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Research Article

An Efficient Hybrid Decision-Making Model for Sustainable Supplier Selection (Case Study: Parts Supply Industry)

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Abstract
Supplier selection has been considered as one of the important decisions taken by firms in supply chain management to enhance profitability in this competitive era. With the emergence of environmental policies and social concerns, companies are forced to consider triple bottom line including economic, environmental, and social attributes into their supply chain activities. Since different criteria affecting sustainable supplier selection conflict with each other, sustsainable supplier selection problem is considered as a multi-criteria decision-making problem. Furthermore, the evaluation of numerous conflicting requirements suffers imprecise and vague in decision makers' judgments. In this paper, an efficient Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method which is integrated by gray theory is developed to deal with uncertainty and imprecise among decision makers' judgments in the most right sustainable supplier selection. The proposed method was performed on tool industry as case study to select the most sustainable alloy supplier which involves three main criteria and twelve sub-criteria. The results indicated that Ara Sanat Asia company performs better than the other companies due to high contribution in the environmental and social criteria in addition to economic criteria as traditional metrics.
Keywords: Sustainable supplier selection, MCDM, TOPSIS, Gray system.

Introduction

Supplier selection is considered the first stage of primary decision-making problems that impact the profitability of organizations in the competitive era (Koufteros et.al. 2012; Spina et al. 2013; Wetzstein et al. 2016). The cost-efficient and high-quality products of firms depend on their supplier (Aissaoui et al., 2007; and Yazdani et al., 2016). Identifying suppliers from many capable suppliers are required to select the highest potential supplier to meet the manufacturer's needs consistent with acceptable overall performance. However, it is taken as a challenging problem due to considering qualitative and quantitative criteria Araz and Ozkarahan, (2007), which is known as a multi-criteria decision-making problem. Several studies have focused on supplier selection problems from a multi-criteria perspective. Most of them attempt to involve traditional criteria to select the most appropriate supplier.

Although previous studies have focused on economic aspects for supplier selection, environmental and social aspects should be considered in choosing suppliers due to

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environmental policies and social concerns. According to the international report, environmental and social issues should be taken alongside financial requirements to select the most proper supplier selection Ghayebloo et al. (2015). Therefore, sustainable supplier selection is considered a new emerging pattern in industries and enterprises, which causes a significant influence on supply chain performance regarding economic, environmental, and social issues.

Sustainable issues have become a primary concern of enterprises and firms, which should be taken in sustainable growth. According to Fahimnia et al. (2015), environmental issues should be handled. (Noci 1997; Nabeeh et.al. 2021; Rashidi et.al. 2020) introduced environmental sustainability for supplier ranking. Definition of criteria and sub-criteria related to sustainable supplier selection investigated in (Govindan K et al. 2015; Zimmer K et al. 2016; Badri Ahmadi et al. 2020)

Interest in sustainable growth causes challenges for a decision-maker to select the most proper sustainable suppliers regarding economic, environmental, and social aspects. Different methods have been applied for the most appropriate supplier. These methods are classified into different groups such as qualitative, mathematical programming, and Artificial Intelligence (AI) methods Memari et al. (2019).

MCDM methods are applied in sustainable supplier selection due to handling the incorporation of multi goals. Since several uncontrollable, unpredictable, and conflicting criteria impact sustainable supplier selection, it is taken as a complex multi-criteria decision-making problem to evaluate suppliers. It is important to note that choosing the impropriate selection causes threats to enterprises and firms' financial and operational status Araz and Ozkarahan, (2007); and Faez et al. 2009. For example, Kilic (2013) pointed out that complexity rises due to conflicting criteria and the current uncertainty of criteria.

