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Green Supplier Selection Using Game Theory Based on Fuzzy SWARA

Mehmet Ali TAŞ[1], Esra ÇAKIR*[2]

Abstract

Green supply chains are supply chains that prioritize nature in every activity and aim to minimize the damage to the environment. Finding suppliers that meet the desired criteria and meet the company's environmental objectives in establishing the green supply chain is a difficult process. The selection problem becomes more complicated when some criteria conflict with each other. It is also critical to consider the strategies that alternative suppliers can implement. Therefore, multi-criteria decision making methods and game theory approaches are suitable to overcome these difficulties. This study proposes a new integrated fuzzy SWARA, which is a multi-criteria decision making method using fuzzy numbers to express uncertainty, and game theory approach to compare green supplier alternatives. The proposed approach is carried out in a chemical company that produces cleaning products in Turkey. The manufacturer company wants to compare two alternative green suppliers. Green strategies of alternative suppliers are weighted via fuzzy SWARA method. Then, the game theory payoff matrix and the iterated elimination of strictly dominated strategies are applied to compare two alternative suppliers. The proposed methodology gets a compromise solution. These results are intended to contribute to green supplier evaluation practices.

Keywords: Green supplier selection, sustainable environment, game theory, fuzzy SWARA, multi-criteria decision making

1. INTRODUCTION

The concept of sustainable environment has become one of the most important and controversial issues of recent years with global warming, carbon footprint and ecological balance [1]. Increasing production and consumption activities cause an increase in greenhouse gas emissions in the atmosphere, which is one of the most important causes of global warming [2]. All living creatures in the ecosystem are under risk due to the effects of global warming and deteriorating ecological balance [3]. Compared to the pre-industrial revolution, it is thought that the temperature increased by 1 ° C only because of the human activities [4]. For this reason, organizations should design their operations to be environmentally accountable [5]. One of these operation areas is supply chain management. The supply chains are anticipated to be environmentally friendly due to the increasing environmental worries and the sanctions that may

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arise as a result of the legal regulations to comply [6].

The green supplier selection problem is investigated as an application of multi-criteria decision making methods in many researches. In the literature, many studies have proven that multi-criteria decision making methods can be used for this problem [7]. In addition to the methods applied alone, there are also combined MCDM studies such as goal programming, linear programming, fuzzy logic etc. [8]. The game theory approaches can also be added to these combinations. Game theory can be used to determine the highest payoff of alternatives as a result of the competition that a number of opponents show according to the strategies [9]. This article proposes a new integrated fuzzy SWARA and game theory approach in the selection of green supplier in chemical industry.

In the last decade, the fuzzy SWARA technique has been highly researched. Mavi et al. [10] used fuzzy SWARA and fuzzy MOORA method to rank nine alternative 3rd-party reverse logistics providers for the plastics industry. Tadić et al. [11] employed an integrated Delphi, AHP, and fuzzy SWARA methods in city logistics initiatives. Zarbakhshnia et al. [12] evaluated sustainable third party reverse logistics providers for an automobile business using fuzzy SWARA and fuzzy COPRAS. Ansari et al. [13] used fuzzy SWARA and fuzzy COPRAS to assess the sustainable supply chains of a business in India. Kaya and Erginel [14] made the sustainable design for an airport in Turkey using hesitant fuzzy sustainable Quality Function Deployment as well as hesitant fuzzy SWARA. Ulutas [15] used hybrid fuzzy SWARA and fuzzy ARAS methods in supplier selection. Rani et al. [16] used Pythagorean fuzzy numbers on SWARA and VIKOR methods in solar panel selection. Moniri et al. [17] selected fuzzy SWARA and fuzzy EDAS methods in order to risk assessment in the oil processing industry.

In the literature, the game theory has been examined in numerous application researches. Hu and Rao [18] sought an answer to the optimization problem by using a game theory for optimum design. Tan et al. [19] investigated the competition in the software market in South Korea with a game theory approach. Peldschus et al. [20] discussed the site assessment using the theory of the two-person zero-sum game. Madani and Lund [21] used the Monte-carlo game theory approach to solve the California's Sacramento-San Joaquin Delta problem.

