum_{j=1}^{n}a_{ij},\sum_{j=1}^{n}b_{ij},\sum_{j=1}^{n}c_{ij};\min(w_{ij})\right)$, $i,j=1,2,\ldots,n$

- Calculate the distance between the centroid point $S_i=(\bar{x}_{S_i},\bar{y}_{S_i}),i=1,2,\ldots,n$ and the minimum point $G=(x_{\min},y_{\min})$:

$$D(S_i,G)=\sqrt{(\bar{x}_{S_i}-x_{\min})^2+(\bar{y}_{S_i}-\frac{\varpi}{3}y_{\min})^2} \tag{7}$$

Where $x_{\min} = \min(g_i), y_{\min} = \min(w_{ij}), \bar{x}_{S_i} = (g_i + h_i + k_i)/3, \bar{y}_{S_i} = \min(w_{ij})/3$

Defining the weight vector $W = (w_1, \ldots, w_n)^T$ of the fuzzy comparison matrix:

$$w_i = \frac{D(S_i,G)}{\sum_{i=1}^{n} D(S_i,G)} = \frac{\sqrt{(\bar{x}_{S_i} - x_{\min})^2 + (\bar{y}_{S_i} - \frac{\varpi}{3} y_{\min})^2}}{\sum_{i=1}^{n} \sqrt{(\bar{x}_{S_i} - x_{\min})^2 + (\bar{y}_{S_i} - \frac{\varpi}{3} y_{\min})^2}}, \quad i = 1, \ldots, n \tag{8}$$

4. Application

This section employs Hue *et al.*'s (2022) [7] fuzzy AHP approach to assess and choose green suppliers within a Vietnamese company. A committee comprising three experienced decision-makers (D1, D2, and D3), all of whom are managers at the company, evaluated the suppliers A1, A2, and A3. The study incorporates various criteria, including cost (C1), quality (C2), green design (C3), green technology (C4), and green image (C5). Table 1 is utilized in this research to present linguistic values and triangular fuzzy numbers. The committee members relied on the information from Table 1 to ascertain the priority levels of both the criteria and the suppliers.

Table 1: Intensity scale for generalized fuzzy AHP pairwise comparison

Order	Linguistic values	TFNs
1	Equal importance	(1,1,1)
2	Importance	(2,3,4)
3	Strong importance	(4,5,6)
4	Very strong importance	(6,7,8)
5	Absolute importance	(8,9,9)

Table 2 shows the averaged fuzzy comparison matrix of criteria assessed by the committee.

Table 2: Averaged fuzzy comparison matrix of five criteria

Criteria	C1	C2	C3	C4	C5
C1	(1.00, 1.00, 1.00)	(3.00, 3.67, 4.33)	(1.39, 2.07, 2.75)	(1.67, 2.33, 3.00)	(2.00, 3.00, 4.00)
C2	(0.23, 0.27, 0.33)	(1.00, 1.00, 1.00)	(1.45, 1.81, 2.21)	(2.67, 3.67, 4.67)	(1.06, 1.40, 1.75)
C3	(0.36, 0.48, 0.72)	(0.45, 0.55, 0.69)	(1.00, 1.00, 1.00)	(3.06, 3.40, 3.42)	(3.33, 3.67, 3.67)
C4	(0.33, 0.43, 0.60)	(0.21, 0.27, 0.38)	(0.29, 0.29, 0.33)	(1.00, 1.00, 1.00)	(1.08, 1.44, 1.83)
C5	(0.25, 0.33, 0.50)	(0.57, 0.71, 0.95)	(0.27, 0.27, 0.30)	(0.55, 0.69, 0.92)	(1.00, 1.00, 1.00)

Using Hue *et al.*'s (2022) [7] approach, the fuzzy synthetic extent values of criteria were calculated.

Table 3: Fuzzy synthetic extent values of criteria

Criteria	C1	C2	C3	C4	C5
Fuzzy synthetic extent values	(0.25, 0.34, 0.43)	(0.17, 0.23, 0.30)	(0.20, 0.25, 0.31)	(0.07, 0.10, 0.14)	(0.06, 0.08, 0.12)
Centroid index	0.338	0.232	0.255	0.101	0.09

Table 4 presents the aggregated ratings of green suppliers versus criteria. The final value and ranking order of green suppliers is shown in Table 5.

Table 4: Aggregating the ratings of green suppliers versus criteria

Criteria	Green suppliers	Aggregated ratings	Centroid index
C1	A1	(0.48, 0.61, 0.68)	0.591
	A2	(0.21, 0.29, 0.38)	0.294
	A3	(0.09, 0.11, 0.16)	0.120
C2	A1	(0.54, 0.64, 0.73)	0.636
	A2	(0.14, 0.19, 0.27)	0.199
	A3	(0.10, 0.13, 0.19)	0.142
C3	A1	(0.31, 0.42, 0.52)	0.420
	A2	(0.26, 0.35, 0.45)	0.353
	A3	(0.09, 0.11, 0.16)	0.117
C4	A1	(0.48, 0.61, 0.68)	0.591
	A2	(0.14, 0.18, 0.26)	0.195
	A3	(0.11, 0.14, 0.21)	0.152
C5	A1	(0.25, 0.35, 0.45)	0.349
	A2	(0.25, 0.34, 0.44)	0.340
	A3	(0.10, 0.12, 0.17)	0.128

Table 5: Ranking of green suppliers

Green suppliers	Final values	Ranking
A1	0.546	1
A2	0.286	2
A3	0.130	3

5. Conclusion

This study applied the fuzzy AHP approach to assess green suppliers. Five criteria were used in the evaluation process including cost (C1), quality (C2), green design (C3), green technology (C4), and green image (C5). To gather data, the study conducted interviews with managers responsible for directly overseeing the supply chain and materials of the business. An application was utilized to demonstrate the procedural steps of the approach.

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