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ORIGINAL RESEARCH PAPER

Green Supplier Evaluation by Using the Integrated Fuzzy AHP Model and Fuzzy Copras

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Abstract

Since being environment-friendly has become more important for manufacturers, green supplier evaluation is one of the most crucial challenges for supply chain in the industry. This study aims to evaluate and choose the best green suppliers by integrating fuzzy AHP and fuzzy Copras for seven green suppliers. Fuzzy AHP is used to determine the importance of green supplier performance criteria. Because the criteria and options that are considered in this study are associated with uncertainty, the fuzzy theory is applied as one of the key tools for modeling uncertainties. In this study, a set of criteria for evaluating the green suppliers is identified. Afterwards, fuzzy Copras is employed to evaluate and choose the best green supplier. The contribution of this study lies in the integration of Copras and analytic hierarchy process techniques for green supplier evaluation. That is fuzzy Copras reveals a solution as an optimized respond when the uncertainty is a significant factor in decision-making process, this enhances the accuracy of AHP pairwise comparison. The findings of this study are beneficial for manufacturers, suppliers, and organizations which attempt to improve the supply chain network by eliminating waste.

Keywords Green supply chain · Supplier selection · Fuzzy · Analytic hierarchy process · Copras

Introduction

Nowadays, the green supply chain is a trendy topic due to the increase in greenhouse gases (El-Berishy and Scholz-Reiter 2016). More companies attempt to be environmental-friendly in the recent years (Min and Kim 2012). One of the processes which is essential in any organization and can be efficiently applied in all business processes is supply chain networks (Lockamy and McCormack 2004). Supply chain management is defined as managing and coordinating many complex activities involved in delivering the final goods to the customer (Abbasi et al. 2016). Beyond this definition, green supply chain management refers to green procurement, green manufacturing, green delivery, and reverse logistics (Seuring and Müller 2008).

One of the main goals of green supply chain management is to eliminate or minimize waste (e.g., energy, greenhouse gas emissions, chemical and hazardous and solid waste) within the supply chain. Moreover, improving supply chain facility locations that improves waste management can result in significant benefits for manufacturers and suppliers. For instance, Wichapa and Khokhajaikiat (2017) employed the fuzzy analytic hierarchy process (FAHP) to optimize the locations of waste disposal centers. It is also essential to consider integrated supply chain strategy as a primary factor which can generate performance improvement of companies (Kim 2017). Environmental problems have become a major concern of manufacturers in developed regions, like, North America, European Union, and Japan for many years. Green supply chain system, a key element in global business, helps organizations in the development of strategies to achieve main objectives related to increasing market share by decreasing the environmental risks and enhancing environmental efficiency (Sheu et al. 2005). In recent years, developing countries such as India and Malaysia have initiated their green supply chain plans as well (Choi and Hwang 2015).

Green supply chain management was introduced in 1996 by the Manufacturing Research Consortium of Michigan State University (Akkucuk 2016). In fact, it is a modern management concept to protect the environment. From the perspective of the product lifecycle, a sustainable logistics system

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involves all stages of production, including raw materials procurement, product design, manufacturing, sales, transportation, goods consumption, and recycling of products. By employing the supply chain system and green technology, organizations can decrease environmental effects and gain optimal utilization of resources and energy (Kannan et al. 2014).

With increasing public awareness and strict state laws to protect the environment and sustainable development, companies cannot ignore environmental problems to compete in the international markets. Also, some companies are obliged to reduce harmful effects of their products on the environment by implementing environmental strategies to sell their products. Thus, the integration of environmental, economic and social functions to obtain sustainable development is a central challenge for businesses in the current century (Ashrafi and Chaharsoghi 2013; Khorasani and Almasifard (2017)). To meet these concerns, organizations have used numerous plans to reduce air emission, reduce energy consumption, decrease solid waste, limit water loss (activities related to the end of the production process), use clean technology, and make changes in production operations.

In general, addressing supply chain management can be an important step in moving toward the improvement of sustainable business. Supply chain management can involve all stages of production from beginning to the end of product life; therefore, the integration of sustainability and supply chain management can have a considerable effect on improving sustainable business (Abbasi et al. 2016). Hence, the green supply chain system and sustainable supply chain management are taken into consideration in the literature (Eskandarpour 2014). In supply chain management systems, especially sustainable supply chain, one of the most fundamental decisions is supplier selection and policies related to suppliers. That is the identification of criteria for supplier selection is essential for organizations (Khorasani 2014). Globalization and transcontinental outsourcing, as well as sustainability, greatly increase the importance of supply chain management in corporate strategies and survival in a competitive environment (Hashemi and Dehghanian 2011).