However, the definition of the applicable criteria is entirely dependent on organizational conditions such that each company may identify its metrics for the supplier selection process Amindoust et al. (2012). The ultimate goal of Khatami Firouz Abadi et al. (2015) was to select the appropriate supplier in the sustainable supply chain of parts supply industry. At this stage, by combining two techniques of fuzzy DEMATEL and fuzzy ANP, suppliers were prioritized using these criteria and sub-criteria. Azimifard, et.al. (2018), criteria for choosing sustainable suppliers have been extracted through literature review to assign the weight of each criterion using AHP. Then, TOPSIS, has been applied to select the best supplier of the Iran steel industry. However, it has not considered ambigious in human judgements.

Decision-making methods are based on human views and attitudes. The quantification of these views and preferences is the main challenge due to suffering ambiguity in human views. Govindan et al. (2015) expressed that fuzzy concepts could be integrated into MCDM methods to capture the uncertainty of the human judgment impreciseness. Moreover, the Gray theory introduced by Deng, J.L. (1982) is based on the concept of gray sets to capture uncertain information in the mathematical analysis.

A gray system, which is developed by Deng, J.L. (1982), could be integrated into the MCDM problem to solve problems in the case of incomplete information and uncertainty. Gray theory can examine the conditions of being fuzzy, which is taken as the main advantage of gray theory over fuzzy theory. Gray's theory is also flexible with fuzzy conditions. Gray theory has a higher priority in solving MCDM problems due to facing semi-complex and uncertain problems compared to fuzzy statistics and probabilities facing simple problems and uncertainties. Furthermore, the gray theory can solve complex problems, especially in nonlinear mathematics, in the case of uncertainty.

TOPSIS method, which is introduced by Hwang and Yoon (1981), integrating with gray theory is developed to select the most suitable supplier selection for organizations.

Material and Methods

Gray Theory

The mathematical basis of the gray theory proposed by Deng, J.L. (1982) derives from gray sets. The main advantage of the gray theory is the capability of solving uncertain problems with discrete data. This theory is composed of five main sections, including gray predictions, gray relative analysis, gray decisions, gray planning, and gray control (Chen, M.T., 2004 and Zhang, J.W. 2005). In this section, definitions of the gray system are introduced alongside mathematical operations on gray theory. The gray system contains uncertain information that is displayed using gray numbers and variables. In the theory of gray systems, depending on the degree of information, it is called a white system if the information is thoroughly known. If the information is unknown, it is called a black system. If part of the information is known and part of the information is unknown, it is called a gray system.

A gray number is a number whose exact value is unknown, but a range is specified. A gray number is an indefinite number that takes its possible value from an interval or set of numbers. According to definition 1, gray numbers can be defined as follows.

Definition 1: If X is the reference set, the gray subset G of X is defined by two membership functions:

$$\mu_G^l(x) \leq \mu_G^h(x) \quad x \in X \;\; and \; X = R: \\ \mu_G^l(x): x \to [0,1], \qquad \mu_G^h(x): x \to [0,1] \tag{1}$$

in which $\mu_G^l(x)$, and $\mu_G^h(x)$ are the lower and upper limit of membership function G. If $\mu_G^l(x) = \mu_G^h(x)$ then the gray sum G becomes a fuzzy sum. This shows that the gray theory covers the conditions of fuzzy logic.

The gray number can be considered as uncertain information. For example, the ranking of indicators can be explained as linguistic variables so that ranking is done using numerical intervals. Numerical intervals represent uncertain information. Gray numbers are usually displayed as $\otimes G = G \left| \begin{matrix} \mu_G^l(x) \\ \mu_G^h(x) \end{matrix} \right.$. If it is possible to estimate the upper and lower limits, the gray number can be displayed as an interval given $\otimes G = [G^l, G^h]$ Gray number operations are performed on intervals.

