Research Article

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To cite to this article: Sarıoğlu, D. Ö. (2023). Including Sustainability Strategy For Supplier Selection And Evaluating Selection Criteria With Fuzzy AHP . International Journal of Engineering and Innovative Research , 5(3),180-190 . DOI: 10.47933/ijeir.1269399

DOI: 10.47933/ijeir.1269399

To link to this artice: https://dergipark.org.tr/tr/pub/ijeir/archive

International Journal of Engineering and Innovative Research

http://dergipark.gov.tr/ijeir

Including Sustainability Strategy for Supplier Selection And Evaluating Selection Criteria With Fuzzy AHP

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(**Received:** 22.03.2023; **Accepted:** 10.07.2023)

https://doi.org/10.47933/ijeir.1269399

Abstract: Businesses in an effort to create a sustainable supply chain try to make their production processes the least harmful to the environment. In that way, they expect the companies that they supply raw materials, semi-finished products and other materials used in production, which directly affect the production process, to be sensitive to the environment. For this reason, the first collaborative partners of companies that carry out sustainability studies are their suppliers. This makes supplier selection important. In the literature, basic criteria such as price, quality and performance are frequently encountered in supplier selection studies. In addition to these basic criteria, adding criteria for sustainability will strengthen the management strategy. The aim of this study is to create a guide for supplier evaluation that includes sustainability criteria. For this, in the first part of the study, supplier selection criteria are determined by considering the sustainability strategy. In the second part, the order of importance of these criteria is calculated. Taking into the sustainability report of the company, three new sustainability criteria that the business finds important were determined as "supplier's sustainability score", "CO2 emissions in the supply process", "supplier's level of working with sustainable suppliers". according to the business strategy, Eight supplier criteria were weighted with the fuzzy AHP method. It is seen that the company attaches importance to sustainability studies at the beginning level in supplier evaluation.

Keywords: Sustainable Supply, Fuzzy AHP, Supplier Selection, Sustainable Inbound Logistics, Decision Making.

1. INTRODUCTION

The scope of sustainability in the supply chain is a very wide-ranging journey. The journey that starts with the procurement of the most basic raw material of the product from the final consumer continues until the final consumer. Complying with the standards determined for the respect of human, nature and law by all stakeholders participating in this journey constitutes the concept of sustainable supply chain. These standards cover all operational activities. A business that has adopted sustainability therefore expects this from the stakeholders involved in its supply chain. The suppliers, which were previously selected according to basic criteria such as price and product quality, are also questioned today in terms of their compliance with sustainable standards. In this study, a textile company tries to select its suppliers by including sustainability. With the decision of the textile business to nearshoring as of the covid period, they had to identify new suppliers. In the first part of the study, the factors affecting the selection of suppliers were determined together with the new management group of the enterprise that increased its sustainability studies. The importance degrees of the determined elements relative to each other were also created with fuzzy AHP, which is one of the most frequently used prioritization methods in the literature

2. LITERATURE

It can be said that supplier selection started with a survey conducted by Dickson [1]. Noci determined [2] the criteria of "green capabilities", "environmental efficiency", "green image" and "product life cycle cost" to evaluate the performance of suppliers in the model he developed for supplier selection from an environmental perspective. Noci used the Analytic Hierarchy Process (AHP) model for the automotive industry and brought different results to the literature. Handfield et al. wanted to evaluate green suppliers [3]. They provided some companies in the Fortune 500 ranking with a list of criteria by which the supplier can be evaluated. Negotiations continued until an agreement was reached. As a result, they identified the most important measurable criteria for supplier selection. In the study of Güner [4], the supplier evaluation and selection problem of a marble-travertine business operating in Denizli is discussed. Hsu and Hu conducted a study on the management of harmful substances while choosing a supplier[5]. In the study, they developed an Analytic Network Process model that covers the criteria (with sub-criteria) of "supply management", "R&D management", "process management", "input quality management" and "management systems". Büyüközkan and Çifçi developed an AHP model [6] in which traditional supplier selection criteria and green supplier selection criteria are evaluated together. With that model, they selected a supplier for a manufacturer operating in the Turkish automotive industry. Tsui and Wen [7] evaluated ten suppliers on thirty criteria for a Taiwanese panel manufacturer company. AHP and PROMETHEE methods were used in the evaluation and selection stages. Hashemi et al. [8] developed a green supplier selection model that takes into account the interaction between criteria. Sancaklı examined the performance evaluation of metal accessory suppliers of the company operating in the textile sector using Fuzzy Analytical Hierarchy Process (BAHP) and Fuzzy TOPSIS[9].

