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Fuzzy Trapezoidal DEMATEL Method for Criteria Weights in Supplier Selection: A Case Study of Ice Cream Producer

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Abstract

Supplier selection is one of the most critical processes in the food industry. The requirement for manufacturers to work with different suppliers for many materials often requires them to plan their supply systems separately. Supplier selection in the food industry is one of the multi-criteria decision-making problems that food businesses need to evaluate many qualitative and quantitative criteria. The study aims to determine the criteria weightings that affect the supplier selection decision for the auxiliary materials of an ice cream producer company. It is expected that the study's findings will contribute to manufacturers with similar procurement processes by presenting a procedure that they can refer to in the supplier selection decision. In practice, seven criteria to guide supplier selection were evaluated by three experts with the Fuzzy-Trapezoidal DEMATEL method. The study identifies quality as the criterion with the highest weight, while also highlighting procedures compliance and a good supplier profile as other essential criteria.

Keywords: Supplier Selection, Ice cream industry, Auxiliary foods, Fuzzy-Trapezoidal DEMATEL, Fuzzy DEMATEL

JEL Codes: L21, L66, M11

1. Introduction

Suppliers are a vital element of any supply chain. Suppliers' performance directly or indirectly affects the activities of the businesses. Suppliers' failure results in negative consequences throughout the entire supply chain. On the contrary, the successful performance of suppliers can also increase the efficiency of businesses. However, an effective supply chain adds value to businesses in many ways (Taherdoost & Brard, 2019). For this reason, the managers should plan the evaluation of suppliers in detail.

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Deciding on supplier selection is one of the essential issues that both industries and academies are interested in. It has a wide working area due to many parameters in supplier selection, changing situations in different sectors, and the priorities of enterprises. It will not be possible to talk about the existence of a single model for determining supplier selection in line with fixed criteria. For this reason, many researchers have studied this subject. One of the essential fields of study in this regard is food supply chains. Suppliers often play a vital role in food supply chains. A mistake in supplier selection can cause the business to face many problems.

It has been stated for a long time that the studies on supplier selection in the food sector are in the minimal area (Banaeian et al., 2015; Ada, 2022; Yazdani et al., 2022). The food industry is one of the most essential industries in the world, but there is no reference supplier selection procedure for food manufacturers (Başaran & Çakir, 2021). Proper planning by suppliers is crucial, especially considering the perishable nature of food products. For this reason, the gap in the relevant subject reveals the necessity of studying in this field. Since the food sector is huge, studies for different product groups in different sectors will support the literature.

The current paper contains the actual supply chain problems of an ice cream producer company. The increase in ice cream consumption and production has been effective in the rapid development of the sector. In this study, a producer in the food industry needs to review its supplier decisions with the growth of the problems related to the supply of auxiliary materials. The product group that is the subject of the study does not originate from the primary raw material of the ice cream producer. Depending on the product content, the company faces challenges in sourcing auxiliary food materials such as hazelnuts, peanuts, almonds, etc. Problems with the supply of auxiliary materials make it difficult to produce the final product, despite the completeness of other materials. In this study, this paper aims to determine the weights of criteria that guide the selection of suppliers that will provide maximum benefit to the ice cream producer.

The study findings reveal the evaluation of criteria that will facilitate the supply of auxiliary materials for producers in complex industries such as the food industry. It is expected that this study will contribute to both the literature and practitioners. The fact that the ice cream industry in which the case study took place has not been studied before is also a significant opportunity. The fact that the ice cream industry has not been studied by researchers before is an essential opportunity for this study. The ice cream sector has become one of the fastest-growing sectors in our country, with consumption being in all seasons. Another contribution of the study is in terms of method. The Trapezoidal Fuzzy DEMATEL Method was used in this study. As far as is known, the use of the trapezoidal fuzzy DEMATEL method in evaluating supplier selection is the first attempt.

The first section of this study provides a theoretical background on supplier selection in the food supply chain in recent years. The second section provides information on the fuzzy-trapezoidal DEMATEL method. The third section of the study includes the application and study findings. The last section includes the evaluation of the application results.

2. Recent Studies on Supplier Selection in the Food Supply Chain

The supplier selection literature has a wide field of study. Initial studies have been the guide for many subsequent studies. Researchers often transform the criteria according to their field of study and include time-changing situations in their processes. The decision-makers of the companies make the selection of the best supplier by considering many criteria. The criteria are the most crucial issue in the supplier selection decision. In this section, it provides information on some studies on supplier selection, focusing on food suppliers. Theoretical support thus provides a foundation for this study.

The complexities of the sector limit the study of the subject of supplier selection in the food sector (Yazdani et al., 2022). Since food supply chains are directly related to human health, they are supervised by many organizations. For this reason, food producers have much more responsibilities. Consumers, whose awareness is increasing daily, are also interested in the quality of products, safety, traceability, production methods, packaging methods, hygiene, and other standards. Food manufacturers must take into account various parameters to meet consumer expectations. Researchers have worked with very different parameters related to the subject. One of the essential reasons for this is that the food sector has a vast variety.