Traditionally, supply chain management involved the integrated guidance for all members of the supply chain to improve performance, which leads to higher productivity and profitability. Supply chain managers endeavored to achieve fast delivery of products and services, decrease costs, and increase the quality of the supply chain network (Gilaninia et al. 2016). However, the negative effects of the environmental degradation on supply chain expenditure have not been studied thoroughly yet. Pressure from government regulations to achieve environmental standards and the expanding consumer demand for green products (without hazardous impacts on the environment) gave rise to the idea of green supply chain (Gilaninia et al. 2016). Currently, supply chain managers of leading companies attempt to take advantage of their improved sustainability and use the green methodology in all components of a supply chain to empower the organizations to obtain continuous competitive advantages by satisfying environmental, economic, and social standards throughout the supply chain (Srivastava 2007).

Selecting the supplier is one of the critical elements in achieving a sustainable supply chain. For example, hazardous substances used in suppliers' raw materials can result in enormous negative environmental effects (Shen et al. 2013). In previous studies, supplier selection has been considered in the traditional management environment in which sustainability factors were ignored most of the time. This study discusses supplier selection in sustainable development environments. For this purpose, traditional criteria and sustainable development criteria are integrated, and their mutual relationship is considered in the supplier evaluation process.

Many studies have been conducted on traditional supplier evaluation. For example, Luthra et al. (2017) used conventional criteria and multi-criteria decision methods to evaluate and select suppliers. However, there are few studies regarding sustainable supplier evaluation and selection in the supply chain literature. Nonetheless, some authors in the literature discussed the sustainable supply chain and revealed a set of criteria regarding environmental aspects of sustainable development. For example, Tseng and Chiu (2013) used 18 criteria to evaluate suppliers in green supply chain management systems. Some of the criteria considered by the authors included delivery time, financial performance, quality, price, green design, green purchase, and clean production. In another study, Büyükozkan and Çifçi (2012) used environmental and social criteria to evaluate green suppliers. Shaw et al. (2012) developed an interactive model using conventional and environmental criteria for the evaluation and selection of green suppliers. Chang et al. (2011) used fuzzy DEMATEL to evaluate and prioritize practices of green supply chain management. Besides, Kannan et al. (2014) employed fuzzy TOPSIS to evaluate green suppliers. Kuo et al. (2010) applied neural network and multi-criteria decision-making methods to select green suppliers. In addition, Bai and Sarkis (2010) evaluated green suppliers by using rough set theory in a single industry. In another study, Handfield et al. (2003) considered environmental criteria along with common traditional criteria to evaluate suppliers. They applied analytic hierarchy process (AHP) to rank suppliers. In a similar study, Humphreys et al. (2003) utilized environmental criteria to develop a model for supplier evaluation. Buyukozkan et al. (2010) employed a fuzzy multi-criteria decision framework to select the best supplier. In another study that was conducted in this field, Govindan and Sivakumar (2016) integrated linear multi-objective optimization and multi-criteria decision-making methods to assess and identify the best green suppliers. Banaeian et al. (2016) used fuzzy VIKOR, fuzzy TOPSIS, and gray fuzzy numbers to evaluate green suppliers in the food chain.

The following authors Awasthi and Kannan (2016) used fuzzy VIKOR, NGT, integrated MCDM, and QFD to evaluate green suppliers, respectively. As the literature illustrates, green supplier evaluation has not been studied by combining fuzzy AHP and fuzzy Copras so far. Therefore, the purpose of this study is to present the green supply chain evaluation by integration of fuzzy AHP and Copras to improve green supplier selection.

Section 2 describes an integrated fuzzy AHP and fuzzy Copras approach in full detail. Through a case study, Section 3 evaluates green suppliers of ISACO by determining options and criteria of a green supplier evaluation. Section 4 implements the integrated AHP and fuzzy Copras to assess green suppliers of ISACO. Section 5 concludes.

Integrated AHP and Fuzzy Copras

This study integrates fuzzy AHP and fuzzy Copras to assess and prioritize suppliers. Fuzzy AHP and fuzzy Copras are explained below.