Definition 2: If $\otimes G_1 = [G_1^l, G_1^h]$ and $\otimes G_2 = [G_2^l, G_2^h]$, the principal operations are similar with definite numbers as follows (Ardavan, A., (2013); Wu, Q.Z., (2005)).

$$\begin{aligned} &\otimes G_1 + \otimes G_2 = [G_1^l + G_2^l, G_1^h + G_2^h] \\ &\otimes G_1 - \otimes G_2 = [G_1^l - G_2^l, G_1^h - G_2^h] \\ &\otimes G_1 * \otimes G_2 = [G_1^l * G_2^l, G_1^h * G_2^h] \\ &\otimes G_1 / \otimes G_2 = [G_1^l / G_2^l, G_1^h / G_2^h] \end{aligned} \tag{2}$$

Definition 3: When comparing two gray numbers $\otimes G_1 = [G_1^l, G_1^h]$ and $\otimes G_2 = [G_2^l, G_2^h]$, the degree of probability that $\otimes G_1 <= \otimes G_2$ is defined as follows (Ardavan, A., (2013); Wu, Q.Z., (2005)):

$$P\{\otimes G_1 \leq \otimes G_2\} = \frac{max\left(0, L(\otimes G_1) + L(\otimes G_2) - max\left(0, G_1^h - G_2^l\right)\right)}{L(\otimes G_1) + L(\otimes G_2)} \tag{3}$$

In which $L(\otimes G) = [G^h - G^l]$. Based on equation (3), the following four cases are obtained:

$$\begin{aligned} &if\ (G_1^l = G_2^l\ and\ G_1^h = G_2^h)\ then\ \otimes G_1 = \otimes G_2\ and\ P\{\otimes G_1 \leq \otimes G_2\} = 0.5 \\ &if\ (G_1^h < G_2^l)\ then\ \otimes G_1 < \otimes G_2\ and\ P\{\otimes G_1 \leq \otimes G_2\} = 1 \\ &if\ (G_1^l > G_2^h)\ then\ \otimes G_1 > \otimes G_2\ and\ P\{\otimes G_1 \leq \otimes G_2\} = 0 \\ &if\ (\otimes G_1 overlap\ with\ \otimes G_2)\ and\ P\{\otimes G_1 \leq \otimes G_2\} > 0.5\ then\ \otimes G_1 < \otimes G_2 \end{aligned} \quad (4)$$

TOPSIS Method

The TOPSIS method is a multi-criteria decision-making (MCDM) method that ranks alternatives Hwang and Yoon (1981). In this method, the two concepts of "positive ideal solution" and "negative ideal solution" are used. According to this method, the best option is the closest option to the positive ideal solution and the farthest from the negative ideal solution. The positive ideal solution is the solution that has the highest profit and the lowest cost. In contrast, the negative ideal solution is the solution that has the highest cost and the lowest profit. The structure of the TOPSIS method is presented in the following steps.

Step 1: The decision matrix and weight vector should be formed.

Step 2: The decision matrix should be normalized.

Step 3: The weighted normalized decision matrix is carried out by multiplying the weighted vector's normalized decision matrix.

Step 4: Positive ideal solutions should be obtained as the measurement for ranking alternatives. The positive ideal solution is obtained from the maximum value of alternatives for each criterion.

Step 5: It is noted that the positive ideal solution, as its name implies, is the solution that is the best in every way, which generally does not exist in practice, and it tries to get closer to it. Therefore, to measure the similarity of an alternative (or option) to a positive ideal solution, the distance of that option from the positive ideal is computed.

Step 6: The alternatives are then evaluated and ranked based on the distance from the positive ideal ideal solution.

Methodology

The evaluation team of decision-makers consisting of k members is considered, which is shown as $D = \{D_1, D_2, \dots, D_K\}$. Also, m suppliers (alternatives) as $A = \{A_1, A_2, \dots, A_m\}$ and n criteria as a set of $C = \{C_1, C_2, \dots, C_n\}$ should be taken into account. Each of the members presents their preferences for each criterion and different alternatives regarding each metric according to Table.1. Li, G.Y., (2007).