The literature on supplier selection criteria spans multiple dimensions. In particular, quality, cost, delivery, and service criteria have been studied frequently. Minimal documents published in recent years regarding supplier selection in the food sector have been reached. Başaran and Çakir (2021) conducted a study on the supply of dairy products, evaluating packaging suppliers with the Complex Proportional Assessment-F (COPRAS-F) method in terms of twelve criteria. They were quality, cost, service, delivery, technical position, general perception, supplier audit performance, environmental issues, food safety, social responsibility, occupational health, and halal perspective.

Ada (2022) analyzed the criteria for sustainable supplier selection with the Fuzzy Analytical Network Process (F-ANP). She evaluated supplier selection in an agri-food company with the fuzzy VIKOR (VIseKriterijumsa Optimizacija I Kompromisno Resenje) method. Ada (2020) used economic, social, and environmental sustainability criteria. Ikinci and Type (2022) used the Analytical Hierarchy Process (AHP) to determine supplier selection criteria and select the most suitable supplier in the catering industry. They used crisis management, quality, payment condition, reliability, cost, experience, and green production criteria in the study. Thanh and Lan (2022) used the Fuzzy Analytical Hierarchy Process (FAHP) method and Combined Compromise Solution (CoCoSo) to create a model for supplier selection of an additive in the food processing industry. The criteria used in the study were designed from an economic, environmental, and social perspective to include all three aspects of sustainability.

Leong et al. (2022) used seven criteria to evaluate suppliers in a food business: quality, delivery time, cost, flexibility, visibility, responsiveness, and financial stability. These criteria were evaluated with BWM by five experts. As a result of the study, Leong et al. (2022) determined cost, financial stability, visibility, responsiveness, flexibility, lead time, and quality in order of importance. Kazançoglu et al. (2022) conducted a study to determine the supplier selection criteria for the sustainable supply chain in the food sector and to decide the most appropriate supplier. In this study, researchers analyzed criteria with BWM, and supply chain visibility was the most essential criterion, while also recognizing environmental responsibilities and competencies as other critical criteria.

Hajiaghaei-Keshteli et al. (2023) studied the selection of a new green supplier for food business packaging operations. They used the Pythagorean Fuzzy Technique for Order Preference by Similarity to Ideal Solution TOPSIS (PF-TOPSIS) method to select the best supplier. They used many criteria such as service, environmental requirements, price, quality, production, eco-design, green image, environmental management system, waste system, social concern, pollution control, environmentally friendly materials, resource consumption, and logistics. Magableh (2023) studied to evaluate primary wheat suppliers according to the criteria of quality, expenditure, delivery, sourcing, flexibility, communication, and reliability. A few experts evaluated the criteria. According to the highest weight value, the criteria were quality, expenditure, resource, and reliability.

3. Method

Researchers have used various criteria weighting methods in addressing supplier selection problems. Best Worst Method (BWM) (Afrasiabi et al., 2022; Leong et al., 2022), Decision Making Trial and Evaluation Laboratory (DEMATEL) (Göncü & Çetin, 2022; Sumrit & Jiamanukulkij, 2022), and Step-wise Weight Evaluation Rate Analysis (SWARA) (Tus & Adali, 2022; Xie et al., 2022) have been studied in this regard. Also, many researchers used TOPSIS (Modibbo et al., 2022), ANP (Wang et al., 2022), and AHP (Dang et al., 2022; Lahdhiri et al., 2022). There are applications of the subject in the food industry. Validi et al. (2014) used TOPSIS and Genetic algorithm for supplier selection problems in daily food production. Lau et al. (2018) used AHP, TOPSIS, and Elimination and Choice Translating Reality English (ELECTRE) for the supplier selection problem in the fresh food sector. In the criterion selection problem, Banaeian et al. (2015) used Delphi, AHP, and Grey Incidence Analysis (GIA) and Banaeian et al. (2018) used TOPSIS, VIKOR, and GRA methods in the study.

In this study, the DEMATEL was used for criterion weighting. DEMATEL has become a less used method in supplier selection for food businesses compared to other multi-criteria decision-making methods. Shen et al. (2012), Ramadhani & Dachyar (2018), and Zhang et al. (2021) used the DEMATEL method in their studies. Also, Singh et al. (2018) used the Fuzzy DEMATEL.

One of the reasons for preferring the DEMATEL method in the study is that more than one criterion needs to be evaluated by more than one decision-maker. However, many other multi-criteria decision-making methods can achieve this goal. There is a more realistic reason to prefer the DEMATEL method. The DEMATEL method was especially preferred to have indirect or direct relationships among the criteria in this study and to reveal the effects of these relationships. The DEMATEL method was used together with fuzzy logic due to some uncertainties in the application and linguistic evaluations of the decision-makers. In practice, it was studied with the Trapezoidal Fuzzy DEMATEL method. Trapezoidal fuzzy sets make an essential contribution to solving uncertainty problems.

