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Green Supplier Assessment with Fuzzy Expert System Approach

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Abstract: Today, reasons such as increasing pollution on a global extent and limited raw material resources are increasing the interest in green supply chain management (GSCM). GSCM includes the processes starting from the very beginning of the production process of a product, completing the production, delivering the product to the customer, and recycling the product at the end of its useful life. Its main purpose is to eliminate or minimize the damages caused to the environment in all of these processes. In order to achieve this goal, it has great importance to assess the suppliers, which are one of the most important components of the production process, in terms of becoming a green supplier.

In this study, a fuzzy expert system model has been developed to assess the green suppliers based on green production technology, environmental management system, pollution control, product cost, quality, and lead time criteria. To test the performance of the developed model, 32 different suppliers were assessed with this model and the green supplier score was calculated. Also, Mean Square Error (MSE) and coefficient of determination (R^2) have been calculated to measure the performance of the developed model. While the MSE value was found to be 0.0481, the R^2 value was 0.9999. These values show that the green supplier assessment performance of the developed model is quite high.

Bulanık Uzman Sistem Yaklaşımı ile Yeşil Tedarikçi Değerlendirmesi

Anahtar Kelimeler
Bulanık uzman sistem,
Yeşil tedarikçi,
Yeşil tedarikçi değerlendirmesi,
Yeşil tedarik zinciri yönetimi

Öz: Günümüzde küresel ölçekte artan kirlilik ve sınırlı hammadde kaynakları gibi nedenler, yeşil tedarik zinciri yönetimine (YTZY) olan ilgiyi artırmaktadır. YTZY, bir ürünün üretim sürecinin en başından başlayarak, üretiminin tamamlanması, ürünün müşteriye teslim edilmesi ve kullanım ömrü sonunda ürünün geri dönüştürülmesine kadar olan süreçleri kapsamaktadır. Temel amacı, tüm bu süreçlerde çevreye verilen zararları ortadan kaldırmak veya en aza indirmektir. Bu hedefe ulaşmak için üretim sürecinin en önemli bileşenlerinden biri olan tedarikçilerin yeşil tedarikçi olma açısından değerlendirilmesi büyük önem taşımaktadır.

Bu çalışmada, yeşil üretim teknolojisi, çevre yönetim sistemi, kirlilik kontrolü, ürün maliyeti, kalite ve teslim süresi kriterlerine dayalı olarak yeşil tedarikçilerin değerlendirilmesi için bulanık bir uzman sistem modeli geliştirilmiştir. Geliştirilen modelin performansını test etmek amacıyla 32 farklı tedarikçi bu modelle değerlendirilmiş ve yeşil tedarikçi puanı hesaplanmıştır. Ayrıca, geliştirilen modelin performansını ölçmek için Ortalama Karesel Hata (MSE) ve belirlilik katsayısı (R^2) hesaplanmıştır. MSE değeri 0,0481, R^2 değeri ise 0,9999 olarak elde edilmiştir. Hesaplanan bu değerler, geliştirilen modelin yeşil tedarikçi değerlendirme performansının oldukça yüksek olduğunu göstermektedir.

1. INTRODUCTION

Supply chain management (SCM) can be considered as integrating planning, implementation, and control activities related to the flow of information, services, and materials with a strategic approach in the process from raw materials to finished products in the production process. SCM plays a key role in increasing operational efficiency in the enterprise. By eliminating unnecessary operations, cost minimization will be ensured and time loss will be prevented. Thus, it will be possible for the enterprise to direct its relevant resources to other areas [1].

When SCM is mentioned, supply chain and supplier concepts come to mind. Supplier is the name given to the external organizations in which the products to be offered to the last users of the enterprise are supplied by purchasing the raw materials or materials used in the production process in the production enterprises. The supply chain, on the other hand, is the process of purchasing and shipping the raw materials of the product desired to be produced in the production enterprises from the supplier and finally entering the warehouse of the enterprise.

Green Supply Chain Management (GSCM) has garnered a great deal of attention with increasing pressures on environmental sustainability. Instead of focusing on products, services, and intra-business organizational activities, the focus has shifted to life cycle analysis, supply chains, and extended producer responsibility. GSCM can be defined in several ways. Most of these definitions depend on the practitioner's or researcher's perspective. This perspective is similar to describing supply chain management in general [2]. GSCM can be defined as integrating environmental thinking into supply chain management, which includes product design, material sourcing, material selection, manufacturing processes, delivery of products to final consumers, and end-of-life management of products. That is, it obliges to include the idea of the environment as a whole in every stage of the product and service [3].