A number of combined approaches with game theory have also appeared in the literature. Medineckiene et al. [22] practiced choosing the best alternative between eight houses (two houses and four different heating combinations of them). They combined fuzzy sets and game theory. Kermani et al. [9] evaluated two alternatives by considering three criteria using ordinal game theory and TOPSIS, which is a multi-criteria decision making method. Zolfani and Banihashemi [23] solved the problem of choosing CEO among two candidates of GATA company in Iran by SWARA integrated game theory approach. Hindia et al. [24] implemented the planning scheme in LTE high speed wireless data transmission network with cooperative game theory (bankruptcy and shapely) and TOPSIS. Hashemkhani Zolfani et al. [25] examined supplier cooperation strategies using game theory, SWARA and WASPAS. Moradi et al. [26] evaluated the seismic vulnerability of Tehran city in Iran using a combination of methods including game theory and Choquet Integral. Debnath et al. [27] discussed strategies between the tea industry and the government tea board in India with Dempster-Shafer belief structure and evolutionary game. Liu et al. [28] investigated the Salzer manufacturing company's selection among four evidential suppliers as a case study. They determined the subjective criteria weights by ANP, the objective criteria weights by Entropy, and the comprehensive weights combined by DEMATEL-game theory methods. Dempster-Shafer evidence theory was discussed to remove uncertainty and order alternatives. Najafi et al. [29] selected best alternative among four suppliers for the casting plant. The criteria weights are calculated via BWM and SWARA. DEMATEL and game theory were used together to calculate comprehensive weights. Alternatives are evaluated by Dempster-Shafer evidence theory.

In this study, SWARA method and game theory approach are integrated. Since the SWARA method depends on pairwise comparisons within the order, it contains fewer computation processes than the most frequently used multi-criteria decision making methods. Therefore, the SWARA method was chosen to progress in a shorter time. Subsequently, the game theory approach is used in the selection of two alternatives. The technique of iterated elimination of strictly dominated strategies is used to properly observe the situation between the strategies of the players competing with each other and to select the most suitable green supplier.

This article contributes to the literature by proposing a new integration of game theory and fuzzy SWARA approaches. Also, the proposed methodology is a pioneering work on the green supplier selection problem.

The rest of the article is organized as follows. The introduction section is followed by the Section 2 which introduces the fuzzy SWARA and the game theory approaches. The steps of the new integrated methodology is detailed in this section. The proposed approch is applied on the selection of best option for chemical company case study in Section 3. Finally, the article ends with the conclusions in Section 4 that contains results, limitations, theoretical and managerial implications, and future directions.

2. METHODOLOGY

2.1. Fuzzy SWARA

The Step-wise Weight Assessment Ratio Analysis (SWARA) method is a multi-criteria decision making method introduced in 2010 by Keršuliene et al. [30]. Although relatively being a novel method, it is frequently employed due to its simple utilization and ability to reach results rapidly [31].

Fuzzy set is to express the uncertainties that occurs in decision makers' evaluations. In this study, triangular fuzzy numbers are used to include the uncertainty opinions in the calculation steps. A triangle fuzzy number is presented by (l,m,u). The membership function μ, where $\tilde{A}$ is a triangular fuzzy number is described as follows (Eq. 1) [32]:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < l, \\ \frac{x-l}{m-l}, & l \leq x \leq m, \\ \frac{u-x}{u-m}, & m \leq x \leq u, \\ 0, & x > u. \end{cases} \quad (1)$$

Let $A_1 = (l_1, m_1, u_1)$ and $B_1 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers and the arithmetic operations (addition, subtraction, multiplication, and division) on fuzzy numbers are formulated as follows (Eq. 2-5):

$$A_1 \oplus B_1 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$
$$A_1 \ominus B_1 = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \quad (3)$$
$$A_1 \otimes B_1 = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (4)$$
$$A_1 \oslash B_1 = \left({}^{l_1}/_{u_2}, {}^{m_1}/_{m_2}, {}^{u_1}/_{l_2} \right) \quad (5)$$

The steps of the triangular fuzzy SWARA method are as follows [10]:

Step 1. Ranking of alternatives from the most to the least important according to the evaluations of decision makers.