The Battelle Memorial Institute, Geneva Research Center, implemented the DEMATEL method as a project (Gabus & Fontela, 1972). The method is a multi-criteria decision-making method that reveals the relationships between criteria. The DEMATEL method divides the criteria into two parts. The DEMATEL method divides the factors that will enable us to understand the causal relationship into cause and effect groups. This stage will make it easier to solve problems. It is crucial to determine which criteria belong to the cause group and which belong to the effect group. Criteria with a higher impact level are categorized as causal criteria, while criteria with lower priority and impact level are classified as outcome criteria

The fuzzy DEMATEL method is one of the multi-criteria decision-making methods used in uncertain situations. The method analyzes the interrelationships between factors in various domains of uncertainty (Zhang et al., 2023). In fuzzy DEMATEL, researchers express the interaction between criteria in linguistic terms and their corresponding fuzzy numbers (Sathyan et al., 2023). The method can evaluate the relationships between factors and find the most influencing factor through the visual structure mode (Gedam et al., 2021).

The fuzzy DEMATEL method has been used in recent years to determine the strategic priorities for nuclear energy investments (Yüksel & Dinçer, 2022), to solve the supplier selection problem in sustainable supply chain management (Gri et al., 2022), to prioritize the barriers to adoption of the circular economy (Govindan et al., 2022), to determine the factors affecting the effective implementation of green human resource management (Rajabpour et al., 2022), to examine the impact of Industry 4.0 technologies on production strategy outputs (Dolatabad et al., 2022). Also the method has been used to develop a multi-featured model for the selection of construction program manager (Yan et al., 2023), to identify the key elements that ensure the responsiveness of the automotive supply chain (Sathyan et al., 2023), to investigate the difficulties encountered in choosing the human resources practices of newly established companies (Priyanka et al., 2023), to determine financial resilience measurement indices and classification (Zahedi et al., 2023).

The analytical procedure of the Fuzzy Trapezoidal DEMATEL method is explained as follows to increase the practicality of decision-makers in making group decisions in the case of fuzzy (Saraswathi, 2019; Eroğlu & Gencer, 2021).

Step 1: Determining the criteria and detecting fuzzy linguistic expressions. These are the fuzzy numbers such as triangles and trapezoids.

Step 2: Constructing the fuzzy direct relation matrix ($\tilde{z}$). Evaluation factors have causal relationships, and decision-makers establish meaningful connections between these factors. The linguistic variable 'impact' is represented by positive trapezoidal fuzzy numbers (l_{ij}, m_{ij}, n_{ij}, and u_{ij}), as illustrated in Table 1. This step is important to deal with uncertainties in the evaluations of decision-makers.

Step 3: Obtaining the mean direct relationship matrix. The average of the values in the matrices obtained for each decision-maker is taken and the average fuzzy direct relationship matrix (C) showing the decision-makers is obtained.

Step 4: Generating the normalized fuzzy direct relation matrix. All trapezoidal fuzzy numbers in the fuzzy direct relation matrix are normalized by dividing by the highest number value of their block using Equation (1) and Equation (2). As a result, since all cell elements have values between 0-1, a normalized fuzzy direct relationship matrix $\tilde{C}$ is obtained.

$$\tilde{C}=\frac{\boldsymbol{c}}{\boldsymbol{rj}}=(\frac{l_{ij}}{r_l},\frac{m_{ij}}{r_m},\frac{u_{ij}}{r_u}) \tag{1}$$

$$r_l = 1 \leq j \leq n \ ^{max}(\sum_{n=1}^{H} l_{ij})$$
$$r_m = 1 \leq i \leq n \ ^{max}(\sum_{n=1}^{H} m_{ij}) \tag{2}$$
$$r_n = 1 \leq i \leq n \ ^{max}(\sum_{n=1}^{H} n_{ij})$$
$$r_u = 1 \leq i \leq n \ ^{max}(\sum_{n=1}^{H} u_{ij})$$

Step 5: Constructing the fuzzy sum relationship matrix ($\widetilde{F}$). In this step, the cluster sets that make up the normalized fuzzy total relationship matrix are converted to the total relationship matrix by applying Equation 3 and Equation 4 equations.

$$\lim_{n\to\infty} \widetilde{C} + \tilde{C}^2 + \tilde{C}^3 \dots + \tilde{C}^n \tag{3}$$

$$\tilde{F} = \sum_{n=1}^{\infty} \widetilde{C} = \widetilde{C}\,(1 - \widetilde{C})^{-1} \tag{4}$$

"I" is the unit matrix of size n*n. The obtained matrices are combined into a single matrix, and a fuzzy sum relation matrix consisting of trapezoidal fuzzy numbers is obtained.

Step 6: Simplifying. The fuzzy set sets that form the fuzzy sum relationship matrix ($\widetilde{F}$) reached in the 5th step are simplified. Equation (5) is applied to convert values to a single number.

$$X_{ij} *= \frac{\int_{x\,min}^{x\,max} \mu Ax\, dx}{\int_{x\,min}^{x\,max} \mu A\, x\, dx} = \frac{\left(n_{ij}^2 + u_{ij}^2 + n_{ij}u_{ij}\right) - \left(l_{ij}^2 + m_{ij}^2 + l_{ij}m_{ij}\right)}{3[\left(n_{ij} + u_{ij}\right) - (l_{ij} + m_{ij})]} \tag{5}$$

Step 7: Determining the relationship between the criteria. This step is the stage of determining which criterion is more affected and influential. The row (R_j) and column (C_j) sums of the clarified fuzzy sum relationship matrix are obtained. While R_j shows the sum of the direct or indirect effects sent by a factor to other factors, the sum of the effects on the same factor from other factors is shown as Cj. The sum and difference of these vectors are calculated. The factor with the highest total value has the most vital relationship with other factors. Factors with a positive difference between row and column totals exert a significant impact on other factors.