Figure 1. The main corporate, commercial, and technical factors affecting green supply chain management [2]

If we examine the concept of a green supply chain, it aims to reduce environmental degradation through the adoption of green practices in business processes. Air pollution and water pollution can be given as examples of these environmental distortions. It can reduce environmental pollution and production costs, and at the same time promote economic growth. In addition, it can create a competitive advantage with greater customer satisfaction and provide better opportunities for the enterprise to export its products to environmentally friendly countries [4]. On the other hand, a green supplier can be defined as an external actor in the production process that supplies the raw materials needed by an enterprise in the production process in accordance with the factors in the production environment and environmental standards [5].

The rest of this study has the following structure; Section 2 provides the literature review of the related article. Section 3 proposes a fuzzy expert system model. Section 4 presents the results and discussion. In the final section, the gains obtained through the study were evaluated in a general framework.

2. LITERATURE REVIEW

When the literature is examined, there are many studies on the selection of green suppliers. For example, Daldir and Tosun [6] used multi-criteria decision-making techniques for the selection of green suppliers in their study. Specified criteria for green supplier selection have been identified as green storage, green recycling, green production capacity, green packaging, resource consumption, pollution control, product cost, lead time, error rate, warranty policies, and environmental competencies and documents. Fuzzy analytical hierarchy process (FAHP), one of the multi-criteria decision-making techniques, was used to determine the criterion weights. Within the framework of the existing criteria, five suppliers were evaluated and the Fuzzy WASPAS method was used to select the most suitable green supplier.

Denizhan et al. [7] conducted a study to select the most suitable green supplier. Three alternative suppliers were examined using FAHP and AHP methods, and the most appropriate green supplier selection application was carried out. Within the scope of the study, six main criteria were determined as quality, cost, delivery, service, technical criteria, and green criteria. Four different results were obtained after the application. The first of these is the selection of the most suitable supplier using the FAHP method, and the second is the selection of the most suitable green supplier using the FAHP method. Then, the most appropriate supplier selection and the most appropriate green supplier selection were carried out using the AHP method.

In the study conducted by Çınar and Uygun [8], the criteria of quality conformity, green product design, green purchasing, green production, and environmental management system were based and the intuitive FAHP method, which is one of the multi-criteria decision-making techniques, was used. Three different alternative suppliers were examined and the most suitable one among them was tried to be determined.

Şişman [9] made the selection and assessment of green supplier development programs. In this context, the criteria that will enable the assessment of green supplier development programs with the nominal group technique have been determined first. The specified criteria were determined as cost, manufacturing output, resource use, quality, technology, environmental design, environmental management system, green image, green purchasing, reverse logistics, manufacturing and use. Then, the fuzzy MOORA method, one of the multi-criteria decision-making techniques, was used to rank and assess alternative programs.

Çalık [10] carried out an application to select the best green supplier among five alternative suppliers by using fuzzy multi-objective linear programming and interval type 2 FAHP method. Within the scope of the study, a manufacturing manager, an academician, and an industrial engineer were first selected and this three-person committee determined the five criteria to be used in practice. These criteria are cost, late delivery, carbon dioxide emission, pollution generation, and the use of environmentally friendly materials. In order to determine the weights of the criteria, interval type 2 FAHP method was used. In the ranking of alternative green suppliers, fuzzy multi-purpose linear programming method was used.

Akın [11] addressed the green supplier selection problem and used the generalized trapezoidal fuzzy flexible sets method to solve this problem. The green supplier selection problem has four criteria and these are service level, quality, price, and environmental management systems. There are a total of eleven suppliers assessed within the scope of the study, of which three are palm oil suppliers, three are sunflower oil suppliers, four are olive oil suppliers and one is a soybean oil supplier. While choosing the best green supplier, it was decided to determine the most suitable supplier for each oil type.

Erbıyık et al. [12] carried out the most appropriate green supplier selection application in the automotive industry by using the electre method in their study. The criteria for the selection of green suppliers are determined as quality competencies, engineering competencies, green logistics management, cost performance, and management strategies. The SWARA method was used to determine the weights of the criteria. Three alternative suppliers were ranked using the Electre method.

