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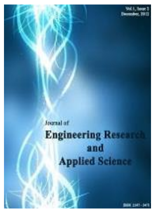

Green supplier selection using topsis method: a case study from the automotive supply industry

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Abstract
Climate change and increasing global warming have raised increasing environmental concerns around the world. Firms seeking to gain and maintain competitive advantages in the global market began to focus on the development of green products to meet customers' environmental requirements. As a result, green supply chain management (GSCM) through environmental procurement has become an important task for companies. Accordingly, green supplier selection has gained importance with the addition of environmental criteria to traditional supplier selection processes. In this study, it is aimed to select the best green supplier for a large scale company operating in the automotive supply industry and exporting the majority of its products. Environmental management system, reverse logistics applications, environment-friendly material use, waste management, pollution, and pollution level are selected as green supplier selection criteria. Five alternative green suppliers identified by the firm are evaluated using the TOPSIS (Technique for Order Preference by Similarity to Ideal Solutions) method according to these criteria. At the end of the study, the best green supplier selection is made considering the sensitivity analysis results.

Keywords: supply chain, green supplier selection, TOPSIS method.

1. Introduction

Due to increasing environmental concerns, governments, manufacturers, and distributors have become more aware of environmental issues. They have adopted new and strict regulations [1]. Today, the most important objectives to be considered in the planning and management of supply chain networks are the response and production with the lowest cost and highest quality. In addition, cost minimization, customer satisfaction and long-term competitive advantage for organizations are among the objectives [2]. With increasing concern for the protection of the environment, many businesses have taken increasing sustainable responsibilities in a sustainable environment to reduce the pollution to their products. In addition, consumers' increased environmental awareness has encouraged many companies to make their products greener [3].

Consumers are demanding greener products, and regulatory authorities are more sensitive to environmental issues. As environmental awareness increases, companies are forced to make green attempt in logistics, production and waste management [4, 5]. This prompted companies to adopt positive changes in supply chain operations, such as GSCM practices. GSCM has attracted the attention of many businesses that want to improve their sustainability aspects. These businesses apply different strategies during purchasing and production activities, such as, lean manufacturing, eco-design and eco-friendly materials. GSCM comes from both supply chain management and environmental management philosophy. It is emphasized that when a green component is added to any process, the effects and relationships of GSCM and the natural environment are improved [4]. GSCM's goal is to provide a comprehensive integration of logistics and financial information, resulting in sustainable corporate development and improved environmental protection by increasing the competitiveness of supply chain units [6]. The success of a green supply chain depends largely on its stakeholders [5]. Therefore, supplier evaluation and selection is very important in GSCM [3].

Therefore, this study aims to select the best green supplier for a company operating in the automotive supplier industry. The TOPSIS method is used in the selection of suppliers, one of the multi-criteria decision making methods (MCDM).

The rest of the study is organized as follows: In the second section, the green supply chain is explained and the green supplier selection criteria are specified,

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in the third section the materials and methods used in the study are explained, in the fourth section, the results of the study are discussed and finally the discussion section is given.

2. Green supply chain

Competitive advantages regarding the SCM philosophy can be achieved through strategic cooperation with suppliers and service providers. The success of a supply chain is highly dependent on its suppliers and therefore the problem of supplier selection has been a major field of research. In recent years, an additional strategic dimension has been taken into account in relation to the environment of suppliers contributing to sustainable development [1].

Supplier selection is defined as one of the most important processes in the procurement and supply management function and is understood as a very important management responsibility. Organizations have taken into account criteria such as price, flexibility, quality and delivery to evaluate the performance of their suppliers. However, environmental degradation has forced organizations to consider environmental issues. For this reason, the selection of green or sustainable suppliers has become increasingly popular [7].

Because the environmental performance of the supply chain is significantly affected by all suppliers, green supplier selection is critical for organizations. Selecting the right supplier provides a competitive advantage to reduce costs, improve quality and minimize adverse environmental impact without violating the relevant legislation. Green suppliers are selected to meet the expectations and goals of a firm to minimize adverse environmental impacts and maximize economic performance. Therefore, the green supplier selection process integrates environmental concerns into the interagency practices of supply chain management, including reverse logistics [8].