Step 2. Starting from the first row, determining the differences in importances of two successive criteria in order of importance. The difference in importances of the two alternatives compared is called "comparative importance of average value" [30] and it is represented by $\tilde{s}_j$.

Step 3. Determination of $\tilde{k}_j$ coefficient. The $\tilde{k}_j$ coefficient is calculated as follows (Eq. 6):

$$\begin{cases} \tilde{1} & j = 1 \\ \tilde{s}_j + \tilde{1} & j > 1 \end{cases} \quad (6)$$

Step 4. Calculation of fuzzy weight $\tilde{q}_j$ (Eq. 7):

$$\begin{cases} \tilde{1} & j = 1 \\ \frac{\tilde{x}_{j-1}}{\tilde{k}_j} & j > 1 \end{cases} \quad (7)$$

Step 5. Calculation of final fuzzy weight by normalizing (Eq. 8):

$$\tilde{w}_j = \frac{\tilde{q}_j}{\sum_{k=1}^{n} \tilde{q}_k} \quad (8)$$

The fuzzy weights calculated by fuzzy SWARA must be converted into crisp numbers via defuzzification process. The following formula of the Best Nonfuzzy Performance Value (BNP) [33] is used for defuzzification of trianguler fuzzy numbers (Eq. 9):

$$BNP = \frac{[(u-l)+(m-l)]}{3} + l \quad (9)$$

2.2. Game Theory

Mathematical interpretations that occur in interactive situations are called game theory. The theory was developed and implemented by Nash [34]. In game theory, the strategies that the players implement are not only relevant to themselves, but also to the strategy of the opponents [9]. The result of the payoff function shows the returns of the decisions made by the players, and this is shown in the payoff matrix, also called normal-form game representation.

The concept of the game theory in which no player in a game changes her/his strategy after evaluating her/his opponent's choice is Nash Equilibrium [34]. In a Nash Equilibrium game, when the strategies of other players remain the same, no player benefits from the strategies that are changed [28].

The assumptions for the game theory about human behavior can be listed as follows [35]: players in the game are rational, players in the game have expectations of other players and think everyone will play the rational, players' priorities are common and all players know the rules of the game, the terms of winning and losing.

In fact, since it is accepted that all events are games, everything becomes the subject of game theory [23]. Although game theory first appeared in the field of economics, it is frequently used in many areas such as politics, management, marketing, chemistry, an so on [36, 37]. Game theory can be considered as an important tool used in supply chain studies [38].

2.3. A new integrated game theory and fuzzy SWARA methodology

Game theory is a concept that can be used in decision making [21]. There is a relationship between the games and multi-criteria decision making outcomes. In this paper, the game theory approach is combined with multi-criteria decision making methods. The strategies of alternative suppliers are set as the criteria in the fuzzy SWARA method (Figure 1).

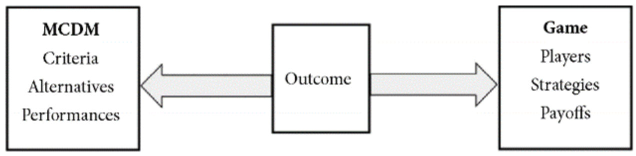

Figure 1 The relationship between multi-criteria decision making and game theory [21]