Step 8: Determining the final criteria weights. For this, the square of (R_j + C_j) is taken as the root of the sum of the square of (R_j - C_j) Equation (6), and each weight is divided by the total value of the weight Equation (7).

$$W_i = \left[\left(R_j + C_j\right)^2 + \left(R_j - C_j\right)^2\right]^{1/2} \tag{6}$$

$$W_i = \frac{\mathrm{w_i}}{\Sigma \mathrm{w}_i} \tag{7}$$

4. Implementation

This application is an actual case study. This application is based on the problems in the supply of auxiliary materials for the ice cream producer company. The manufacturer company has encountered problems such as mold-related deterioration because the products are damp and airless in the materials coming from their suppliers. In addition, the ice cream producer company encountered products with a shorter lifespan by looking at the production time and storage conditions of the products supplied. These problems with the supplier led to the disruption of the ice cream producer's production plans. Thus, production was significantly disrupted in some cases. For this reason, the producer must seek out new suppliers based on specific criteria. This research focuses on determining the criteria for supplier selection and establishing the order of importance for these criteria.

4.1. Identification of Decision Makers

Each of the decision-makers in the study consists of experts who are experienced in the food sector. In the study, three decision-makers participated in a problem-oriented application. In the study, it was especially preferred to select researchers from different departments. Although it may seem that the supplier decision is the responsibility of the purchasing department, it is a necessary process involving people from many departments. The decision-makers work full-time in the ice cream manufacturer's production department or purchasing department.

One of the decision makers is a woman, who has been working in this company for four years as a purchasing specialist. Another decision maker is male and has been working as a purchasing manager for five years. He has more than twenty years of work experience in the food industry. In addition, this purchasing manager is actively engaged in supply chain projects. The final decision maker of the study is responsible for on-site production depending on the production department and has more work experience in this company than other decision-makers. He has been working in his department for six years.

4.2. Determination of Criteria

It can be stated that there are many criteria because supplier selection problems take place a lot in the literature. In the study, the criteria were determined by conducting a literature search. Then, these criteria were reduced to seven criteria by interviewing the decision-makers. These criteria are shown in Table 1. Decision-making experts have shaped the criteria based on the problems they have experienced with their suppliers in their production system. However, it should be known that these criteria may vary according to the sector, the working area of the enterprise, the size of the enterprise, and the types of materials.

Table 1. Selection Criteria and Explanations

No	Criteria	Description
1	Cost	Unit price of the product, price stability
2	Quality	Product shelf life, hygiene
3	Delivery	Delivery speed, compliance with the delivery schedule
4	Procedures compliance	Food safety management system, traceability system, disciplinary practices
5	Packaging capability	Keeping the product intact
6	Geolocation	Distance between supplier and manufacturer
7	Supplier profile	Reliability, references, financial stability

Although quality, cost, and delivery are used extensively in the literature, packaging capability, and procedures compliance are particularly essential for this study.

4.3. Results

Reaching the study findings involved following these steps:

Step 1: The criteria in the study were determined, and fuzzy expressions were created. A trapezoidal fuzzy set (Table 2) was used in this study.

Table 2. The Trapezoidal Fuzzy Linguistic Scale

		Trapezoidal fuzzy numbers			
Linguistic terms	**Influence score**	l_{ij}	m_{ij}	n_{ij}	u_{ij}
No Impact (N)	0.000	0.00	0.00	0.00	0.00
Very low (VL)	0.125	0.00	0.00	0.25	0.25
Low (L)	0.1875	0.00	0.00	0.25	0.50
Medium (M)	0.3750	0.00	0.25	0.50	0.75
High (H)	0.6250	0.25	0.50	0.75	1.00
Very high (VH)	0.8125	0.50	0.75	1.00	1.00

Step 2: In the study, the decision-makers (E_n) evaluated n number of criteria, and they designed a fuzzy language scale (Table 3).

Table 3. Evaluation by Decision-Makers (E_n)

				E_1									E_2									E_3		
	C_1	C_2	C_3	C_4	C_5	C_6	C_7		C_1	C_2	C_3	C_4	C_5	C_6	C_7		C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	*	H	M	M	H	N	L	C_1	*	M	H	H	L	N	L	C_1	*	H	H	M	M	N	L
C_2	VH	*	L	H	M	N	VH	C_2	H	*	L	H	L	N	VH	C_2	VH	*	VL	VH	L	N	VH
C_3	L	H	*	VL	N	N	H	C_3	VL	H	*	N	N	N	VH	C_3	VL	M	*	N	N	N	H
C_4	H	VH	H	*	H	N	VH	C_4	H	VH	H	*	H	N	H	C_4	H	VH	VH	*	H	N	VH
C_5	H	VH	H	M	*	N	M	C_5	VH	H	M	L	*	N	L	C_5	H	VH	M	L	*	N	L
C_6	H	M	VH	N	H	*	VL	C_6	H	M	VH	N	H	*	VL	C_6	H	M	H	N	H	*	M
C_7	M	H	H	H	M	N	*	C_7	H	H	H	H	L	N	*	C_7	VH	H	H	H	L	N	*

