Supplier Selection with Fuzzy Analytical Hierarchy Process

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Abstract. Today, competition is increasing rapidly due to developments in technology. Firms should follow new methods in the process of the product from the producer to the consumer (Supply Chain) to maintain their place in the competition. For the continuation of a successful Supply Chain, long-term cooperation based on mutual trust and cooperation should be established between the supplier and the customer. Purchasing timely and quality raw materials from suppliers is the first step of this chain. If one of the supplier links is broken, the entire chain will be broken. As a result, business decisions on supplier selection are critical. The difficulty of supplier selection is complicated by several competing considerations. Cost, quality, design capability, manufacturing competence, technical capability, technological capability, performance history, managerial capability, degree of collaboration, financial performance, and closeness are only a few of these considerations. In this instance, multi-purpose decision-making methodologies should be applied rather than traditional supplier selection analyses. One of the Multi-Criteria Decision Making strategies that aid the decision maker is the Fuzzy Analytical Hierarchy Process. This study started by examining the factors affecting supplier selection. The literature review focused on Fuzzy AHP applications. Criteria suitable for the examined company were determined and the process was started by creating matrixes. Finally, the best supplier was determined.

Keywords: Fuzzy AHP · Quality · Selection · Supplier

1 Introduction

In today's world, where globalization and technological developments accelerate rapidly, the understanding of competition between businesses has started to increase. Businesses that follow innovation and technology are at the forefront of the competition. Businesses are targeting fundamental, long-term, strategic improvements apart from superficial, short-term improvements. The concept of the supply chain, which is very important for businesses and is considered a complex structure, also comes to the fore at this point (Benyoucef, L., Ding, H., & Xie, X. 2003). Supply chain management is defined as an important system for businesses to respond to competition and meet customers' demands and expectations. The general functions of the concept of procurement are as follows:

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to determine the requirements of the business, to determine and select a supplier that can meet the requirements, to determine the issues related to product delivery, and to monitor the delivery-related transactions. One of the first and most important steps of the supply chain is the supply of the production input and where the inputs will be obtained. Extensive research on potential suppliers is required. Suppliers' general and technical criteria need to be evaluated. There are many criteria to consider when choosing among suppliers. These criteria are cost (price), quality (suitability of the product for use), design ability (different thicknesses and lengths), manufacturing ability, technical ability (sophistication of measuring devices), technological ability, performance history (low return rates), management ability, cooperation degree, financial performance, proximity, and possession of the required documentation (such as ISO 9000, DIN, TSE, etc.). In this study, it is investigated which supplier would be better to work with the Fuzzy Ahp method in supplier selection.

2 Problem Definition

In this study, the evaluations of a metal factory in Izmir in the selection of suppliers were examined. This business includes pipe bending, welding, and CNC departments. One of the most important first and common steps for all these departments is supplier selection (Taherdoost, H., & Brard, A. 2019). In this context, the company has been working with companies from which it has purchased raw materials since its establishment. With the uncertainties brought by the covid epidemic and the exchange of dollar rate, the company wants to work with this supplier to find the best among the suppliers it has worked with before and to bring profit in financial terms. Some of the priority criteria determined by the Quality Department are as follows; quality (availability of raw materials), proximity (availability of location), price (comparison of costs with other suppliers), on-time delivery (to avoid delays in delivery times to the customer), and quality documentation status. An evaluation will be made among 5 suppliers. In the Problem Definition part, firstly, a few criteria determined by the quality department of the company are mentioned. Then, general information about Fuzzy AHP will be given.

First, the focus will be on the quality criterion. If the steps of the incoming raw material in the incoming quality department are examined:

- First, conformity is checked against general acceptance rules (other than quality level). These are general acceptance conditions such as quantity, time, etc.
- Compliance with the specified specifications (thickness and diameter for pipes) is determined by inspection and analysis and written on the quality control record forms.
- The codes (identities) of the raw materials were determined by the ERP system and the previous work of the input quality specialist (Included in the quality registration form.).
- Inspection and analysis results are evaluated and decided by the entrance quality department. The decision alternatives to be made in this regard are as follows;

  - Incoming raw material or material is accepted.
  - Inadmissible.

- The suspicious situation is seen and a 100% sorting examination is performed. (One-by-one measurement is performed.)
- Faulty ones are returned to be corrected or replaced.
- Even if it is unacceptable according to the specification, it is accepted as temporary. (Customer approval is essential.)

The data were analyzed by looking at the return and deviation rates of the company in previous years. Due to the privacy policy of the business, the supplier does not share their names and rates. The return rate for the quality criteria is listed as follows, from the best supplier to the worst supplier; supplier 3, supplier 2, supplier 5, supplier 4, and supplier 1.

Secondly, the focus is on the proximity criterion. Proximity affects the movement of products from one place to another in the supply chain, their efficiency, stock, and facilities. Proximity is an important point in increasing the responsiveness of the transported product by using different transportation methods and reducing stock holding costs. Firms want to minimize transportation costs due to the sudden changes in the covid epidemic and the dollar exchange rate. The order of the suppliers that the company wants to choose from the closest to the farthest is as follows; supplier 1, supplier 3, supplier 4, supplier 5, and supplier 2.

Thirdly, the importance of price in supplier selection will be examined. Production cost is the cost required by businesses to procure raw materials and convert those raw materials into final products. Considering the costs of the enterprise, a large proportion of it is seen as the cost of raw materials. In this respect, the criticality of supplier selection is revealed again. By choosing the right supplier, businesses that minimize raw material costs can ensure their sustainability. In addition, choosing the right supplier also affects production and post-production costs. Faulty and unsuitable products from the supplier cause quality problems and thus increase quality costs. As an example, the formation of cracks in pipe end shaping, which occurs frequently in the enterprise, in cases where the raw material quality is not suitable can be given (Kahraman, C., Cebeci, U., & Ulukan, Z. 2003). The order of suppliers according to the prices of various raw materials is as follows: supplier 2, supplier 3, supplier 4, supplier 5, and supplier 1 (closest to farthest).