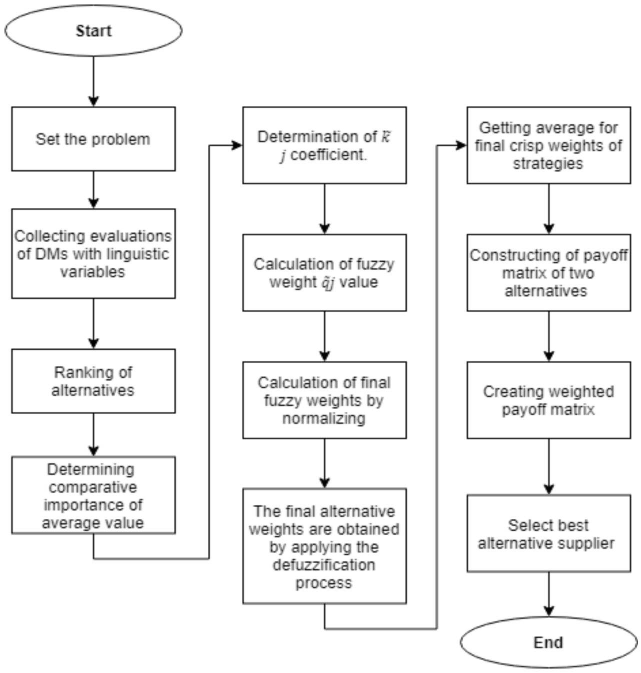

Figure 2 Flowchart of the proposed methodology

In the game theory part, the strategies of two alternatives are solved with the superiority they establish over each other. This technique is called iterated elimination of strictly dominated strategies [39]. The normal-form game representation of an n-player game shows the strategy space of players $S_1,\dots,S_n$. The payoff functions of these players are $u_1,\dots,u_n$ and the game can be shown as $G=\{S_1,\dots,S_n;u_1,\dots,u_n\}$. Let s_i' and s_i'' are the feasible strategies of each players, all strategies are from $S_1,\ldots,S_n$ strategy space, then :

$$u_i(s_1, s_2, \ldots, s_i'', s_{i+1}, \ldots, s_n) > u_i(s_1, s_2, \ldots, s_i', s_{i+1}, \ldots, s_n) \quad (10)$$

Therefore, s_i' strategy is strictly dominated by s_i'', which means that the player prefers strategy s_i'' to s_i' under all circumstances assuming all players are rational [40].

The flowchart of the new integrated methodology of two approaches described above is shown in Figure 2.

3. CASE STUDY

The manufacturers in the chemical industry have expansively negative impacts on the environment due to the essence of the raw materials and products. Measures should be taken for the chemical raw materials and products used in the industry to cause the least harm to nature. International environmental norms must be strictly followed and obligations must be fulfilled. In this manner, the proposed approach is applied to a chemical company that wants to choose the supplier that offers the best environmental strategy.

The case company is a chemical cleaning product manufacturer located in Turkey's southern region. In the sector of the chemical products used for cleaning industry, it is one of Turkey's leader company. In addition, it has become one of the big exporters of the region with its numerous brands by exporting to more than 40 countries in five continents.

The company wants to choose an environmentally friendly supplier for the chemical raw materials used in processes. At first, the purchasing department of the company evaluates a number of alternative suppliers in the market. As a result of market research, the best two suppliers that performed very close to each other are presented to the management. These alternative suppliers are named as S_1 and S_2. Seven experts working within the company are identified, and the information of these experts is displayed in Table 1.

Table 1 The information of experts

Experts	Titles	Experiences in the industry (years)	Academic degrees
E_1	Project engineer	5	Bachelor's degree in engineering
E_2	Supply chain manager	12	Bachelor's degree in engineering
E_3	Project manager	14	Master's degree in engineering
E_4	Project engineer	8	Master's degree in engineering
E_5	Assisstant project manager	6	Bachelor's degree in economics
E_6	Purchasing engineer	9	Master's degree in engineering
E_7	Production chief	11	Master's degree in engineering

The strategies that these suppliers can implement in order to contribute to the company's green objectives are shown in Table 2 and Table 3.

Table 2 Strategies of S_1

Code	Strategy	Definition	Reference
S_{11}	Investing in ecological packing activities	Increasing the green material and technology investment in the enfoldment used to reduce the harmful effect on nature [41].	[41], [42], [43]
S_{12}	Promoting scientific studies on ecological shipping	It refers to supporting studies examining the reduction of environmentally harmful effects in shipping and storage processes by various methods.	[41], [44]
S_{13}	Focusing on energy usage level	It expresses the amount of energy consumption during the processes [45].	[45], [46], [47]

Table 3 Strategies of S_2

Code	Strategy	Definition	Reference

S_{21}	Making more efforts to apply pollution-reducing techniques	It shows the tendency and focus on pollution reduction techniques.	[47], [48] [49]
S_{22}	Increasing level on green instructions	It specifies to provide environmental practices to all employees of enterprises in the supply chain.	[50], [51], [52]
S_{23}	Increasing green perception activities	It describes advertising for the elements in the supply chain and for the consumer in order to increase the perception of green image.	[52], [53], [54]