Table 3 shows the criteria evaluation results of three decision-makers. For example, Expert 1 (E_1) and Expert 3 (E_3) saw the cost criterion (C_1) as high impact compared to the quality criterion (C_2), while Expert 2 (E_2) saw it as medium impact. A striking situation in the table is that any criteria are effective on the geographical location criterion. Accordingly, it is marked as "no impact" in the table. In the next step, the linguistic variables of Table 3, which are formed by the evaluations of each expert, should be converted into trapezoidal fuzzy numbers. To achieve this, each decision-maker contributed to the creation of fuzzy direct relationship matrices through their evaluations.

Table 4. Expert 1's Fuzzy Direct Relationship Matrix

E_1	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.25, 0.50,0.75)	(0.00,0.25, 0.50,0.75)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25,0.50)
C_2	(0.50,0.75, 1.00,1.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25, 0.50)	(0.25,0.50, 0.75,1.00)	(0.00,0.25, 0.50,0.75)	(0.00,0.00, 0.00,0.00)	(0.50,0.75, 1.00,1.00)
C_3	(0.00,0.00, 0.25,0.50)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00, 0.00)	(0.00,0.00, 0.25,0.25)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)
C_4	(0.25,0.50, 0.75,1.00)	(0.50,0.75, 1.00,1.00)	(0.25,0.50, 0.75, 1.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.50,0.75, 1.00,1.00)
C_5	(0.25,0.50, 0.75,1.00)	(0.50,0.75, 1.00,1.00)	(0.25,0.50, 0.75, 1.00)	(0.00,0.25, 0.50,0.75)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.25, 0.50,0.75)
C_6	(0.25,0.50, 0.75,1.00)	(0.00,0.25, 0.50,0.75)	(0.50,0.75, 1.00, 1.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25,0.25)
C_7	(0.00,0.25, 0.50,0.75)	(0.25,0.50, 0.75,1.00)	(0.25,0.50, 0.75, 1.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.25, 0.50,0.75)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)

Table 5. Expert 2's Fuzzy Direct Relationship Matrix

E_2	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	(0.00,0.00, 0.00,0.00)	(0.00,0.25, 0.50,0.75)	(0.25,0.50, 0.75,1.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.25,0.50)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25,0.50)
C_2	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25,0.50)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.25,0.50)	(0.00,0.00, 0.00,0.00)	(0.50,0.75, 1.00,1.00)
C_3	(0.00,0.00, 0.25,0.25)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.50,0.75, 1.00,1.00)
C_4	(0.25,0.50, 0.75,1.00)	(0.50,0.75, 1.00,1.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)
C_5	(0.50,0.75, 1.00,1.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.25, 0.50,0.75)	(0.00,0.00, 0.25,0.50)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25,0.50)
C_6	(0.25,0.50, 0.75,1.00)	(0.00,0.25, 0.50,0.75)	(0.50,0.75, 1.00,1.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25,0.25)
C_7	(0.25,0.50, 0.75,1.00)	(0.25,0.50, 0.75,1.00)	(0.25,0.50, 0.75,1.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.25,0.50)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00, 0.00)

Table 6. Expert 3's Fuzzy Direct Relationship Matrix

E_3	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.25, 0.50,0.75)	(0.00,0.25, 0.50,0.75)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25,0.50)
C_2	(0.50,0.75, 1.00,1.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25,0.25)	(0.50,0.75, 1.00,1.00)	(0.00,0.00, 0.25,0.50)	(0.00,0.00, 0.00,0.00)	(0.50,0.75, 1.00,1.00)
C_3	(0.00,0.00, 0.25,0.25)	(0.00,0.25, 0.50,0.75)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)
C_4	(0.25,0.50, 0.75,1.00)	(0.50,0.75, 1.00,1.00)	(0.50,0.75, 1.00,1.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.50,0.75, 1.00,1.00)
C_5	(0.25,0.50, 0.75,1.00)	(0.50,0.75, 1.00,1.00)	(0.00,0.25, 0.50,0.75)	(0.00,0.00, 0.25,0.50)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25,0.50)
C_6	(0.25,0.50, 0.75,1.00)	(0.00,0.25, 0.50,0.75)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.25, 0.50,0.75)
C_7	(0.50,0.75, 1.00,1.00)	(0.25,0.50, 0.75,1.00)	(0.25,0.50, 0.75,1.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.25,0.50)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)

Step 3: The mean fuzzy direct relationship matrices were created in line with the three matrices (Table 4, Table 5, and Table 6) obtained. To achieve this, the arithmetic average of the cluster sets was taken.