Sustainability included researches on supplier selection has different multi-criteria decision making methods. Zhou and Xu [10] studied on hybrid information aggregation. The model is a Triple Bottom Line theory that includes DEMATEL, Analythic Network Process and VIKOR methods. With this theory, they aimed to use sustainable supplier selection for manufacturing. Vahidi et al. [11] studied sustainable supplier selection and they suggested A hybrid systematic framework that includes SWOT and Quality Function Deployment methods. Lin et al [12] proposed a fuzzy weight avarage model used to establish an analysis matrix of green supplier selection. Wang et al.[13] developed an approach via Analytic Hierarchy Process(AHP) and Grey Relational Analysis(GRA) for a resilient construction supply chain. Enhanced supply chain status visualization based on sustainability was applied. A green supplier selection model was developed with Using the DANP with VIKOR by Kuo et al.[14]. Green suppliers have proposed a new hybrid multi-criteria decision making (MCDM) method to evaluate an electronics company. Jia and his friends [15] studied for supplier selection problems in fashion business operations with sustainability considerations. For this aim they framed twelve criteria from the economic, environmental and social perspectives to evaluate supplier. And they used TOPSIS method for the research.

Also the aim of this study is to prioritize the supplier criteria, which includes sustainability criteria, in accordance with the strategy of a textile company. For this, fuzzy AHP technique, which is the most frequently[16-18] used in the literature and has proven its reliability in this field, will be used.

3. METHOD

The fuzzy AHP approach was first applied by Yager [10]. Today, it is frequently used in multi-criteria decision-making problems to eliminate the uncertainty of the decision maker's personal views. In the fuzzy AHP approach, triangular and trapezoidal fuzzy numbers can be used in pairwise comparisons [11].

The fuzzy triangular numbers given in Table 1 created by Prakash [12] based on the 1-9 comparison scale suggested by Saaty [13] in the creation of the matrices of the criteria.

After the comparative matrix is prepared by formula (1), geometric means are found and clarification is done. The clarification formula(2) of Hus and Nian [14] and Lious and Wang [15] is used. And The value is normalized (formula (3)). After normalization, the criteria affecting each criterion are weighted separately. A table is created with these importance weights and is called a supermatrix. After the supermatrix is created, the criterion weights are found by creating the limit matrix in which all row values are equalized thanks to great exponent of the supermatrix.

Table 1. Triangle Fuzzy Numbers [12]

Triangular Fuzzy Numbers	Inverted Triangular Fuzzy Numbers
(1.1,1)	(1/1, 1/1, 1/1)
(1,2,4)	(1/4, 1/2, 1/1)
(1,3,5)	(1/5, 1/3, 1/1)
(3,5,7)	(1/7, 1/5, 1/3)
(5,7,9)	(1/9, 1/7, 1/5)
(7,9,11)	(1/11, 1/9, 1/7)

Comparative matrix;

$$\tilde{A} = [\tilde{a}_{ij}] = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \frac{1}{\tilde{a}_{12}} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{\tilde{a}_{1n}} & \frac{1}{\tilde{a}_{2n}} & \cdots & 1 \end{bmatrix} \end{array} \qquad (1)$$

Clarification;

$$\left(a_{ij}^{\alpha}\right) = \left[\lambda . L_{ij}^{\alpha} + (1-\lambda) . U_{ij}^{\alpha}\right], 0 \leq \lambda \leq 1, 0 \leq 1, 0 \leq \alpha \leq 1, \qquad (2)$$