2.1. Green supplier selection criteria

When buying products, a company selects the favorite supplier on the basis of specific specifications and conditions. Effective evaluation criteria can help the company reduce risks associated with suppliers [8]. Historically, various methods have been developed to evaluate, the potential suppliers, taking into account factors such as delivery, flexibility, quality, and price. However, none of these methods considered the importance of environmental factors in the selection supplier. In recent years, some researchers have begun to identify environmental criteria such as design for the environment, life cycle analysis, green supply chain and environmental management system [1]. In addition to the variety of assessment and selection techniques, there is also diversity for the assessment criteria used. It can be said that there is no consensus on the decision criteria for green supplier selection. On the other hand, some research articles based solely on green evaluation criteria have combined green and non-green criteria in the selection process [9].

dos Santos et al. (2019) summarizes the green supplier selection criteria used in the articles of various authors as follows; environmental certificates, recycling, energy use, air and water pollution, clean technologies, environmental pressure, reverse logistics, reclaim, sustainable resource consumption, environmental management system, use of green materials, carbon governance, pollution, green supply, ecological design, environmental policy, environmental regulations, green packaging, environmentally friendly materials use [4]. Demir et al. [5] have emphasized the criteria of green supplier selection, such as recycling program, environmentally friendly materials, proper disposal of waste, energy management, waste recycling, social responsibility projects, environmentally friendly product distribution, emission measurement, environmentally conscious production and training programs on environmental issues. Yu et al. [7] stated that environmental criteria are the basic environmental criteria for green supplier selection, such as wastewater discharge level, solid waste production level, noise level, waste recycling level, carbon dioxide (CO_2) emissions, harmful substance usage level.

In cases where there are too many criteria, organizations can benefit from the use of MCDM methods in the evaluation and selection of suppliers [10]. Some of these studies in the literature are given below.

In their study, Khaksar et al. [11] aimed to evaluate the relationship between environmental performance, green supplier, green innovation, and competitive advantage. Banaeian et al. [10] conducted a green supplier assessment and selection study for a company using TOPSIS, VIKOR and GRA methods. Dos Santos et al. [4] proposed a hybrid Entropy-TOPSIS-F method for the evaluation and selection of green suppliers. Wang Chen et al. [8] used fuzzy AHP and fuzzy TOPSIS for green supplier selection and evaluation. In this study, using both economic and environmental criteria were used. Demir et al. [5] proposed a new VIKOR-based green supplier ranking methodology called VIKORSORT in green supplier evaluation. Tsui et al. [3] used the preference ranking organization method for enrichment evaluations (PROMETHEE) to evaluate green suppliers in the TFT-LCD industry. Fazli-Khalaf et al. [2] aimed to provide a reliable green closed-loop model to minimize the total hazardous gas emissions and network design total costs of operations in the supply chain network. In the study, Büyüközkan [1] used fuzzy analytic hierarchy process (AHP) method and axiomatic design (AD) based fuzzy group decision approach to rank green suppliers. Lo et al. [6] proposed a new model combining fuzzy TOPSIS and fuzzy multipurpose order allocation linear programming (FMOLP) to solve problems in green supplier selection. Yu et al. [7] proposed a supplier selection mechanism to reduce environmental damage based on a carbon footprint containing economic and environmental characteristics.

3.Materials and methods

This study was carried out in a large-scale company operating in the automotive supplier industry and exporting the majority of its products. In line with the company's 2025 vision, the TOPSIS method has been used to select the best among the environmentally conscious suppliers (green suppliers). In the following, this method used in the study is explained briefly and the implementation steps are given.