Soyer and Türkay [13] made an application in the white goods industry within the scope of their study. The subject of the application is the selection of green suppliers and the criteria have been determined first in order to make the selection of green suppliers. These criteria are green competencies, environmental effectiveness, organizational factors, costs, and green image. The criteria were determined by a team of fourteen experts, which includes four production managers, one purchasing manager, four quality specialists, four production staff, and one purchasing specialist. The Analytical Network Process (ANP) method was used both in determining the weights of the criteria and in assessing the two alternatives.

Yerlikaya et al. [14] discussed the supplier selection problem based on environmental waste criteria in their study. The problem consists of four alternative suppliers and five criteria. These criteria are the cost, the percentage of returns, the proportion of chemical waste, the demand, and the percentage of delay in delivery. The entropy method was used to determine the weights of the criteria. In order to determine how much purchase will be made from each supplier, a fuzzy multi-purpose linear programming approach was used.

Çalık [15] conducted a study on the implementation of green supplier selection in the food industry. Nine criteria have been determined within the scope of the application and these criteria are the ratio of cost to price, quality, delivery, technology ability, environmental management system, pollution control, environmental ability, air emissions, and energy consumption. The best worst method, entropy method, and CRITICAL method were used to obtain the criterion weights. The five alternative suppliers were ranked using the COPRAS, WASPAS, and MABAC methods.

Madenoğlu [16] discussed the problem of green supplier selection for a business that produces furniture. The relevant problem includes five criteria and three suppliers. The criteria are determined as cost, quality, delivery, technical and green criteria. The Fuzzy SWARA method was used to determine the weights of the criteria. In the ranking of suppliers, fuzzy TOPSIS, fuzzy VIKOR, fuzzy gray relational analysis, and fuzzy ARAS methods were used. A green supplier ranking was performed with each of these methods, and the most suitable supplier turned out to be the same in all four methods.

Lee et al. [17] developed a model for green supplier selection. Firstly, the criteria for the selection of classical suppliers and green suppliers were differentiated using the Delphi method, and the criteria for the selection of green suppliers were determined. These criteria are quality, technology compatibility, total product life cycle cost, green image, pollution control, environmental management, green production, and green competition. For the selection of the most suitable green supplier, the fuzzy extended AHP method was used.

Hashemi et al. [18] proposes a model for selecting green suppliers. While the proposed model uses the ANP approach to determine the criterion weights, it uses the gray relational analysis method in the supplier selection phase. To illustrate how the model works, an exemplary problem in the automotive industry is considered. In addition, the criteria determined for the selection of green suppliers are collected under the main headings of economic criteria and environmental criteria.

Bali et al. [19] proposed an integrated approach for the selection of green suppliers in their study. This approach incorporates intuitionistic fuzzy sets and gray relational analysis methods. The proposed approach was applied to a numerical example. It includes five alternative suppliers and eight assessment criteria. The criteria were determined as service quality, green image, use of green materials, waste control in production, green product, distribution, reverse logistics, green design-research and development.

Yu and Hou [20] made an application on the green supplier selection problem in an automobile manufacturing company. Four main criteria have been determined in order to assess the five alternative suppliers within the scope of the problem. These criteria are product performance, supplier criterion, cooperation and development potential, and green performance. The modified multiplicative AHP method was used for the assessment of suppliers. In addition, the assessment of suppliers was carried out by the classical AHP method, and the results obtained from both methods were compared.

Freeman and Chen [21] conducted a study using the AHP method, entropy method and TOPSIS method for the selection of green suppliers. Five alternative suppliers were assessed in terms of five main criteria. The main criteria were determined as cost, green competition, quality, delivery schedule, and environmental management performance. The AHP method and entropy methods were used to determine the weights of the criteria. In the process of assessing the alternatives, the TOPSIS method was used.

However, a limited number of studies are available regarding the green supplier assessment [22-26]. On the other hand, no study was found in which a fuzzy expert system model was created based on green production technology, environmental management system, pollution control, product cost, delivery time and quality criteria in order to make a green supplier assessment. Therefore, it can be easily said that this study will be the first research attempt within the framework of this subject. In addition, this study will make a significant contribution to the relevant literature.

3. DEVELOPED FUZZY EXPERT SYSTEM MODEL

The fuzzy expert system is a hybrid artificial intelligence (AI) technique that combines fuzzy logic and expert system methods. Thus, the possibility of combining the advantages of fuzzy set theory with the inference ability of the expert system arises. The working procedure of the fuzzy expert system is shown schematically in Figure 2.