Fuzzy AHP

AHP is a widely-used eminent multi-criteria decision-making technique developed in the 1970s by Thomas L. Saaty. This technique can be useful when decision-makers are faced several options and decision criteria. Criteria can be quantitative or qualitative. This technique is based on pairwise comparisons. In the real world, many decisions involve ambiguous human phrases. In order to integrate experiences, beliefs, and ideas of a decision-maker, it is better to convert linguistic estimation to fuzzy numbers. AHP uses the matrix of pairwise comparisons for rating and ranking preferences; the input data of this matrix is certain numbers. Moreover, wherever the input data is uncertain, this matrix cannot be used to produce optimal results. Fuzzy AHP enhances the ability of the simulated decision-making process in each observance than traditional AHP (Zamani-Sabzi et al. 2016). In fuzzy AHP, local weights and final weights of criteria and sub-criteria can be extracted as follows:

1. Forming matrix of pairwise comparisons of criteria and sub-criteria

Using pairwise comparisons, expert judgments about criteria and sub-criteria were collected. Table 1 is used to convert linguistic variables to fuzzy numbers. The scale used in this study is a 9-point fuzzy scale based on Saaty's scale (Saaty 1980). The 9-point scale gives more freedom to experts in pairwise comparisons.

2. Calculating local weights of criteria and sub-criteria

Table 1 Linguistic variables converted to fuzzy triangular numbers (Huang and Peng 2012)

Linguistic variables	Triangular fuzzy numbers
Equally significant	(1, 1, 1)
Weakly significant	(2, 3, 4)
Strongly significant	(4, 5, 6)
Very strongly significant	(6, 7, 8)
Absolutely significant	(8, 9, 9)
Median values between two levels	$(X-1, X, X+1)$
Reciprocal triangular numbers	$(1/(X+1), 1/X, 1/(X-1)$
	(1.9, 1.9, 1.8)

Matrices of pairwise comparisons were formed by collecting data and converting expert judgments to corresponding fuzzy numbers. Then, expert judgments were integrated by using geometric mean. Let $\tilde{A}$ be the matrix of the integrated pairwise comparisons; based on Wu et al. (2009), a fuzzy local weight of criteria or sub-criteria is calculated as follows:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} \quad (1)$$

$$\tilde{r}_i = \left(\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in}\right)^{\frac{1}{n}} \quad (2)$$

$$\tilde{w}_i = \tilde{r}_i \otimes \left(\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n\right)^{-1} \quad (3)$$

where, $\tilde{a}_{ij}$ is the value of the integrated pairwise comparison of the criterion i compared to the criterion j; $\tilde{r}_i$ is the geometric mean of value of fuzzy pairwise comparison of the criterion i compared to other criteria. Moreover, $\tilde{w}_i$ is local weight of the criterion.

3. Calculating final weight of sub-criteria

Ultimate weight of a sub-criterion was acquired by multiplying the local weight of the criterion by the local weight of that sub-criterion.

Fuzzy Copras

Copras was first proposed by Zavadskas and Kaklauskas (1996). This method presents a solution as ideal answer. Copras is a flexible technique in ranking, decision-making, prioritizing, and selecting the best options, and it is applicable in all fields of science. Various options are independently evaluated in terms of multiple criteria and options are prioritized depending on the objective. Fuzzy Copras is employed to evaluate and prioritize options. When there is uncertainty and confusion in linguistic terms of respondents. Based on Yazdani et al. (2011), steps of fuzzy Copras are as follows:

1. Selecting corresponding fuzzy numbers to evaluate options in relation to criteria

First, expert judgements regarding how options met criteria were collected. The linguistic variables presented in the table below were used to evaluate alternatives regarding evaluation criteria. To rate options' relation to sub-criteria options, Table 2 can be used.