Table 7. Mean Fuzzy Direct Relationship Matrix ($\widetilde{C}$)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	(0.00,0.00, 0.00,0.00)	(0.167,0.417, 0.667,0.917)*	(0.167,0.417, 0.66,0.917)	(0.83,0.33, 0.583,0.833)	(0.083,0.25, 0.50,0.75)	(0.00,0.00, 0.00,0.00)	(0.00,0.083, 0.33,0.583)
C_2	(0.417,0.667 , 0.917,1.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.25,0.417)	(0.33,0.583, 0.833,1.00)	(0.00,0.083, 0.33,0.583)	(0.00,0.00, 0.00,0.00)	(0.50,0.75, 1.00,1.00)
C_3	(0.00,0.00, 0.25,0.333)	(0.167,0.417, 0.667,0.917)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.083,0.083)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.33,0.583, 0.833,1.00)
C_4	(0.25,0.50, 0.75,1.00)	(0.50,0.75, 1.00,1.00)	(0.33,0.583, 0.833,1.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.417,0.667 , 0.97,1.00)
C_5	(0.33,0.583, 0.833,1.00)	(0.417,0.667, 0.917,1.00)	(0.083,0.33, 0.583,0.833)	(0.00,0.083, 0.33,0.583)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.083, 0.33,0.583)
C_6	(0.25,0.50, 0.75,1.00)	(0.00,0.25, 0.50,0.75)	(0.417,0.667, 0.917,1.00)	(0.00,0.00, 0.00,0.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.00, 0.00,0.00)	(0.00,0.083, 0.33,0.417)
C_7	(0.25,0.50, 0.75,0.917)	(0.25,0.50, 0.75,1.00)	(0.25,0.50, 0.75,1.00)	(0.25,0.50, 0.75,1.00)	(0.00,0.083, 0.33,0.583)	(0.00,0.00, 0.00,0.00)	(0.00,0.00, 0.00,0.00)

*For example, this cell was created by taking the average of the data set in Table 4, Table 5, and Table 6. When the arithmetic average of (0.25,0.50.0.75,1.00), (0.00,0.25,0.50.0.75), and (0.25,0.50.0.75,1.00) cells is taken, (0.167,0.417,0.667,0.917) the data set was reached.

Step 4: Table 8 was obtained by applying Equation (1) and Equation (2) to the normalized fuzzy relationship matrix (Table 7). In this process, l_{ij}, m_{ij}, $n_{ij,}$ and u_{ij} matrices were created, and the row and column sums in these matrices were reached. Among these values, the maximum value was chosen and divided into each cell in Table 7. In Table 8, data were provided in four different ways: l_{ij}, m_{ij}, $n_{ij,}$ and u_{ij}. The main reason for this is the necessity of creating trapezoidal fuzzy set elements separately for the maximum value needed to apply Equation (1) and Equation (2).

Table 8. Normalized Fuzzy Matrix

l_{ij}	C_1	C_2	C_3	C_4	C_5	C_6	C_6
C_1	0.000	0.095	0.095	0.048	0.048	0.000	0.000
C_2	0.238	0.000	0.000	0.190	0.000	0.000	0.286
C_3	0.000	0.095	0.000	0.000	0.000	0.000	0.190
C_4	0.143	0.286	0.190	0.000	0.143	0.000	0.238
C_5	0.190	0.238	0.048	0.000	0.000	0.000	0.000
C_6	0.143	0.000	0.238	0.000	0.143	0.000	0.000
C_7	0.143	0.143	0.143	0.143	0.000	0.000	0.000
m_{ij}							
C_1	0.000	0.139	0.139	0.111	0.083	0.000	0.028
C_2	0.222	0.000	0.000	0.194	0.028	0.000	0.250
C_3	0.000	0.139	0.000	0.000	0.000	0.000	0.194
C_4	0.167	0.250	0.194	0.000	0.167	0.000	0.222
C_5	0.194	0.222	0.111	0.028	0.000	0.000	0.028
C_6	0.167	0.083	0.222	0.000	0.167	0.000	0.028
C_7	0.167	0.167	0.167	0.167	0.028	0.000	0.000
n_{ij}							
C_1	0.000	0.148	0.148	0.130	0.111	0.000	0.074
C_2	0.204	0.000	0.056	0.185	0.074	0.000	0.222
C_3	0,056	0.148	0.000	0.019	0.000	0.000	0.185
C_4	0,167	0.222	0.185	0.000	0.167	0.000	0.204
C_5	0.185	0.204	0.130	0.074	0.000	0.000	0.074
C_6	0.167	0.111	0.204	0.000	0.167	0.000	0.074
C_7	0.167	0.167	0.167	0.167	0.074	0.000	0.000
u_{ij}							
C_1	0.000	0.164	0.164	0.149	0.134	0.000	0.104
C_2	0.179	0.000	0.075	0.179	0.104	0.000	0.179
C_3	0.060	0.164	0.000	0.015	0.000	0.000	0.179

C_4	0.179	0.179	0.179	0.000	0.179	0.000	0.179
C_5	0.179	0.179	0.149	0.104	0.000	0.000	0.104
C_6	0.179	0.134	0.179	0.000	0.179	0.000	0.075
C_7	0.164	0.179	0.179	0.179	0.104	0.000	0.000

Step 5: The fuzzy sum relation matrix $(F)\tilde{}$ was obtained by applying Equation (3) and Equation (4) to the data in the normalized fuzzy relation matrix. To create this matrix, the trapezoidal fuzzy set elements obtained in Table 8 were re-formed into a matrix depending on the criteria. Then, this normalized fuzzy relationship matrix (Table 8) was subtracted from the unit matrix (I-$\tilde{C}$), and the inverse of the new matrix obtained was taken (I- $\tilde{C}$)$^{-1}$. Finally, the new matrix was multiplied by the normalized fuzzy matrix ((I- $\tilde{C}$)$^{-1}$*$\tilde{C}$) and Table 9.