Normalization;

$$L_{ij}^{\alpha} = \left(M_{ij} - L_{ij}\right) . \alpha + L_{ij}$$

$$U_{ij}^{\alpha} = U_{ij} - \left(U_{ij} - M_{ij}\right) . \alpha \qquad (3)$$

4. SUPPLIER SELECTION FOR A TEXTILE COMPANY

Nearshoring application was started in the factory of a multinational corporate textile company in İzmir Free Zone. The company shares its sustainability reports with the public every year and aims to minimize CO2 emissions from fabric product supply in the next 5 years. For this reason, the textile company is looking for new suppliers that are close regionally. During this process, meetings were held with the assistant general managers responsible for production, the development projects manager and the sustainability department manager. With these meetings, 21 supplier criteria encountered in the literature were reduced to 8 basic criteria, taking into account the common objectives of business strategy and sustainability. These criteria are; price, quality, delivery performance, agility, technological competence, supplier's sustainability score, CO_2 emissions level in the supply process and supplier's level of working with sustainable suppliers. After the criteria were determined, the relations of the criteria with the same team were analyzed in order to determine the priorities of the criteria. This analysis reflects the perspective of the company in terms of business strategies and work experience. Relationships of the criteria is shown in Table 2. Then each criterion has been interpreted one by one. Finally, the comparison matrices that the price criterion is given in Table 3 as an example were created.

4.1. Price

The criteria that the price affects; quality, delivery performance, agility and technological competence.

The high price of the product will enable to carry out processes that will increase the quality of the product. Otherwise, customer expectations for product quality may not be met. The price of the product will also affect the performance of careful and timely delivery. Agility is about providing the product to the manufacturer in the fastest way whenever it is needed. Being agile requires good planning and a focus on developing logistics skills. This is also a cost. On the other hand, if the product price is low, the supplier may find it difficult to act agile. The demand change made by the manufacturer in the content and amount of the product can be easily answered with the support of technological capabilities.Technological talent requires investment in materials, equipment and people. If the product does not earn enough profit, the necessary costs for the supplier's technological competencies cannot be covered.

The criteria by which the price is affected; quality, delivery performance, agility, technological agility, the supplier's sustainability score and the amount of CO_2 emissions of the supply process.

The effort to increase the product quality level and delivery performance is a situation that directly increases the price. Likewise, suppliers that increase their technological capabilities and agility reflect this situation on the price of their products. When we examine the companies that carry out sustainability studies, it is seen that they bear the labor and investment costs in this field. On the other hand, CO_2 emissions differ clearly according to the type of transportation used. International organizations have measured that there is a linear relationship between the amount of CO_2 emissions and the cost of transportation. For this reason, transportation planning should be done well so that the price does not increase.

4.2. Quality

When low-budget production is desired, there are deficiencies in product features that determine product quality. The quality of the product is affected by the low price. The quality of the product does not depend only on the raw material used. The fact that the product arrives undamaged, clean, useful, on time and considering customer requests also creates its quality. Therefore, the quality criterion of the product is affected by the agility and delivery performance criteria. The demand change made by the manufacturer in the content and quantity of the product will be easily answered with the support of technological capabilities. This supports the level of quality businesses want to have. The quality of the product is closer to the desired level when it is produced with advanced technology. It is necessary to include sustainable activities within the quality of the product. The Higg Index Sustainability View Platform gives an idea about whether or not to work with an environmentally friendly company in product supply. Using this supplier's product increases the quality level of the product. Similarly, if the suppliers determine their suppliers in this way, the product will be of even higher quality. This means continuity of product quality throughout the supply chain. The ability of the product to reduce CO2 emissions along the way through the supply chain brings the business closer to its strategic goals. Therefore, having a product with low emissions is an element that makes the product higher quality.