Table 4 Linguistic variables and fuzzy numbers equivalents [55]

Code	Linguistic variable	Fuzzy number
EI	Equally Important	(1.0000, 1.0000, 1.0000)
MI	Moderately Less Important	(0.6667, 1.0000, 1.5000)
LI	Less Important	(0.4000, 0.5000, 0.6667)
VI	Very Less Important	(0.2857, 0.3333, 0.4000)
ML	Much Less Important	(0.2222, 0.2500, 0.2857)

To handle with uncertainty, linguistic variables are used for the experts evaluations. The description of the linguistic variables are given as triangular fuzzy numbers. Because they allow the effortless conversion of linguistic variables in evaluations into numerical form, triangular fuzzy numbers have opted. The scales of the triangular fuzzy number are represented in Table 4.

The steps of the fuzzy SWARA method are applied sequentially.

Step 1. The importance orders given by E_1 is included in the second column of Table 5. According to E_1, the most important strategy is S_{12} (promoting scientific studies on ecological shipping) while the least important is S_{23} (increasing green perception activities).

Step 2. According to E_1's evaluations, the linguistic variable codes given by the pairwise comparisons of the sequential strategies at the order of importance and their fuzzy number equivalents are determined according to Table 4.

Step 3. The $\tilde{k}_j$ coefficient is determined using Eq. (6).

Step 4. The fuzzy weights $\tilde{q}_j$ are calculated using Eq. (7).

Step 5. The final fuzzy weights of the strategies by using Eq. (8) and the results of all other steps are given in Table 5.

Table 5 The steps of fuzzy SWARA for E_1

No	Strategy	Code	$\tilde{s}_j$	$\tilde{k}_j$	$\tilde{q}_j$	$\tilde{w}_j$
1	S_{12}	-	-	(1.0000, 1.0000, 1.0000)	(1.0000, 1.0000, 1.0000)	(0.3172, 0.3484, 0.3949)
2	S_{11}	LI	(0.4000, 0.5000, 0.6667)	(1.4000, 1.5000, 1.6667)	(0.60000, 0.6667, 0.7143)	(0.1903, 0.2323, 0.2820)
3	S_{13}	VI	(0.2857, 0.3333, 0.4000)	(1.2857, 1.3333, 1.4000)	(0.4286, 0.5000, 0.5556)	(0.1359, 0.1742, 0.2194)
4	S_{21}	LI	(0.4000, 0.5000, 0.6667)	(1.4000, 1.5000, 1.6667)	(0.2571, 0.3333, 0.3968)	(0.0816, 0..1161, 0.1567)
5	S_{22}	LI	(0.4000, 0.5000, 0.6667)	(1.4000, 1.5000, 1.6667)	(0.1543, 0.2222, 0.2834)	(0.0489, 0.0774, 0.1119)
6	S_{23}	LI	(0.4000, 0.5000, 0.6667)	(1.4000, 1.5000, 1.6667)	(0.0926, 0.1481, 0.2025)	(0.0294, 0.0516, 0.0799)

For each experts' evaluations, the steps of the fuzzy SWARA method are applied step by step. The fuzzy weights are defuzzified using the BNP method (Eq. (9)). For example, the $\widetilde{w}_j$ value of S_{22} (increasing level on green instructions) is calculated as $(0.0446, 0.0882, 0.1582)$ by fuzzy SWARA according to the evaluations of E_3.

$$BNP = \frac{[(0.1582 - 0.0446) + (0.0882 - 0.0446)]}{3} + 0.0446 = 0.0970$$

Since the sum of the weights should be 1, it is necessary to normalize the defuzzified values. The normalized crisp weights of the strategies are determined and shown in Table 6.

In order to calculate the final criteria weights, the local criteria weights should be aggregated as in Table 6. The arithmetic mean is used to aggregate the weights of strategies. It is considered appropriate to use the arithmetic mean, as each expert's evaluations are assumed to be weighted equally. Taking the S_{22} strategy as an example to illustrate the use of arithmetic mean, and the weight of the strategy can be calculated as follows:

$$w_{S_{22}} = \frac{0.0782 + 0.2322 + 0.0928 + 0.0466 + 0.1151 + 0.0717 + 0.1918}{7} = 0.1183$$

Subsequently, the final weights in Figure 3 are calculated by using arithmetic averages for other strategies.