Table 9. Fuzzy Total Relationship Matrix ($\widetilde{F}$)

	C_1	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**
C_1	(0.083,0.18, 0.261,0.319)	(0.175,0.331, 0.419,0.500)	(0.139,0.264, 0.358,0.452)	(0.099,0.237, 0.322,0.404)	(0.066,0.153, 0.25,0.345)	(0.00,0.00, 0.00,0.00)	(0.100,0.224, 0.337,0.417)
C_2	(0.416,0.465, 0.502,0.491)	(0.228,0.309, 0.361,0.375)	(0.169,0.237, 0.349,0.401)	(0.319,0.39, 0.428,0.448)	(0.065,0.153, 0.266,0.340)	(0.00,0.00, 0.00,0.00)	(0.459,0.477, 0.511,0.485)
C_3	(0.094,0.14, 0.239,0.256)	(0.174,0.265, 0.327,0.363)	(0.063,0.10, 0.159,0.191)	(0.076,0.121, 0.179,0.200)	(0.015,0.048, 0.106,0.145)	(0.00,0.00, 0.00,0.00)	(0.27,0.312, 0.349,0.356)
C_4	(0.404,0.489, 0.532,0.544)	(0.528,0.598, 0.612,0.591)	(0.346,0.436, 0.497,0.534)	(0.191,0.268, 0.312,0.337)	(0.189,0.284, 0.365,0.431)	(0.00,0.00, 0.00,0.00)	(0.50,0.537, 0.562,0.543)
C_5	(0.31,0.373, 0.44,0.471)	(0.334,0.413, 0.479,0.509)	(0.117,0.248, 0.356,0.439)	(0.099,0.191, 0.297,0.370)	(0.029,0.081, 0.16,0.226)	(0.00,0.00, 0.00,0.00)	(0.141,0.234, 0.351,0.413)
C_6	(0.221,0.34, 0.422,0.47)	(0.114,0.304, 0.403,0.472)	(0.290,0.359, 0.425,0.464)	(0.046,0.140, 0.217,0.269)	(0.16,0.233, 0.305,0.379)	(0.00,0.00, 0.00,0.00)	(0.099,0.221, 0.340,0.379)
C_7	(0.285,0.389, 0.455,0.497)	(0.301,0.429, 0.488,0.552)	(0.245,0.346, 0.42,0.501)	(0.241,0.341, 0.396,0.461)	(0.048,0.136, 0.25,0.349)	(0.00,0.00, 0.00,0.00)	(0.19,0.265, 0.319,0.360)

Step 6: Simplifying fuzzy set sets in the fuzzy total relationship matrix was applied with Centroid of Area, Center of Gravity, Equation (5), and Table 10.

Table 10. Simplified Matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1	0.209*	0.352	0.302	0.263	0.204	0.000	0.268
C_2	0.467	0.315	0.289	0.394	0.206	0.000	0.484
C_3	0.182	0.280	0.128	0.143	0.079	0.000	0.321
C_4	0.489	0.577	0.451	0.275	0.316	0.000	0.534
C_5	0.397	0.423	0.288	0.238	0.124	0.000	0.284
C_6	0.360	0.318	0.383	0.166	0.269	0.000	0.257
C_7	0.404	0.439	0.377	0.358	0.196	0.000	0.282

*For example, the value of C_1-C_1 cell was calculated as (0.261*0.261+0.319*0.319+0.261*0.319-0.083*0.083-0.18*0.18-0.083*0.18)/(3*0.261+3*0.319-3*0.0.83-3*0.18) = 0.209.

Step 7: Row (R_j) and column (C_j) sums showing the effect values of the clarified fuzzy sum relationship matrix were obtained.

Table 11. R_j and C_j Values

	Rj	Cj	$(R_j + C_j)$	$(R_j - C_j)$
C_1	1.598	2.508	4.106	-0.910
C_2	2.155	2.714	4.869	-0.560
C_3	1.133	2.218	3.351	-1.086
C_4	2.642	1.838	4.480	0.805
C_5	1.764	1.395	3.159	0.369
C_6	1.754	0.000	1.754	1.754
C_7	2.056	2.429	4.486	-0.373

Step 8: The criterion weights were obtained. Equation (6) and Equation (7) were used respectively in the study. At this stage, the values obtained in Table 11 were used. The values obtained as a result of applying Equation (6) $W_i = \left[\left(R_j + C_j\right)^2 + \left(R_j - C_j\right)^2\right]^{1/2}$ are shown in the W_i column of Table 12. Then, Equation (7) was applied by calculating the total weight value, and the final weight values were reached.