3.1. TOPSIS Method

The TOPSIS method was first introduced by Hwang and Yoon [12] in 1981 and is one of the most widely used MCDM methods [13, 14]. The principle of this method is to rank the alternatives by calculating the distance between each alternative's positive ideal solution and the negative ideal solution for the problems in decision-making and thus determine the optimum alternative [15-19]. The best alternative in the method is the closest distance to the positive ideal (PIS) and the farthest distance to the negative ideal solution (NIS). PIS is a hypothetical alternative that maximizes benefit criteria and minimizes cost criteria. Conversely, NIS maximizes cost criteria and minimizes benefit criteria [14, 16, 20].

The TOPSIS method has a strong capacity for simple calculation, easy understanding and integration into other methods. Because of these features, it is an effective decision-making approach used in various applications such as risk management, e-commerce, supplier selection, renewable energy, water resource management, climate change and sustainability assessment, logistics, energy management, design, engineering, production systems, health and security management [13, 20] site selection of solar power farms, selection of process parameters in computer networks and manufacturing industries [15]. The steps of the TOPSIS method are described below [12].

Step 1: Construct the decision matrix (A): Alternatives and criteria are listed on the rows and columns, respectively.

$$A = \begin{bmatrix} a_{11} & a_{12} & ... & a_{1n} \\ a_{21} & a_{22} & ... & a_{2n} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ a_{m1} & a_{m2} & ... & a_{mn} \end{bmatrix}$$

where a_{ij} is the real value of the alternative i according to the criteria j.

Step 2: Construct the normalized decision matrix using Equation (1).

$$r_{ij} = \sqrt{\sum_{i=1}^{m} a_{ij}^2} \quad i = 1, 2, ..., m \text{ and } j = 1, 2, ..., n. \quad (1)$$

Step 3: Compute the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as follows:

$$v_{ij} = r_{ij}.w_j \quad (2)$$

where w_j is the weight of the j^{th} criterion or attribute and $\sum_{j=1}^{n} w_j = 1.$

Step 4: Determine the positive ideal A^* and negative ideal A^- solutions.

$$A^* = \left\{ (\max_i v_{ij} \mid j \in B), (\min_i v_{ij} \mid j \in C \right\} \quad (3)$$

$$A^- = \left\{ (\min_i v_{ij} \mid j \in B), (\max_i v_{ij} \mid j \in C \right\} \quad (4)$$

Where B and C are the benefit and cost criteria, respectively.

Step 5: Compute the separation measures of each alternative from the positive ideal solution (S_i^*) and the negative ideal solution (S_i^-).

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \quad (5)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad (6)$$

Step 6: Compute the relative closeness to the ideal solution.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \qquad 0 \le C_i^* \le 1 \quad (7)$$

Step 7: Sort alternatives by the relative closeness (C_i^*).

4. Results

First of all, the criteria of green supplier selection are determined with the help of a team of 4 people working in the quality, logistics and purchasing departments of the company and the literature review mentioned above. The same team then identified five suppliers from the company's potential suppliers that fit the green supply concept and the green supplier selection model in Figure 2 is created.