Table 1. The linguistic term and equivalent gray number

Linguistic term	$\otimes G$
Very Low(VL)	[0,1]
Low(L)	[1,3]
Medium Low(ML)	[3,4]
Medium(M)	[4,5]
Medium High(MH)	[5,6]
High(H)	[6,9]
Very High(VH)	[9,1]

After assigning the significant degree of each criterion by decision-makers, the average weight of each criterion is computed as follows:

$$\otimes C_j = \frac{1}{K}\sum_{k=1}^{K} \otimes C_j^k \tag{5}$$

in which $\otimes C_j^k = \left[C_j^{k^l}, C_j^{k^h}\right]$ shows the weight of the j[th] criterion, which is assigned by the k[th] decision-maker. Moreover, the average importance degree of each alternative regarding each criterion should be calculated based on a gray scale, which is followed by:

$$\otimes G_{ij} = \frac{1}{K}\sum_{k=1}^{K} \otimes G_{ij}^k \tag{6}$$

where $\otimes G_{ij}$ indicates each cell of the decision matrix and $\otimes G_{ij}^k = \left[G_{ij}^{k^l}, G_{ij}^{k^h}\right]$ is allocated by the k[th] decision-maker for the importance degree of i[th] alternative regarding j[th] criterion. Therefore decision matrix is obtained as follows:

$$DM = \begin{bmatrix} \otimes G_{11} & \cdots & \otimes G_{1n} \\ \vdots & \ddots & \vdots \\ \otimes G_{m1} & \cdots & \otimes G_{mn} \end{bmatrix} \tag{7}$$

After getting the decision matrix, it should be normalized regarding the type of each metric, including positive (benefit) and negative (cost). The normalized matrix is made for two reasons: using the same scale for all units and setting the variables between zero and one. Therefore, for positive criteria, normalization of the related cells is performed according to the equation (8).

$$\otimes G_{ij}^N = \left[\frac{G_{ij}^l}{max_{i=1}^m G_{ij}^h}, \frac{G_{ij}^h}{max_{i=1}^m G_{ij}^h}\right] \tag{8}$$

The normalization process for negative criteria is done based on equation (9).

$$\otimes G_{ij}^N = \left[\frac{min_{i=1}^m G_{ij}^l}{G_{ij}^h}, \frac{min_{i=1}^m G_{ij}^l}{G_{ij}^l}\right] \tag{9}$$

Where $\otimes G_{ij}^N = \left[\otimes G_{ij}^{N^l}, \otimes G_{ij}^{N^h}\right]$. According to the obtained normalized decision matrix, the weighted normalized decision matrix is formed as the result of the multiplication of the decision matrix by the weight vector, which is presented as follows:

$$\otimes G_{ij}^w = \otimes G_{ij}^N * \otimes C_j \tag{10}$$

Where $\otimes G_{ij}^w = \left[\otimes G_{ij}^{w^l}, \otimes G_{ij}^{w^h}\right]$. Then, the gray positive (r^+) for each criterion is obtained according to the equation (11).

$$r_i^+ = \left[max_{i=1}^m G_{ij}^l, max_{i=1}^m G_{ij}^h\right] \tag{11}$$

After getting the positive solution for each criterion, each criterion's distance from positive ideal solutions should be computed. To do so, the degree of probability $\otimes G_1 <= \otimes G_2$ is applied for distance calculation as follows.

$$P\{\otimes A_i \leq \otimes r_i^+\} = \frac{1}{m}\sum_{j=1}^{n} P\{\otimes G_{ij}^w \leq \otimes r_i^+\} \tag{12}$$

Finally, alternatives are ranked according to the ranking degree indicator obtained through equation (12). The higher the ranking degree, the shorter the positive ideal solution, which means the best supplier.

Results and discussion

Three experts were selected to form an evaluation team to identify the most appropriate sustainable supplier selection regarding different metrics. Moreover, four alloy suppliers, including Ara Sanat Asia Company (A_1), Aliaz Caran Company (A_2), Kian Science and Technology Company (A_3), and Sanat Barazesh Company (A_4), were considered.

Furthermore, the effective criteria for sustainable supplier selection were extracted through studying comprehensive research and consulting with experts. The main criteria were assigned into different groups, which are summarized as follows.