4.3. Delivery Performance

The criteria that the delivery performance criterion affects; price and quality. Careful and on time deliveries increase the satisfaction of the business. A supplier with a high performance can increase the price of the product with the good service that it provides. The undamaged, clean, useful and timely arrival of the product increases the product quality. If delivery performance is poor, it also lowers the agility of the supplier. It can also increase CO2 emissions in the supply process.

The criteria by which the delivery performance criterion is affected; price, quality and agility. Price and quality have an impact on delivery performance. Price and quality criteria are mentioned in the titles. The delivery performance of the supplier, which can act agile and have high technological competence, will also be high. The delivery performance of suppliers trying to keep their CO2 emissions low in transportation will vary according to their planning success.

4.4. Agility

Criteria affected by the agility criterion; price, quality, delivery performance, the supplier's sustainability score, the amount of CO2 emissions in the supply process and the supplier's level of working with sustainable suppliers may be affected.

It has been stated in the previous titles that price, quality, delivery performance criteria are affected by agility criteria. In an effort to act agile, decisions in logistics processes may increase CO2 emissions. Therefore, agility may have an effect on CO2 emissions. For this reason, the sustainability score of the supplier, the amount of CO2 emissions in the supply process and the criteria of the supplier's level of working with sustainable suppliers may be affected.

The criteria by which the agility criterion is affected; price, delivery performance and technological competence. It has been stated in the previous topics that price and delivery performance criteria affect agility. Agility is also directly proportional to technological competence. A supplier using advanced technology products in the logistics process is expected to be agile.

4.5. Technological competence

Criteria affected by technological competence; price, quality, delivery performance, agility, sustainability score of the supplier, CO_2 emission level in the procurement process.

The relationship between the technological competence criteria and the price, quality, delivery performance and agility criteria has been mentioned in the previous chapters. Choosing the equipment that will create the least carbon emission to the nature in the selection of technology affects the sustainability score of the supplier. Similarly, the level of CO_2 emissions in the supply process also changes.

The only criterion by which technological competence is affected is price. The price of the product must be at a level to meet the investment in technological development. The low price of the product is a situation that will reduce technological competence.

4.6. Supplier sustainability score

This criterion is the information stated in the sustainability reports of the supplier company and their evaluation through the supplier surveys created by the manufacturer company.
Criteria affected by the supplier sustainability score; price and quality criteria are price and quality as mentioned in the titles.

The criteria by which the supplier sustainability score is affected, on the other hand, are also affected by the criteria of delivery performance, agility and technological competence, as well as the level of CO_2 emissions in the procurement process and the level of work of the supplier with the sustainable supplier.

The low level of CO_2 emissions in the supply process and the high level of work of the supplier with the sustainable supplier will increase the sustainability score of the supplier. Sustainability studies carried out by suppliers during the procurement process are directly included in the sustainability reports. This situation reflects positively on the sustainability score of the supplier.

4.7. CO_2 emission level in the supply process

The criteria affected by the level of CO_2 emission in the supply process; price, quality, delivery performance and sustainability score of the supplier.

The investments made by the enterprises in the effort to reduce the CO_2 emission affect the product price. For this reason, it affects the price criterion. The quality of the product is also evaluated in terms of the amount of damage it causes to nature. For this reason, the quality is affected by the carbon emissions that occur during the procurement process. Suppliers that try to reduce CO_2 emissions during the delivery process have higher product quality and delivery performance. The sustainability score of the supplier, which reduces carbon emissions in the supply process, is also positively affected.

The criteria by which the level of CO_2 emission in the supply process is affected; delivery performance, agility and technological competence. Sustainable practices are also included in the delivery performance. Enterprises with high delivery performance and technological competence are expected to have lower carbon emissions. Depending on how the agile supplier manages this process, carbon emissions in the procurement process will vary.

4.8. Supplier's working level with the sustainable supplier

Firms that care about sustainability want to make the entire supply chain sustainable. They are interested in the logistics processes of the raw materials they use. The products of suppliers that choose sustainable suppliers are preferred.