2. Forming fuzzy decision matrix

Fuzzy decision matrix is shaped based on how options meet criteria according to expert judgments. Then, the integrated fuzzy decision matrix is formed by integrating fuzzy decision matrices related to expert judgments. The geometric mean is applied to integrate expert judgments and form the integrated fuzzy decision matrix. Let n criteria and m options exist; the integrated fuzzy decision matrix is shown below. Note that the weights of criteria were calculated previously by using fuzzy AHP.

$$\tilde{D} = \begin{array}{c} \\ \end{array}\begin{matrix} C_1 & C_2 & & C_n \\ \end{matrix}$$
$$\tilde{D} = \begin{bmatrix} \tilde{X}_{11} & \tilde{X}_{12} & \cdots & \tilde{X}_{1n} \\ \tilde{X}_{21} & \tilde{X}_{22} & \cdots & \tilde{X}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{X}_{m1} & \tilde{X}_{m2} & \cdots & \tilde{X}_{mn} \end{bmatrix} \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \tag{4}$$

Assume the final weights of criteria as:

$$\tilde{W} = \left(\tilde{W}_1, \tilde{W}_2, \cdots, \tilde{W}_n\right) \tag{5}$$

Next, the integrated fuzzy decision matrix and weights of evaluation criteria were defuzzified by the center of area (COA) (Wu et al. 2009). Let $\tilde{R}_i = \left(L\tilde{R}_i, M\tilde{R}_i, U\tilde{R}_i\right)$ be a triangular fuzzy number; according to Wu et al. (2009), the defuzzified value was calculated as follows:

$$BN\tilde{P}_i = \frac{\left[\left(U\tilde{R}_i - L\tilde{R}_i\right) + \left(M\tilde{R}_i - L\tilde{R}_i\right)\right]}{3} + L\tilde{R}_i \tag{6}$$

Table 2 Linguistic scales to rate options relative to sub-criteria

Linguistic variable	Triangular fuzzy number
Very weak	(0, 0, 0.25)
Weak	(0, 0.25, 0.5)
Average	(0.25, 0.5, 0.75)
Good	(0.5, 0.75, 1)
Excellent	(0.75, 1, 1)

Using Eq. (6), elements of the fuzzy decision matrix and final weights of criteria were defuzzified to certain numbers.

3. Normalizing the defuzzified decision matrix

The defuzzified decision matrix was normalized by:

$$\overline{X}_{ij} = \frac{X_{ij}}{\sum_{j=1}^{n} X_{ij}}, i = 1, 2, \ldots, m, \; j = 1, 2, \ldots, n \tag{7}$$

where, X_{ij} is the defuzzified element related to the row i and the column j of the defuzzified decision matrix. Accordingly, the normalized decision matrix is shown as:

$$\overline{X} = \begin{bmatrix} \overline{X}_{11} & \overline{X}_{12} & \cdots & \overline{X}_{1n} \\ \overline{X}_{21} & \overline{X}_{22} & \cdots & \overline{X}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \overline{X}_{m1} & \overline{X}_{m2} & \cdots & \overline{X}_{mn} \end{bmatrix} \tag{8}$$

4. Forming the weighted normal decision matrix

The weighted normal decision matrix was calculated as follows:

$$\hat{X}_{ij} = \overline{X}_{ij}\overline{W}_j, i = 1, 2, \ldots, m, \; j = 1, 2, \ldots, n \tag{9}$$

where, $\overline{W}_j$ is the defuzzified weight of the j-th criterion. In other words, fuzzy weight, $\tilde{W}_j$, was defuzzified by Eq. (6) to $\overline{W}_j$. The weighted normal decision matrix is written as:

$$\hat{X} = \begin{bmatrix} \hat{X}_{11} & \hat{X}_{12} & \cdots & \hat{X}_{1n} \\ \hat{X}_{21} & \hat{X}_{22} & \cdots & \hat{X}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{X}_{m1} & \hat{X}_{m2} & \cdots & \hat{X}_{mn} \end{bmatrix} \tag{10}$$

5. Calculating P_i values

Total P_i was calculated for profit-type criteria. Higher values of profit-type criteria were more optimal.

$$P_i = \sum_{j=1}^{K} \hat{X}_{ij} \tag{11}$$

Where it was assumed that K criteria were profit-type and nq-K criteria were cost-type. Lower values of cost-type criteria were more optimal.