Social and Cultural criteria (C_1) included various metrics such as Staff training (C_{11}) Hsu et al. (2011) and Lozano and Huisingh (2011), Interaction with the local community (C_{12}), Occupation (C_{13}), Discipline and safety (C_{14}) Haeri and Rezaei (2019) and Govindan et al. (2013).

Environmental criteria (C_2) was composed of Energy consumption (C_{21}) Carter and Easton (2011), Recycling rate (C_{22}) Lozano and Huisingh (2011), Pollutant emission rate (C_{23}) Bai and Sarkis (2010), Clean technology (C_{24}) Bai and Sarkis (2010).

Economic Criteria (C_3) included various metrics such as Financial position and market share (C_{31}) Govindan et al., (2013) and Hsu et al. (2011), Product quality(C_{32}) Lozano and Huisingh (2011), Price (C_{33}) Govindan et al. (2013), Delivery (C_{34}) (Kannan et al. (2014, 2013); Hashemi et al. 2015, Haeri and Rezaei 2019, Bai and Sarkis 2010).

At first, the importance degree of each criterion should be identified. It is noted that the main criteria, including social, environmental, and economic criteria, affected choosing the most suitable supplier selection. Moeover, the effect of these three main criteria was considered the same as each other. The importance degree of each criterion should be assigned by decision-makers using linguistic variables shown in Table 1. Therefore, Table 2 was concluded as the result of the importance degree of each metric. The final aggregated weight of each criterion was obtained by transforming their value to gray numbers and applying equation 5. Moreover, the aggregated weight should be normalized based on equation 8, represented by Table 3.

Table 2. The importance degree of criteria assigned by decision-makers

Decision-makers	Criteria						
	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}
D_1	H	L	H	M	H	MH	H
D_2	H	ML	MH	H	MH	H	VH
D_3	MH	L	MH	MH	H	M	VH
	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}		
D_1	H	H	MH	MH	ML		
D_2	H	VH	H	M	ML		
D_3	VH	H	M	MH	L		

Table 3. The average weight of criteria assigned by decision-makers

Criteria	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}
Weight	[0.59,0.83]	[0.17,0.34]	[0.55,0.72]	[0.52,0.69]	[0.59,0.83]	[0.52,0.69]	[0.83,1]
Criteria	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}		
Weight	[0.72,0.97]	[0.52,0.69]	[0.52,0.69]	[0.48,0.59]	[0.24,0.38]		

Members gave the importance degree of each alternative according to each metric to evaluate suppliers considered as alternatives. Therefore, Table 4 was obtained as decision matrix by applying linguistic variables to evaluate each supplier regarding each criterion performed by decision-makers. It is important to identify the negative metrics for the next steps. Among the efficient criteria, energy consumption (C_{21}), pollutant emission rate (C_{23}) from environmental criteria (C_2), and price (C_{33}) and delivery date (C_{34}) from economic criteria (C_3) were considered as the negative metrics. The lower value of negative metrics means a higher degree of significance for choosing the best sustainable supplier selection.

In the next step, the decision matrix should be obtained based on gray numbers through aggregating decision makers' judgments using Table 1 and equation (6). Therefore, the aggregated decision matrix is shown in Table 5. Moreover, each metric, including positive and negative, should be identified for the next step of normalization. The normalized decision matrix (Table 6) should be computed based on equations (8) and (9) regarding positive and negative. Moreover, the weighted normalized decision matrix was obtained by multiplying the weight vector's decision matrix extracted from Table 3. Its result is presented in Table 7.