Table 12. Table of Criterion Weights

	W_i	w_j	Rank
C_1	4.206	0.154	4
C_2	4.901	0.179	1
C_3	3.522	0.129	5
C_4	4.552	0.166	2
C_5	3.180	0.116	6
C_6	2.480	0.091	7
C_7	4.501	0.165	3
$\sum$	27.342		

When examining Table 12, the weight values of many criteria are very close to each other. The criterion with the highest weight value is the quality criterion, with a value of 0.179. In other words, the quality criterion has a significance level of approximately 18% among the seven criteria in supplier selection. According to the results of the application, the weight values of the second and third most critical criteria are almost equal to each other. Based on this, these criteria are of equal importance. However, the second highest weighted criterion is procedures compliance, with a value of 0.166. Compliance with procedures is significant at approximately 17% of the seven criteria. The third highest weighted criterion with a weight value of 0.165 is to have a good supplier profile. The first three criteria with the highest weight constitute 51% of the supplier selection criteria.

The fourth highest weighted criterion is cost. The cost criterion determines 15.4% of the supplier selection decision. The cost criterion is the only economic criterion of this study, and this financial aspect has surprisingly not been seen as a top priority. Among the other criteria in selecting suppliers, delivery, packaging capability, and geolocation are determined in order of importance. The technological capability of the supplier affects the supplier selection decision with a rate of 9.17%. The distance of the suppliers to the manufacturing company affects the supplier selection decision with a rate of 9.17%. It has become the criterion with the lowest priority among all criteria with this ratio.

5. Evaluation and Discussion

Supplier selection is one of the most critical issues in almost all industries. A malfunction in the supply process can significantly limit the field of activity of the producers from time to time. This study is prepared for food producers who have problems supplying auxiliary materials.

This study aims to prioritize the criteria for selecting suppliers from whom an ice cream producer purchases auxiliary materials. The enterprise is more likely to correctly select the most accurate supplier according to the criteria weights included in the study findings. It can be stated that this application in the ice cream industry is one of the first attempts in the literature. In particular, the study findings are essential for manufacturers with problems with the quality and lifespan of the products they buy from suppliers.

The criteria in the study were initially derived through a literature review, and subsequently categorized into seven groups by the decision-makers. The criteria included in the study are cost, quality, delivery, compliance with procedures, packaging capability, geolocation, and supplier profile. Although criteria such as cost, quality, and supplier profile are frequently included in the literature, packaging capability and compliance with procedures are included in this study. These two criteria have been studied relatively less than the other criteria. Thus, the criteria have been shaped due to the difficulties experienced by the company in the case study.

This study, focused on the assessment of supplier selection criteria, constitutes a multi-criteria decision-making problem due to the multitude of criteria, and the necessity for expert evaluations. The evaluations made by the expert opinions were analyzed with the trapezoidal fuzzy DEMATEL method in multi-criteria decision-making methods. As far as is known, the trapezoidal fuzzy DEMATEL method has not been used in a study to determine any supplier selection criteria. For this reason, an essential contribution of the study has been in terms of method. This study has shown that the trapezoidal fuzzy DEMATEL method can be easily used in supplier problems.

Considering the study's findings, the criterion that most affected the supplier selection decision is "quality." One significant issue identified in the products supplied in the case study is the relatively short shelf life. The most significant indicator of shelf life is the quality of that product. For this reason, it is expected that the quality of the materials should be seen as one of the top priority criteria, and the study's findings support this. In addition, the quality of a supplied material is one of the critical factors affecting the quality of the final product. Another essential supplier selection criterion is the "compliance with production procedures" of the supplier companies. Compliance with the production procedures of food companies is a subject that is specially audited because it affects human health. For this reason, suppliers must comply with production procedures in line with specific rules. The ice cream producer has identified compliance with the supplier's food safety management systems as a top priority. On the other hand, "compliance with procedures" is one of the most decisive criteria, as the ability of the enterprise to follow its supplier increases its control over the supplier.

The third highest criterion affecting the supplier selection decision of the enterprise is the "supplier profile." According to this result, the ice cream producer company pays great attention to the reliability, financial stability, and references of the supplier in selecting the supplier. The supplier's relationship with other manufacturers can inform the potential situation. One of the surprising findings of the study is the significance of 'cost' as an economic criterion. Contrary to many studies, the cost criterion is not the primary criterion. The fact that the market is not very volatile is likely to have contributed to such an outcome. The sales price of auxiliary materials has a 15% effect on the supplier selection decision. The least influential criterion in the supplier selection decision is "Geolocation." The ice cream producer's proximity to the relevant industries probably has little effect on supplier selection.

These findings cannot be generalized for primary raw materials as they are prepared for the supply of auxiliary materials. If the study addresses an issue related to primary raw material suppliers, the findings are likely to vary. For this reason, the study emphasizes the supply of auxiliary materials. Finally, the findings of researchers with similar study areas on the supply of auxiliary materials in different sectors are also curious. In another, researchers can repeat the study by adding new criteria for businesses where sustainability is essential. In particular, including some environmental criteria in the study will increase the value of the study. Third, researchers can evaluate supplier selection criteria in different sectors due to the originality of the fuzzy trapezoidal DEMATEL method.

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