6. Calculating R_i values

Total R_i was calculated for cost-type criteria.

$$R_i = \sum_{j=K+1}^{n} \hat{X}_{ij} \quad (12)$$

7. Calculating minimum R_i

$$R_{\min} = \min_i R_i; i = 1, 2, \ldots, m \quad (13)$$

8. Calculating relative weight of each option Q_i

The relative weight of each option was calculated by:

$$Q_i = P_i + \frac{R_{\min} \sum_{i=1}^{m} R_i}{R_i \sum_{i=1}^{m} \frac{R_{\min}}{R_i}} \quad (14)$$

Eq. (14) can be written as:

$$Q_i = P_i + \frac{\sum_{i=1}^{m} R_i}{R_i \sum_{i=1}^{m} \frac{1}{R_i}} \quad (15)$$

9. Determining optimality criterion $Q_{\max}$

$$Q_{\max} = \max_i Q_i, \quad i = 1, 2, \ldots., m \quad (16)$$

10. Calculating optimality and priority of options

Using N_i which was optimality of the option i, options are prioritized. N_i shows the weight of the option i to $Q_{\max}$. The term $Q_{\max}$ shows the maximum degree of satisfaction. Higher optimality (N_i) of an option indicates higher priority of that option.

$$N_i = \frac{Q_i}{Q_{\max}} 100\%, \quad i = 1, 2, \ldots., m \quad (17)$$

Case Study: ISACO Green Supplier Evaluation

ISACO Company was established on October 23, 1977, as a Joint Stock Company and registered on November 06, 1977. After a change in management, ISACO was formally recognized as the provider of after-sales services for products of an automobile manufacturer by approving changes in the Articles of Association in 1999 and including “after-sales service” in its subject. In 2003, after-sales service was taken from ISACO; however, it joined ISACO again in 2007.

Table 3 List of ISACO suppliers (options)

	Supplier	Scope	Symbol
2	Mehvarsazan (A1)	Paykan Pickup differential supplier	A1
3	Arisan (A2)	Paykan and Pickup differential supplier	A2
4	Niromohareke (A3)	206 and 405 gearbox supplier	A3
5	Iran Lavazem (A4)	405 seat supplier	A4
8	Shetabkar (A5)	Steering box supplier	A5
9	Taha (A6)	206 full steering supplier	A6
10	Mehrkam Pars (A7)	Decorative parts suppliers	A7

To prove its ability to meet customer requirements, achieving global quality, sustainable development, and customer fulfillment as the main components of corporate, ISACO implemented the integrated management system (IMS). This study tends to evaluate ISACO suppliers. Table 3 lists the suppliers and scope of these suppliers.

An essential step of supplier selection is to determine selection criteria. Various criteria have been presented by

Table 4 Criteria and sub-criteria used in this study for green supplier evaluation

Criterion	Sub-criterion
1 Economic and commercial (C1)	Cost Analysis System (C11)
	Cost reduction activities (C12)
	Economic stability (C13)
	Financial position (C14)
	Long-term relationships (C15)
	Organizational structure and personnel (C16)
2 Environmental (C2)	Environmental goal setting (C21)
	Pollution prevention (C22)
	Eco-design (C23)
	Use of eco-friendly raw materials (C24)
	Energy consumption (C25)
	Waste production (C26)
3 Delivery (C3)	Delivery time (C31)
	High delivery rates (C32)
	Product development time (C33)
4 Technology (C4)	Future productivity (C41)
	Clean technology (C42)
	Ability to design (C43)
	Rapid development (C44)
	Technological ability (C45)
5 Quality (C5)	Low failure rate (C51)
	Quality certification (C52)
	TQEM (C53)
	Warranty (C54)

Table 5 Fuzzy matrix of pairwise comparisons resulting from integrating judgments of 15 experts on criteria

	C1			C2			C3			C4			C5		
C1	1.000	1.000	1.000	2.444	2.873	3.313	3.378	4.165	4.871	3.225	4.144	5.022	0.121	0.152	0.185
C2	0.302	0.348	0.409	1.000	1.000	1.000	0.581	0.693	0.831	1.973	2.164	2.393	2.609	3.199	3.836
C3	0.205	0.240	0.296	1.203	1.443	1.721	1.000	1.000	1.000	0.887	1.034	1.180	1.925	2.384	2.830
C4	0.199	0.241	0.310	0.718	0.859	1.027	0.847	0.967	1.127	1.000	1.000	1.000	1.977	2.468	3.045
C5	0.146	0.169	0.207	0.261	0.313	0.383	0.353	0.420	0.520	0.328	0.405	0.506	1.000	1.000	1.000

scholars to evaluate suppliers; 23 criteria proposed by Dickson (1966) are known as the most basic and most important selection criteria for the best supplier. These criteria are so comprehensive that they are still the basis for many studies identifying the best supplier. However, note that these criteria did not thoroughly consider environmental aspects. Therefore, this study uses criteria extracted by Hashemi and Dehghanian (2011) who integrated traditional criteria and green criteria for supplier evaluation and selection. Although it seems some of these criteria slightly overlap, these criteria are the most complete and comprehensive criteria used so far in the literature to evaluate green suppliers. Table 4 lists five criteria and 24 sub-criteria used in this study.