Table 6 The results of the fuzzy SWARA method according to experts

	S_{11}	S_{12}	S_{13}	S_{21}	S_{22}	S_{23}	Tot.
E_1	0,2312	0,3479	0,1737	0,1163	0,0782	0,0528	1
E_2	0,1307	0,1741	0,0658	0,3100	0,2322	0,0873	1
E_3	0,4545	0,0344	0,0633	0,1222	0,0928	0,2328	1
E_4	0,3902	0,0685	0,2597	0,1338	0,0466	0,1011	1
E_5	0,3241	0,2592	0,1723	0,0520	0,1151	0,0772	1
E_6	0,0948	0,3674	0,2443	0,1836	0,0717	0,0381	1
E_7	0,0982	0,0391	0,3411	0,2556	0,1918	0,0742	1

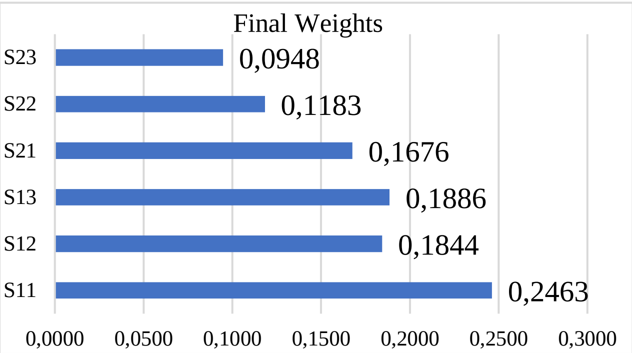

Figure 3 Final weights of strategies

According to the result of the fuzzy SWARA method, the most important strategy is S_{11} (investing in ecological packing activities). This strategy is followed by S_{13} (focusing on energy usage level) and S_{12} (promoting scientific studies on ecological shipping), respectively. S_{23} (increasing green perception activities) is emerged as the strategy with the fewest weight.

The second part of the proposed methodology, which includes a game theory approach, is applied. Representatives of two alternative green suppliers are brought together by the company's experts to ask questions about their green strategy. The aim is to establish a payoff matrix where the payoffs of two alternative suppliers are combined based on their information.

The method of constructing the payoff matrix is based on the study of Zolfani and Banihashemi [23]. According to the method, the values in the payoff matrix express the probability of success of alternative suppliers. The representation of the payoff matrix is given in Table 7, which is created by project manager (E_3), who evaluated the strategies of two alternative suppliers in company. The success probability percentages of the S_1 and S_2 alternatives are used. The success percentages are expressed in the scale of 0-10. In other words, the percentages are added to the table as discrete numbers.

Table 7 The payoff matrix

S_1, S_2	S_{21}	S_{22}	S_{23}
S_{11}	(8, 9)	(6, 7)	(9,8)
S_{12}	(5, 6)	(8, 5)	(6, 7)
S_{13}	(6, 5)	(5, 8)	(4, 4)

By applying the iterated elimination of strictly dominated strategies technique, the strategies in the payoff matrix are evaluated. It first starts with the strategies that the S_1 alternative can play. In the strategies of the S_1 alternative, it is clear that the strategy S_{13} is strictly dominated by S_{11} using Eq. (10), which means that the S_1 player never plays S_{13}. Therefore, S_{13} strategy is removed from the matrix and operations are continued. Since the strategies S_{11} and S_{12} do not dominate each other, S_2 players' strategies are followed. Strategy S_{22} is strictly dominated by strategy S_{23}. Because player S_2 never plays the S_{22} strategy, this strategy is removed from the matrix. In the resulting 2*2 matrix, since strategy S_{12} is dominated by S_{11}, it is concluded that S_{11} is the only strategy that can be played for alternative S_1. When S_1 plays strategy S_{11}, S_2 has chance to play strategies S_{21} and S_{23}. If these strategies are played out, it is seen that the payoffs of the two alternatives are (8, 9) and (9, 8), respectively. As the highest payoff of both alternatives is 9 and the company wants to choose the highest one, there is an impasse for the company. In the case of equality, it is necessary to examine the weighted payoff matrix.