The criteria that the supplier's level of working with the sustainable supplier affects; quality and supplier sustainability score. The criteria that the supplier's level of working with the sustainable supplier is affected is agility.

4.9. Relationships of criteria

The criteria that each criterion affects and is affected by were determined by the opinion of the experts in the textile company. This is the first part of the study. In this process, experts have explained why the criteria are related to each other. All these explanations are explained on the basis of criteria. The relationship matrix that emerged as a result of these explanations is given in Table 2.

Table 2. Relationships of Criteria

Criteria	**Symbol**	**Effects Criteria**	**Effected Criteria**
Price	P	Q,D,A,T	Q,D,A,T,SE,SS
Quality	Q	P,D	P,D,A,T,SS,SE,SSS
Delivery Performance	D	P,A,Q,SS,SE	P,Q,A,T,SE
Agility	A	P,Q,D,SS,SE,SSS	P,D,T
Technological Capability	T	P,Q,D,A,SS,SE	P
Supplier's sustainability score	SS	P,Q	D,A,T,SE,SSS
CO2 emissions level in the supply process	SE	P,Q,D,SS	D,A,T
Supplier's level of working with sustainable suppliers	SSS	Q,SS	A

4.10. Prioritization of criteria

As stated in the methodology, the steps were carried out sequentially. First of all, for all criteria, the criteria affecting them were compared with each other. The comparison table for the price criterion is given in Table 3 as an example.

Table 3. Comparision matrix of criteria

Price						
	Q	D	A	T	SS	SE
Q	(1,1,1)	(1,2,4)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)
D	(0.25,0.5,1)	(1,1,1)	(1,3,5)	(1,2,4)	(3,5,7)	(1,2,4)
A	(0.14,0.2,0.33)	(0.2,0.33,1)	(1,1,1)	(0.2,0.33,1)	(1,2,4)	(0.25,0.5,1)
T	(0.2,0.33,1)	(0.25,0.5,1)	(1,3,5)	(1,1,1)	(3,5,7)	(1,1,1)
SS	(0.14,0.2,0.33)	(0.14,0.2,0.33)	(0.25,0.5,1)	(0.14,0.2,0.33)	(1,1,1)	(0.2,0.33,1)
SE	(0.2,0.33,1)	(0.25,0.5,1)	(1,2,4)	(1,1,1)	(1,3,5)	(1,1,1)

After the comparison matrix was prepared, the geometric mean of each criterion was calculated as triangular. In the table above, the geometric calculation of the quality criterion affecting the price criterion is given below as an example.

Q1=$\sqrt[6]{1*1*3*1*3*1} = 1{,}44225$
Q2=$\sqrt[6]{1*2*5*3*5*3} = 2{,}768229457$
Q3=$\sqrt[6]{1*4*7*5*7*5} = 4{,}1212853$

The effect weight of the criterion was found by dividing the scores of all criteria by the total criterion score. The process for the quality criterion is given below as an example.

$$FFQ1 = \frac{1{,}44}{13{,}98} = 0{,}103165205 \qquad FFQ2 = \frac{2{,}77}{9{,}76} = 0{,}28363 \qquad FFQ3 = \frac{4{,}12}{7{,}8} = 0{,}52837$$

With the clarification process, a single score for a criterion is obtained. For this, α and ℵ=0.5 were treated.

$$FQ = \{0{,}5 * (0{,}28 - 0{,}10) * 0{,}5 + 0{,}10\} + (1 - 0{,}5) * (0{,}53 - (0{,}53 - 0{,}28)0{,}5\} = 0{,}3475$$

$$FQn = \frac{0{,}3475}{1{,}32} = 0{,}263258$$

Table 4. Importance weights for price criterion

Criteria	Clarification	Normalized importance weights
Q	0,3475	0,263258
D	0,2625	0,198864
A	0,2255	0,170833
T	0,2525	0,191288
SS	0,104	0,078758
SE	0,1365	0,103409
		1

The criteria affecting each criterion were evaluated comparatively with the support of the managers. Table 4 shows the example for the price criterion that is effected criterias of importance weights. Accordingly, the three most important criteria affecting the price criterion are; quality, delivery performance and technological competence. This calculation was made for all criteria and 8 tables emerged. The importance weights in these tables are shown by the supermatrix formed by Table 5 below.