Results

Once data was collected by the questionnaire, fuzzy AHP was run. For this purpose, the matrix of pairwise comparisons was designed by using Table 1 for criteria and sub-criteria. Then, the integrated matrix of pairwise comparisons was shaped. For example, the following matrix shows the integrated matrix of pairwise comparisons based on judgments of 15 experts about criteria (Table 5).

Similarly, the integrated matrix of pairwise comparisons was formed for sub-criteria. Using Eqs. (2) and (3), local weights were calculated for criteria and sub-criteria. Lastly, the final weights of sub-criteria are calculated by multiplying the local

Table 6 Local weight and final weight of criteria and sub-criteria

Criterion	Fuzzy local weight criterion	Su-criterion	Fuzzy local weight of sub-criterion	Fuzzy final weight of sub-criterion	Defuzzified final weight
C1	(0.087, 0.103, 0.118)	C11	(0.167, 0.358, 0.697)	(0.014, 0.037, 0.082)	0.044
		C12	(0.017, 0.035, 0.078)	(0.001, 0.004, 0.009)	0.005
		C13	(0.046, 0.114, 0.271)	(0.004, 0.012, 0.032)	0.016
		C14	(0.025, 0.048, 0.143)	(0.002, 0.005, 0.017)	0.008
		C15	(0.180, 0.359, 0.752)	(0.016, 0.037, 0.089)	0.047
		C16	(0.013, 0.028, 0.063)	(0.001, 0.003, 0.007)	0.004
C2	(0.067, 0.076, 0.086)	C21	(0.016, 0.034, 0.094)	(0.001, 0.003, 0.008)	0.004
		C22	(0.020, 0.050, 0.101)	(0.001, 0.004, 0.009)	0.005
		C23	(0.214, 0.470, 0.976)	(0.014, 0.036, 0.084)	0.045
		C24	(0.121, 0.276, 0.668)	(0.008, 0.021, 0.058)	0.029
		C25	(0.031, 0.069, 0.194)	(0.002, 0.005, 0.017)	0.008
		C26	(0.038, 0.101, 0.236)	(0.003, 0.008, 0.020)	0.010
C3	(0.058, 0.066, 0.076)	C31	(0.058, 0.107, 0.225)	(0.003, 0.007, 0.017)	0.009
		C32	(0.062, 0.130, 0.224)	(0.004, 0.009, 0.017)	0.010
		C33	(0.395, 0.762, 1.493)	(0.023, 0.051, 0.114)	0.062
C4	(0.052, 0.060, 0.070)	C41	(0.041, 0.101, 0.201)	(0.002, 0.006, 0.014)	0.007
		C42	(0.194, 0.495, 1.170)	(0.010, 0.030, 0.082)	0.040
		C43	(0.098, 0.219, 0.590)	(0.005, 0.013, 0.041)	0.020
		C44	(0.079, 0.185, 0.469)	(0.004, 0.011, 0.033)	0.016
		C45	(0.016, 0.040, 0.115)	(0.001, 0.002, 0.008)	0.004
C5	(0.023, 0.027, 0.032)	C51	(0.069, 0.155, 0.404)	(0.002, 0.004, 0.013)	0.006
		C52	(0.152, 0.387, 0.918)	(0.004, 0.010, 0.029)	0.014
		C53	(0.041, 0.151, 0.364)	(0.001, 0.004, 0.012)	0.006
		C54	(0.060, 0.142, 0.470)	(0.001, 0.004, 0.015)	0.007