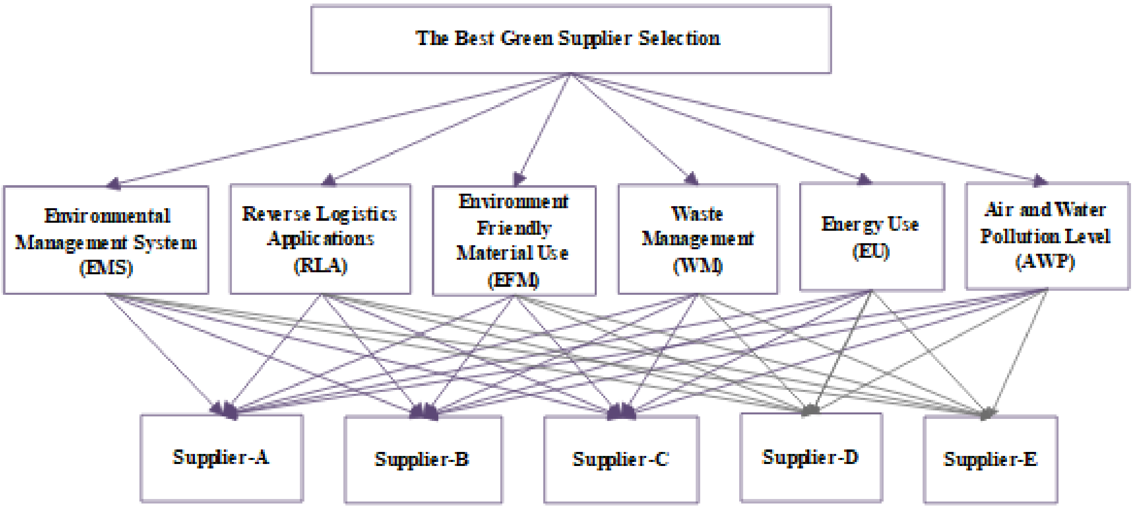

Figure 1. Green supplier selection model.

According to the model, alternative green suppliers were evaluated according to the selection criteria with the common opinion of the team consisting of 4 people. In addition, the importance weights of the selection criteria are determined. Based on these evaluations, the decision matrix given in Table 1 is formed. 1-9 weight scale is used to evaluate the suppliers of the team. (1: Very Low, 9: Very High).

Then, the data in the decision matrix is normalized using eq. (1) and given in Table 2.

The weighted normalized matrix given in Table 3 was obtained by multiplying the values in the normalized matrix (Table 2) and the criterion importance weights.

All selection criteria in the study are accepted as benefit criteria. Positive ideal solution (A*) is obtained with eq. (3), and negative ideal solution (A^-) is obtained with eq. (4).

A^*={0,099; 0,075; 0,097; 0,092; 0,092; 0,077}

A^-={0,074; 0,050; 0,048; 0,061; 0,055; 0,051}

In the next step, using the eq. (5) and (6), the separation measures of each alternative from the positive ideal solution (S_i^*) and the negative ideal solution (S_i^-) is calculated. In addition, the relative closeness of the alternatives to the ideal solution is obtained using eq. (7) and as shown in Table 4, alternative green suppliers are ranked according to these closeness values.

Table 1. Decision matrix.

Alternatives Green Suppliers	Environmental Management System (EMS)	Reverse Logistics Applications (RLA)	Environment Friendly Material Use (EFM)	Waste Management (WM)	Energy Use (EU)	Air and Water Pollution Level (AWP)
	Green Supplier Selection Criteria					
Supplier-A	8	5	5	6	3	4
Supplier-B	7	4	6	6	4	5
Supplier-C	7	5	5	4	5	6
Supplier-D	8	6	4	5	3	5
Supplier-E	6	5	3	5	4	6
Criteria Importance Weights	0,20	0,14	0,17	0,18	0,16	0,15

Table 2. Normalized matrix.

Alternatives Green Suppliers	Green Supplier Selection Criteria					
	EMS	**RLA**	**EFM**	**WM**	**EU**	**WP**
Supplier-A	0,49	0,44	0,47	0,51	0,35	0,34
Supplier-B	0,43	0,35	0,57	0,51	0,46	0,43
Supplier-C	0,43	0,44	0,47	0,34	0,58	0,51
Supplier-D	0,49	0,53	0,38	0,43	0,35	0,43
Supplier-E	0,37	0,44	0,28	0,43	0,46	0,51

Table 3. Weighted normalized matrix.

Alternatives Green Suppliers	Green Supplier Selection Criteria					
	EMS	**RLA**	**EFM**	**WM**	**EU**	**WP**
Supplier-A	0,099	0,062	0,081	0,092	0,055	0,051
Supplier-B	0,086	0,050	0,097	0,092	0,074	0,064
Supplier-C	0,086	0,062	0,081	0,061	0,092	0,077
Supplier-D	0,099	0,075	0,065	0,077	0,055	0,064
Supplier-E	0,074	0,062	0,048	0,077	0,074	0,077

Table 4. S_i^*, S_i^-, C_i^* values and ranking.