The first step of the fuzzy expert system model developed within the scope of the study is to determine the input and output variables. For this purpose, the opinions of a team of six experts on purchasing and GSCM and the studies in the literature were taken as a basis. As a result, green production technology, environmental management system, pollution control, product cost, quality, and lead time were determined as input parameters. The output parameter is determined as the green supplier assessment score.

The general structure of the developed fuzzy expert system is shown in Figure 3.

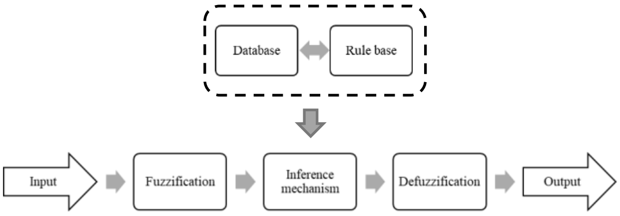

Figure 2. The working procedure of the fuzzy expert system

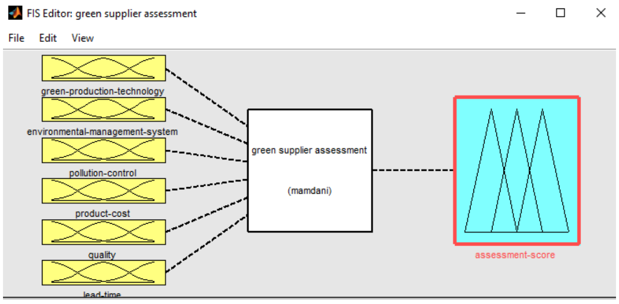

Figure 3. The general structure of the developed fuzzy expert system

Then, fuzzy sets and membership functions of each variable were determined according to the opinions of the expert team. Triangular and trapezoidal membership functions were used as membership functions. The fuzzy sets of the variables are shown in Table 1, and the mathematical representation of the membership functions is as follows:

$$\mu(X_i) = \begin{cases} 0 & , x \leq a_1 \text{ and } x \geq a_3 \\ \frac{x-a_1}{a_2-a_1} & , a_1 < x \leq a_2 \\ \frac{a_3-x}{a_3-a_2} & , a_2 < x < a_3 \end{cases} \quad (1)$$

$$\mu(X_i) = \begin{cases} 0 & , x \leq a \text{ and } x \geq d \\ \frac{x-a}{b-a} & , a < x < b \\ 1 & , b \leq x \leq c \\ \frac{d-x}{d-c} & , c < x < d \end{cases} \quad (2)$$

Afterward, the rule base of the developed fuzzy expert system model has been established by taking into account the expertise of the relevant team. Four input variables have two fuzzy sets. The two input variables have three fuzzy sets each. Therefore, there are a total of 2^4 x 3^2 = 144 rules in the rule base. Different methods can be used as an inference mechanism. These are methods Mamdani, Sugeno, Tsukamoto, Larsen, Şen, Zadeh, Dines-Rescher, and Gödel [27]. Mamdani approach was used as the inference mechanism in the model, depending on the type of information modeling. Thus, the output of the model will be included in a fuzzy set.

Table 1. The fuzzy sets of the variables

Variable	Range	Fuzzy set
Green production technology	0 1	No Yes
Environmental management system	0 1	No Yes
Pollution control	0 1	No Yes
Product cost	0-40 30-70 60-100	Low Medium High
Quality	0-40 30-70 60-100	Low Medium High
Lead time	0 1	Delayed In-time
Assessment score	0-36 5-40 14-86 60-95 64-100	Very low Low Medium High Very high

It is necessary to defuzzificate the fuzzy values obtained as a result of inference mechanism. This is done in the defuzzification interface. In this interface, fuzzy values are converted to net values by using the center of gravity method. Finally, the obtained value is the output of the model and gives the assessment score of the green supplier.

4. RESULTS AND DISCUSSION

The surface view of the developed fuzzy expert system model is available in Figure 4.