Table 5. Supermatrix

	P	**Q**	**D**	**A**	**T**	**SS**	**SE**	**SSS**
P	0	0,246453901	0,2464539	0,29275362	1	0	0	0
Q	0,263258	0	0,20985401	0	0	0	0	0
D	0,198864	0,17748227	0	0,40289855	0	0,2675841	0,363071	0
A	0,170833	0,159929078	0,16736263	0	0	0,10601427	0,28769	1
T	0,191288	0,179078014	0,08848678	0,30434783	0	0,25739042	0,349239	0
SS	0,078758	0,094680851	0	0	0	0	0	0
SE	0,103409	0,10035461	0,03927222	0	0	0,22986748	0	0
SSS	0	0,042021277	0	0	0	0,13914373	0	0

The limit matrix (Table 6) is formed by the supermatrix and the high exponent of the supermatrix.

Table 6. Limit matrix

	P	Q	D	A	T	SS	SE	SSS
P	0,156934	0,156703	0,122321	0,151245	0,163655	0,153933	0,151291	0,157722
Q	0,063196	0,063102	0,049257	0,060905	0,065902	0,061987	0,060923	0,063513
D	0,091903	0,091768	0,071633	0,088572	0,095839	0,090146	0,088598	0,092365
A	0,002001	0,071894	0,056120	0,069390	0,075084	0,070624	0,069411	0,072362
T	0,091186	0,091052	0,071074	0,087881	0,095091	0,089442	0,087907	0,091644
SS	0,019129	0,019101	0,014910	0,018435	0,019948	0,018763	0,018441	0,019225
SE	0,031886	0,031839	0,024853	0,030730	0,033252	0,031276	0,030739	0,032046
SSS	0,005545	0,005537	0,004322	0,005344	0,005782	0,005439	0,005346	0,005573

5. RESULTS

The criteria priority scores made with the managers by considering the business strategy were determined with the Fuzzy AHP. Accordingly, the first three criteria that the textile company is affected by in the supplier selection are; price, delivery performance and technological competence. Criterion scores are the price of the product has 15.6 point, delivery performance of the supplier has 9 point, technological competence of the supplier has 9 point too, quality of the product has 6.3 point, agility of the supplier has 0.2 point, the CO2 emission released to the environment during the supply of the product has 3 point, sustainability score of the supplier has 1 point and lastly the supplier's sustainability score has 0.5 point.

6. CONCLUSIONS

It is known that supplier selection is an important milestone in the transition to the formation of more environmentally sustainable supply chains. This transition will take time in line with the strategic goals of the enterprises. The criteria weights, which are important in the supplier selection of the textile company where this study was carried out, were determined by the limit matrix. Accordingly, although the company gives importance to sustainable supplier selection, price, delivery performance and technological development criteria are still more influential in supplier selection.

The very low weight of the Supplier's working level with the sustainable supplier criterion shows that the company is at the beginning of the road to make the entire supply chain process sustainable. It has been observed that the enterprise primarily focuses on the sustainability criteria with the highest controllability in the supply chain. The CO2 emission level in the supply process criterion, which is related to the distance to the supplier, is a situation under the control of the textile business according to the supplier's sustainability score criterion. According to the business strategy, it is reasonable to start by giving priority to strengthening self-capabilities before external factors. However, the company does not make a radical change in its approach to sustainable supplier selection. It is a procedural change over time. This situation can be explained by looking at the weight levels given to the sustainability criteria and the evaluation of the weights of these sustainability criteria among them.

The benefit of this study for the business is that it has created a reliable and applicable consensus decision framework to solve the supplier selection problem in accordance with the strategies of the business.

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