Table 7 The weighted standard decision matrix

	C11	C12	C13	C14	C15	C16	C21	C22	C23	C24	C25	C26	C31	C32	C33	C41	C42	C43	C44	C45	C51	C52	C53	C54
A1	0.009	0.001	0.002	0.001	0.007	0.001	0.001	0.001	0.004	0.003	0.001	0.001	0.002	0.002	0.004	0.001	0.008	0.002	0.002	0.000	0.001	0.001	0.001	0.001
A2	0.006	0.001	0.003	0.001	0.007	0.001	0.001	0.001	0.009	0.005	0.001	0.002	0.001	0.002	0.009	0.001	0.005	0.004	0.001	0.000	0.001	0.002	0.001	0.001
A3	0.008	0.001	0.002	0.001	0.006	0.001	0.001	0.001	0.006	0.003	0.001	0.001	0.001	0.001	0.010	0.001	0.005	0.003	0.003	0.001	0.001	0.002	0.001	0.001
A4	0.006	0.001	0.003	0.001	0.006	0.000	0.000	0.001	0.005	0.004	0.001	0.002	0.001	0.001	0.008	0.001	0.006	0.002	0.001	0.001	0.001	0.003	0.001	0.001
A5	0.007	0.001	0.003	0.001	0.006	0.001	0.000	0.000	0.010	0.005	0.002	0.002	0.002	0.002	0.009	0.001	0.006	0.002	0.002	0.000	0.001	0.002	0.001	0.001
A6	0.005	0.000	0.002	0.001	0.007	0.001	0.001	0.000	0.005	0.003	0.001	0.002	0.001	0.001	0.010	0.001	0.005	0.002	0.002	0.001	0.001	0.002	0.000	0.001
A7	0.004	0.000	0.002	0.002	0.008	0.001	0.001	0.001	0.005	0.006	0.001	0.001	0.001	0.001	0.011	0.001	0.006	0.004	0.004	0.001	0.001	0.002	0.001	0.001

weight of criterion by relevant sub-criterion. Table 6 shows the local and final weights of criteria. The last column calculates and reports the final defuzzified weights based on Eq. (6).

To run fuzzy Copras, the integrated fuzzy decision matrix was formed based on judgments of 15 experts. Table 2 was used to convert expert judgments to corresponding fuzzy numbers. A fuzzy decision matrix calculated the extent to which a sub-criterion was met by options based on judgments of an expert. Then, the integrated fuzzy decision matrix was formed based on arithmetic mean. The integrated fuzzy decision matrix is defuzzified based on Eq. (6). Using Eqs. (7) and (9), the weighted standard decision matrix was formed, as shown in Table 7.

Finally, Eqs. (11)–(17) were applied to the weighted normal decision matrix to calculate P_i, R_i, relative weights of options Q_i, and optimality of options N_i (%). These values are reported in Table 8.

Based on results presented in the above table, the best green supplier is Mehvarsazan (A1), followed by Shetabkar (A5). Green suppliers are prioritized as follows:

1. Mehvarsazan (A1)
2. Shetabkar (A5)
3. Arisan (A2)
4. Mehrkam Pars (A7)
5. Niromohareke (A3)
6. Taha (A6)
7. Iran Lavazem (A4)

Conclusion

This study presents a model for evaluation of the best green suppliers by integrating fuzzy AHP and fuzzy Copras. By integrating the fuzzy Copras and AHP not only the supplier selection is carried out based on the defined criteria but also the uncertain parameters in the decision-making process can be accurately controlled. For this purpose, five criteria and 24 sub-criteria were identified for green supplier evaluation.

Table 8 Relative weight and optimality of options

	P_i	R_i	Q_i	N_i(%)	Rank
A1	0.045	0.009	0.066	15.60	1
A2	0.050	0.015	0.064	14.92	3
A3	0.046	0.015	0.060	14.07	5
A4	0.044	0.014	0.058	13.70	7
A5	0.051	0.016	0.064	15.03	2
A6	0.040	0.015	0.053	12.35	6
A7	0.049	0.017	0.061	14.32	4

Since expert judgments about criteria and options were uncertain, fuzzy concepts were used to consider uncertainties. Fuzzy AHP was also applied to calculate the local and final weight of the criteria and the sub-criteria. Then, these weights were applied in fuzzy Copras to calculate optimal suppliers. The result showed that Mehvarsazan was selected as the best ISACO green supplier. Supplier selection by consideration of environmental aspects prevents the severe damages to the global trade and human quality of life. In traditional supply chain management, the agility of system, lower distribution cost, and higher service quality were the main objectives. Nowadays, the sustainability of supply chain systems emerged as a new significant supply chain target. Therefore, selecting the best green suppliers and evaluating the sustainability power of suppliers are essential. One of the vital processes concerning the green supply chain is the ability of suppliers in the recycling the used material. In this case, evaluating suppliers from their ability to recycle the used material and the quality of recycled material that suppliers consume can be examined in the future.

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