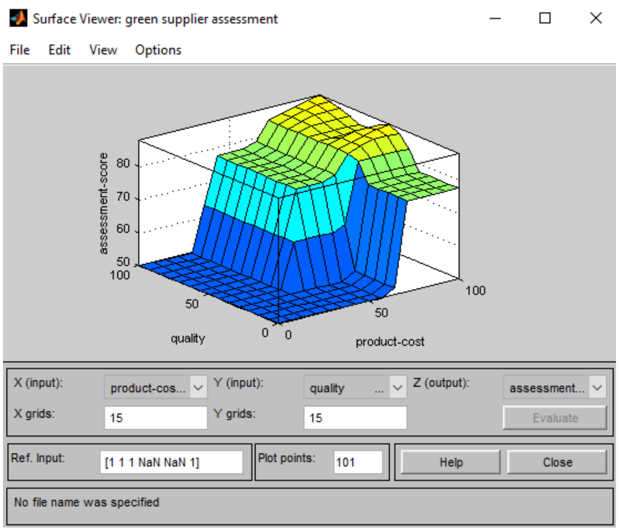

Figure 4. Surface viewer for product cost and quality variables

This surface view shows the impact of quality and product cost variables on the supplier assessment score. Both the quality variable and the product cost variable have a positive relationship with the supplier assessment score. In other words, increasing the value of both variables increases the supplier assessment score.

In order to test the performance of the model, a green supplier assessment of 32 different suppliers was made. A sample of these assessment data is given in Table 2.

Table 2. A small example of the data set

No	GPT	EMS	PC	PCost	Quality	LT	ASM	ASE
1	1	1	0	70	65	1	77.1	77
2	0	1	1	80	45	0	70	70
3	1	0	1	55	70	1	62.6	63
…	…	…	…	…	…	…	…	…
15	1	0	0	85	50	0	53.3	53
16	1	1	1	20	95	0	58.7	59
17	0	1	0	30	25	1	38.9	39
…	…	…	…	…	…	…	…	…
30	1	1	1	85	80	0	86.8	87
31	1	0	1	65	35	0	45	45
32	0	0	1	40	15	0	20.1	20

GPT: Green Production Technology, EMS: Environmental Management System, PC: Pollution Control, PCost: Product Cost, Quality: Quality, LT: Lead Time, ASM: Assessment Score of the Model, ASE: Assessment Score of the Experts

MSE error type was used to measure the error in green supplier assessment. The formula for this method is as follows:

$$MSE = \frac{1}{n}\sum_{t=1}^{n}(At - Ft)^2 \quad (3)$$

While F_t refers to the estimated value, A_t refers to the actual value. When these definitions are associated with the study, the value obtained from the model is called Ft. A_t is the assessment score of the experts. Additionally, this value represents the average score of the experts. As a result of the calculation made with the available data, the MSE value was found to be 0.0481. In other words, the performance of the developed fuzzy expert system model was determined as 95.19%. In addition, regression analysis was performed to confirm the high prediction performance. The information regarding this analysis is given in Figure 5.

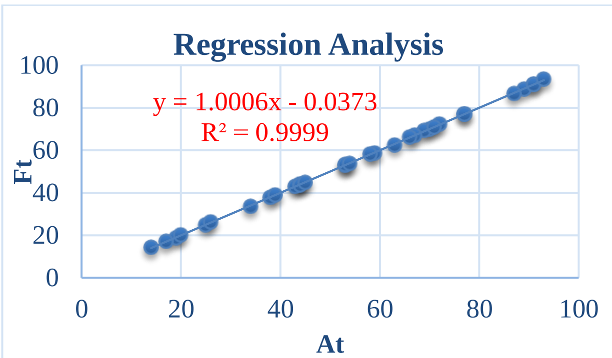

Figure 5. Regression analysis of the developed model

As a result of the regression analysis, the coefficient of determination (R^2) was calculated as 0.999. This value shows that the developed fuzzy expert system model represents the expertise of the experts in the green supplier assessment quite well.

5. CONCLUSION

This study aims to develop a fuzzy expert system model to perform green supplier assessment. In this context, a team of experts in green supplier assessment has been established. As a result of the expert knowledge of this team and the examination of the studies in the literature, the input variables of the fuzzy expert system model were determined as green production technology, environmental management system, pollution control, product cost, quality, and lead time. The output variable of the model is the green supplier assessment score. MSE and R^2 are calculated to measure the performance of the model. The calculated MSE and R^2 values showed that the developed fuzzy expert system model has a very high performance. Especially in cases where experts in green supplier assessment are limited or difficult to reach, the relevant model will be an important tool for fast and accurate decision making.

AI-driven green supplier assessment will require improving explainable AI for transparent decision-making, integrating the internet of things for real-time environmental monitoring, addressing ethical concerns, ensuring global standardization, and exploring collaborations between humans and AI. Future studies are expected to show a trend in this context.

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