The weighted payoff matrix is established in Table 8 by multiplying the weights calculated via fuzzy SWARA method by the values in the payoff matrix.

Table 8 The payoff matrix with weights

Weight	**S_2**	**0,1676**	**0,1183**	**0,0948**
S_1	**S_1, S_2**	**S_{21}**	**S_{22}**	**S_{23}**
0,2463	**S_{11}**	(1.9704, 1.5084)	(1.4778, 0.8281)	(2.2167, 0.7584)
0,1844	**S_{12}**	(0.922, 1.0056)	(1.4752, 0.5915)	(1.1064, 0.6636)
0,1886	**S_{13}**	(1.1316, 0.838)	(0.943, 0.9464)	(0.7544, 0.3792)

The game is replayed with the same approach based on the weighted payoff matrix. As an outcome of the game, it is seen that the strategies are the same. S_1 has strategy S_{11} against S_2's S_{21} and S_{23} strategies. The payoffs of these strategies are (1.9704, 1.5084) and (2.2167, 0.7584), respectively. In the new case, the strategy that offers the highest payoff for the company is for S_2 alternative to play S_{23}. Thus, S_1 alternative becomes the most suitable supplier by playing the S_{11} (investing in ecological packing activities) strategy. Offering the highest payoff in this weighted game, S_1 is the most suitable alternative for the chemical company. Thus, it is clear that the weight of strategies can affect the outcome of the games.

4. CONCLUSION

Due to conflict relations between criteria, green supplier selection is a complex task. Numerous multi criteria decision making tools applied on the decision-making process in supplier selection practices. Furthermore, the strategies of alternatives that can be managed by game theory approaches should be considered. In this paper, a new integrated multi-criteria decision-making method and game theory approach is proposed for green supplier selection problem. Triangular fuzzy numbers are used in SWARA, which is determined as a multi-criteria decision-making method to handle uncertainties in evaluations of experts. This method is used to weight the strategies of alternative green suppliers. Then, a payoff matrix is created, and a best alternative is selected between two alternative green suppliers. Thanks to the new integrated approach, decision making processes is dynamically managed. When the game is solved with dominance, two strategies with the highest payoffs are emerged. Considering the weights calculated by the fuzzy SWARA, the S_1 alternative green supplier that offers the highest payoff to the company is selected as the most suitable supplier for company's green goals. With regard to unweighted strategies, the game has different consequences. Therefore, weighting the strategies with fuzzy SWARA affects the outcome of the game.

To compare this study with the existing literature, the research of Zolfani and Banihashemi [23] proposed an approach involving multi-criteria decision making and game theory. They applied SWARA and game theory methodology on human resource assessment. In the study of the Taş et al. [56], a hybrid fuzzy SWARA method is examined to select green suppliers. Therefore, it is inferred that multi-criteria decision making and game theory approaches can also be used in green supplier selection problems.

Working with the suitable green supplier increases the green supply chain performance of companies.This methodology benefits industry in developing strategies for green supply chains and selecting the best supplier.

Besides the benefits, this study has some limitations such as the combined fuzzy SWARA and game theory approach is performed according to the subjective evaluations of the experts. Therefore, the group decision, which is the aggregated opinions, may vary due to their different education level or experience. Moreover, selecting a chemical manufacturer as a case study creates a limitation in determining the strategies of green suppliers. For different sectors, new green strategies should be considered with new weights. Also, as the priorities of green targets of countries may change, the results may vary.

For further research, the proposed methodology can be adapted for businesses in other sectors. Different types of fuzzy numbers (neutrosophic, Pythagorean, etc.) can be used to develop the new integrated approach. By increasing the number of players and the number of strategies, large-scale problems for real-life problems can be examined. In addition, other multi-criteria decision-making methods can be combined with game theory to contribute to the literature.

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No conflict of interest or common interest has been declared by the authors.

Authors' Contribution

All authors have contributed in experimental study and writing of the manuscript equally.

Ethics Committee Approval Notice

This study does not require ethics committee approval or any special permission.

The Declaration of Research and Publication Ethics

“The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.”

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