	S_i^*	S_i^-	C_i^*	**Ranking**
Supplier-A	0,049	0,052	0,515	3
Supplier-B	0,036	0,063	0,637	1
Supplier-C	0,039	0,058	0,599	2
Supplier-D	0,053	0,043	0,451	4
Supplier-E	0,061	0,037	0,380	5

According to Table 4, Supplier-B ranks first among green supplier alternatives with a closeness value of 0.637. This is followed by Supplier-C (0.599) and Supplier-A (0.515). Supplier-E is at the last place among alternatives with its closeness value of 0.380.

Then, sensitivity analysis is performed depending on the scenarios in Table 5 to determine whether the rankings of alternative suppliers would change according to different criteria weights and the results obtained are given in Figure 2.

Table 5. Scenarios created according to different criteria weights.

Scenarios	Criteria Importance Weights Combinations
Scenario 1	Current
Scenario 2	EMS 0,14; The Rest current
Scenario 3	RLA 0,14; The Rest current
Scenario 4	EFM 0,14; The Rest current
Scenario 5	WM 0,14; The Rest current
Scenario 6	EU 0,14; The Rest current
Scenario 7	WP 0,14; The Rest current
Scenario 8	EMS 0,20; The Rest current
Scenario 9	RLA 0,20; The Rest current
Scenario 10	EFM 0,20; The Rest current
Scenario 11	WM 0,20; The Rest current
Scenario 12	EU 0,20; The Rest current
Scenario 13	WP 0,20; The Rest current

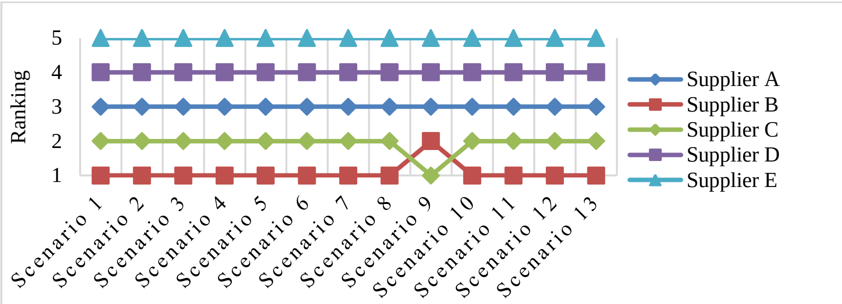

Figure 2. Sensitivity analysis.

Looking at the results obtained from the sensitivity analysis in Figure 3; Supplier-B takes the first place in all scenarios except Scenario 9, where the importance weight of the RLA criterion is 0.20. Supplier-C takes first place in this scenario. In all other scenarios, the rankings were the same as the current situation. This result shows that the results obtained by TOPSIS method are sensitive based on the criteria and alternatives used in the study.

5. Discussion

In the manufacturing industries, the frequency of competition among companies on a global scale is increasing. In addition, environmental challenges such as climate change, water and air pollution, and scarcity of resources have increased the environmental concerns of organizations and countries. In other words, they need to take into account the environmental criteria as well as the classical criteria. The selection of green suppliers based on these criteria is an important issue due to the increased awareness of environmental protection and its long-term impact on business and marketing.

This study was carried out in a company operating in automotive supplier industry. The company exports many of its products, and businesses and countries that purchase their products attach great importance to the green supply chain. The company also wants to increase its export share and protect the environment through its green chain by fulfilling the green / sustainable conditions mentioned in the contracts presented to it. Accordingly, its suppliers should also be green suppliers. Therefore, in this study, it is aimed to select the best green supplier among the suppliers of the enterprise. TOPSIS method was applied according to the selected green supplier selection criteria. At the end of the study, Supplier-B was identified as the best green supplier among the five suppliers. According to this result, the company has the following advantages when working with this supplier.

- increase its financial earnings by using green resources.
- contribute to the environment in terms of energy use, air and water pollution.
- gain competitive advantage with the use of environmentally friendly materials.

In this study, green supplier selection was made considering only environmental factors. In future studies, both environmental and economic criteria can be taken into consideration and selection process can be done by using fuzzy clusters.

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