Table 4. Decision matrix for the importance of suppliers regarding different metrics which decision makers assign

Decision-makers	D1				D2				D3			
Criteria	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4
C_1												
C_{11}	VH	H	MH	M	H	MH	MH	ML	VH	H	H	ML
C_{12}	MH	VH	L	H	MH	H	L	H	MH	H	ML	MH
C_{13}	VH	ML	H	H	VH	M	MH	H	H	ML	MH	H
C_{14}	MH	M	ML	M	MH	M	L	MH	M	ML	VL	MH
C_2												
C_{21}	ML	VL	H	H	MH	VL	VH	MH	MH	L	H	MH
C_{22}	ML	MH	M	H	L	MH	MH	MH	L	M	MH	MH
C_{23}	ML	MH	H	MH	ML	H	H	ML	M	VH	H	ML
C_{24}	ML	L	ML	ML	M	L	ML	ML	ML	VL	ML	MH
C_3												
C_{31}	VH	MH	H	M	H	ML	MH	M	VH	ML	MH	ML
C_{32}	H	H	M	MH	H	MH	MH	MH	MH	MH	M	M
C_{33}	VH	L	MH	H	H	ML	H	H	H	ML	MH	MH
C_{34}	H	L	H	H	VH	VL	MH	H	VH	VL	H	H

Table 5. Aggregated gray decision matrix for suppliers based on criteria

	Criteria	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}
Alternatives	A_1	[8,9.67]	[5,6]	[8,9.67]	[4.67,5.67]	[4.33,5.33]	[1.67,3.33]
	A_2	[5.67,8]	[7,9.33]	[3.33,4.33]	[3.67,4.67]	[0.33,1.67]	[4.67,5.67]
	A_3	[5.33,7]	[1.67,3.33]	[5.33,7]	[1.33,2.67]	[7,9.33]	[4.67,5.67]
	A_4	[3.33,4.33]	[5.67,8]	[6,9]	[4.67,5.67]	[5.33,7]	[5.33,7]
	Criteria	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}
Alternatives	A_1	[3.33,4.33]	[3.33,4.33]	[8,9.67]	[5.67,8]	[7,9.33]	[8,9.67]
	A_2	[6,67,8.33]	[0.67,2.33]	[3.67,4.67]	[5.33,7]	[2.33,3.67]	[0.33,1,67]
	A_3	[6,9]	[3,4]	[5.33,7]	[4.33,5.33]	[5.33,7]	[5.67,8]
	A_4	[3.67,4.67]	[3.67,4.67]	[3.67,4.67]	[4.67,5.67]	[5.67,8]	[6,9]

Table 6. Gray normalized decision matrix for suppliers based on different metrics

	Criteria	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}
Alter native	A_1	[0.83,1]	[0.54,0.64]	[0.83,1]	[0.82,1]	[0.06,0.08]	[0.29,0.48]
	A_2	[0.59,0.83]	[0.75,1]	[0.34,0.45]	[0.65,0.82]	[0.20,1]	[0.67,0.81]
	A_3	[0.55,0.72]	[0.18,0.36]	[0.55,0.72]	[0.24,0.47]	[0.04,0.05]	[0.67,0.81]
	A_4	[0.34,0.45]	[0.61,0.86]	[0.62,0.93]	[0.82,1]	[0.05,0.06]	[0.76,1]
	Criteria	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}
Alter nativ	A_1	[0.77,1]	[0.71,0.93]	[0.83,1]	[0.71,1]	[0.25,0.33]	[0.03,0.04]
	A_2	[0.40,0.50]	[0.14,0.50]	[0.38,0.48]	[0.67,0.88]	[0.64,1]	[0.20,1]
	A_3	[0.37,0.56]	[0.64,0.86]	[0.55,0.72]	[0.54,0.67]	[0.33,0.44]	[0.04,0.06]
	A_4	[0.71,0.91]	[0.79,1]	[0.38,0.48]	[0.58,0.71]	[0.29,0.41]	[0.04,0.06]

Table 7. Gray weight normalized decision matrix for suppliers based on different metrics

	Criteria	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}
Alter native	A_1	[0.49,0.83]	[0.09,0.22]	[0.46,0.72]	[0.43,0.69]	[0.04,0.06]	[0.15,0.33]
	A_2	[0.34,0.68]	[0.13,0.34]	[0.19,0.32]	[0.33,0.57]	[0.12,0.83]	[0.34,0.56]
	A_3	[0.32,0.60]	[0.03,0.12]	[0.30,0.52]	[0.12,0.32]	[0.02,0.04]	[0.34,0.56]
	A_4	[0.20,0.37]	[0.10,0.30]	[0.34,0.67]	[0.43,0.69]	[0.03,0.05]	[0.39,0.69]
	Criteria	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}
Alter nativ	A_1	[0.64,1]	[0.52,0.90]	[0.60,0.97]	[0.17,0.38]	[0.12,0.20]	[0.02,0.03]
	A_2	[0.33,0.50]	[0.10,0.48]	[0.27,0.47]	[0.16,0.33]	[0.31,0.59]	[0.10,0.69]
	A_3	[0.31,0.56]	[0.47,0.83]	[0.40,0.70]	[0.13,0.25]	[0.16,0.26]	[0.02,0.04]
	A_4	[0.59,0.91]	[0.57,0.97]	[0.27,0.47]	[0.14,0.27]	[0.14,0.24]	[0.02,0.04]

Finally, Table 8 presents the calculation of the ideal positive solution for each criterion based on equation (11). Then, Table 9 shows the distance of each alternative from the ideal solution through equation (12).

Table 8. Gray Ideal solution for each criterion

Criteria	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}
R^+	[0.49,0.83]	[0.13,0.34]	[0.46,0.72]	[0.43,0.69]	[0.12,0.83]	[0.39,0.69]
Criteria	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}
R^+	[0.64,1]	[0.57,0.97]	[0.60,0.97]	[0.17,0.38]	[0.31,0.59]	[0.10,0.69]

Table 9. Distance of each alternative from the ideal solution

Alternatives	A_1	A_2	A_3	A_4
Distance from R^+	0.69	0.72	0.88	0.75

Therefore, the probability of each alternatives being smaller than the ideal solution were presented in equation 13.

$$
\begin{aligned}
&P\{\otimes A_1 \leq \otimes r_i^+\} = 0.69\\
&P\{\otimes A_2 \leq \otimes r_i^+\} = 0.72\\
&P\{\otimes A_3 \leq \otimes r_i^+\} = 0.88\\
&P\{\otimes A_4 \leq \otimes r_i^+\} = 0.75
\end{aligned} \tag{13}
$$

It means that an alternative with a lower probability is the closest to the ideal solution. According to equation 13, it is concluded that Ara Sanat Asia Company (A_1) was selected as the most suitable supplier selection with the probability of 0.69, far from an ideal solution. It is due to the fact that Ara Sanat Asia Company (A_1) have played an important role in environmental criteria such as reduction of pollutant emission rate (C_{23}) with the degree of

[0.77,1] and applying clean technologies (C_{24}) with the degree of [0.71,0.93] in sustainable supplier selection. It is noticed that pollutant emission rate (C_{23}) was the most important metric with a significant degree of [0.83,1] in solving sustainable supplier problems. Using clean technologies (C_{24}) was the second important metric that an evaluation team identified. Furthermore, financial position and market share (C_{31}), product quality (C_{32}) were participated with [0.83,1] and [0.71,1], respectively. Also, as is mentioned, financial position and market share (C_{31}) contributed as the second rank on the effective metrics on the most suitable sustainable supplier selection. Besides, it is necessary to mention that Ara Sanat Asia Company (A_1) assigned the highest priority on social criteria, including staff training (C_{13}), job opportunity (C_{33}), and discipline and safety (C_{34}).

Although Ara Sanat Asia Company (A_1) performed weakly on price (C_{33}) and delivere date (C_{34}), these two metrics were not taken as the high priority on the most suitable sustainable supplier selection. As mentioned above, Ara Sanat Asia Company (A_1) had the most significant effect on the most efficient criteria in different groups. However, it has suffered high consumption of energy and low recycling rate.

Kian Science and Technology Company (A_3) was allocated as the last rank for sustainable supplier selection with a probability of 0.88 for distance from the ideal solution. Kian Science and Technology Company (A_3) seemed weak in most of the efficient criteria. Although pollutant emission rate (C_{33}) affected the most suitable supplier selection significantly, the role of Kian Science and Technology Company (A_3) on this efficient criteria with a degree of [0.37,0.56] was not considerable. Despite defining the high impact on interaction with communities (C_{12}) and deliver date (C_{34}), its proficiency was weak on the other metrics.

Aliaz Caran Company (A_2) was ranked as the second alternative with a probability of 0.72 for the most sustainable supplier selection. However, Aliaz Caran Company (A_2) and Sanat Barazesh Company (A_4) (probability of 0.75) performed approximately near to each other. While Aliaz Caran Company was a more suitable choice in economic criteria, Sanat Barazesh Company (A_4) affected positively on environmental criteria. It implies that environmental criteria should be considered in the most appropriate sustainable supplier selection in addition to economic criteria.

The obtained results confirmed Khatami Firouz Abadi et al. (2015) for the appropriate supplier selection in the sustainable supply chain of the parts supply industry using ANP method. Ara Sanat Asia Company with the highest weight was in the first rank, and Aliaz Karan Company with the lowest weight was the last priority.

Similar to Azimifard, et.al. (2018), it is important to notice the sustainability issues in supplier selection leads to improving productivity, environmental footprints as well as satisfying the customers and society for the whole supply chain. Similar to Azimifard, et.al. (2018), environmental issues such as water consumption, number of employees, and CO2 emission rate obtained the maximum importance degree for sustainable supplier selection. Furthermore, applying grey system theory in our proposed method could tackle the uncertainty of a human's subjective judgments challenge which was not considered by Azimifard, et.al. (2018).

Conclusion

In the context of sustainable supply chain management, sustainable supplier selection is considered the main field that influences a company's entire operational activities. The most suitable supplier selection is considered the foremost challenge due to considering various effective qualitative and quantitative criteria that conflict with each other. Therefore, the paper's main contribution was to propose an efficient TOPSIS approach integrated with a gray system to capture imprecise, uncertain, and incomplete information associated with sustainable supplier selection. A parts supply industry was provided to illustrate the capability of the proposed method. Therefore, effective criteria should be identified in different aspects according to aggregation of customers' and managers' viewpoints to assign the importance degree of each metric using the gray system. It is concluded that pollutant emission rate (C_{23}), financial position and market share (C_{31}), and using clean technology (C_{24}) contributed as the most influential metrics on the most suitable sustainable supplier selection process. In the next step, four suppliers, including Ara Sanat Asia Company (A_1), Aliaz Caran Company (A_2), Kian Science and Technology Company (A_3), and Sanat Barazesh Company (A_4), were assessed to select the proper sustainable supplier selection.

Moreover, the gray system was capable of capturing ambiguity and imprecise among experts' judgments. The results showed that supplier selection could balance social, environmental, and economic criteria taken from customers and experts. Moreover, the results indicated that Ara Sanat Asia Company (A_1) was selected as the most suitable supplier because it addressed economic criteria (such as financial position and market share (C_{31}), product quality (C_{32})) and environmental criteria (such as pollutant emission rate (C_{23}) and applying clean technologies (C_{24})) and almost all social criteria. Moreover, it should be noted that although Ara Sanat Asia Company (A_1) could be capable of high contribution in the most suitable supplier selection, it suffered high price (C_{33}) and long deliver date (C_{34}). However, Kian Science and Technology Company (A_3) was considered the last choice for sustainable supplier selection due to low performance in the most effective criteria. Finally, it should be noted that Aliaz Caran Company (A_2) and Sanat Barazesh Company (A_4) were considered approximately the same priority for sustainable supplier selection because Aliaz Caran Company (A_2) performed better in economic criteria and Sanat Barazesh Company (A_4) in environmental criteria. However, the weakness of paper is related to considering the unlimited potential production capacity in part supply industries. Therefore, production capacity limitations should be taken into consideration for future studies.

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