As another supplier evaluation criterion, the on-time delivery criterion was considered. Delivery time is the key point for product and service agreements. Suppliers are obliged to deliver their products at the right time, in the right quantity, quickly, and reliably. Companies that do not deliver on time and cannot meet the deadline may have to pay a line stop allowance to their customers. In addition, companies may not be able to cover this cost and fall behind in the competition, and businesses may have to close in different situations. On the other hand, suppliers should have delivery flexibility in addition to on-time delivery. Delivery flexibility is concerned with whether the changes that may occur in the order quantity or the urgent product requests of the enterprises can be met by the suppliers. By quickly responding to the requests of the customers and providing delivery flexibility, relations with the customers are developed. When the suppliers are evaluated for the on-time delivery criterion, the suppliers are ranked as follows, from the best supplier to the worst supplier: supplier 4, supplier 3, supplier 2, supplier 1, and supplier 5.

Finally, the status of quality certificates is considered a criterion. These days when technology competition is most important, the concept of standardizing quality has emerged. Many organizations have various quality certificates showing that they meet the standards and quality accepted around the world. Especially supplier organizations that have ISO 9001 Quality Management System Certificates stand out for their customers. Having this certificate is proof that the supplier has adopted a policy of continuous improvement and a certain quality standard. In this case, suppliers with this certificate will have an advantage over their other competitors. Documenting processes, workflows, and application instructions are one of the biggest advantages of this document. On the other hand, one of the most important quality documents of the company is material certificates. According to the status of having ISO 9001 Quality Management System Certificate and sending the material certificate, the suppliers are ranked as follows: supplier 2, supplier 3, supplier 4, supplier 1, and supplier 5.

Secondly, before looking at fuzzy AHP definitions and applications, the concept of fuzzy logic will be examined. Fuzzy logic first entered the literature with the study titled "Fuzzy sets" published by Dr. Lütfi Askerzade Zadeh in 1965 (Ogrodnik, K. 2019). Fuzzy logic is especially difficult to understand and very complex, based on interpretation. It is useful in processes that rely on the fact of decision-making. Contrary to classical logic, in fuzzy logic, the truth values of certain propositions can take values as "1", "0" and "between zero and one" as true, false, and uncertain, respectively. With fuzzy logic applications, the alternatives that are in the classical logic principles and that indicate certainty are stretched, so that the alternatives are multiplied through models that also cover more uncertain situations, and the variables are graded in the light of certain rules (Wang, Y. M., Luo, Y., & Hua, Z. 2008).

It is aimed to solve complex and multidimensional problems related to variables that are uncertain, contradictory, and ambiguous and to make them manageable. Values that seem difficult to understand can provide mathematical models based on strong probabilities and predictions in non-linear situations where it is not possible to reach precise inputs because they are used in data delays. Since fuzzy logic is close to human logic, decisions taken using techniques that take this logic into account are more accurate. Since the weights of the criteria are taken as a certain range to decide the fuzzy AHP, it provides a more comfortable movement in the decisions. Because the analytic hierarchical process, which is one of the multi-criteria decision-making approaches, is not entirely adequate for making decisions in the face of uncertainty, a fuzzy analytic hierarchy process has been discovered by combining fuzzy logic with AHP. It is done by experts in the field at the decision-making stage, so there is a risk of subjectivity in the evaluation of the decision-making process, but this problem is avoided with the Fuzzy AHP (Çetintav, Ulutagay, Gürler and Demirel 2016a, 2016b). In most cases, a decision-maker will find an intermittent evaluation more credible than a precise value evaluation. Supplier selection for the company will be done during the research.

3 Literature Review

The information results on the themes and subheadings mentioned in this study were gathered from a variety of sources. The literature review began by investigating general

concepts of the Fuzzy Analytical Hierarchical Process. The continuation of the literature review focused on implementations of AHP. As it is seen in the research that similar policies meet on common ground in implementations.

Companies should manage supply chain management more effectively because there is a hard competitive situation in the world. This study focuses on leather apparel companies. According to the company's expectations and criteria, managers must choose the most suitable suppliers. This choice is a critical decision issue in supply chain management. In the content of this study, firstly a Turkish leather apparel company was chosen. Then, this study focuses on a field survey about leather supply with purchasing managers of this company. To analyze the data, Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) methods are used. Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) approaches are used to choose the best provider. Furthermore, certain conclusions and recommendations for the firm and industry were presented in advance (Ofluoğlu, Nilay, Mutlu, and Atilgan 2017).

According to Vahidnia, Alesheikh, Alimohammadi, and Bassir (2008) because Analytical Hierarchy Process (AHP) is a multi-criteria decision-making process, AHP is particularly useful in challenges of a spatial character or that are GIS-based. Besides, this research focus on some points which are stages of the AHP, implementation of AHP, defects and abilities OF AHP, concepts of fuzziness, uncertainty, and ambiguity in expert decision-making. The research conclusions show a clear priority vector from the triangular fuzzy comparison matrix of Chang's fuzzy range analysis method and the cut-based approach of fuzzy AHP.

According to Putra et al. (2018), gem evaluation options require excellent ability to select and investigate the type of gem to be replaced. The variety of gemstones and buyers is an obstacle in itself if the information and people's ability to analyze the nature of the gemstone is negligible. The decision-making method used is the Fuzzy Analytic Hierarchy Process (FAHP) strategy, which is widely used in various disciplines. FAHP can easily adapt to many decision problems. This study proposes a decision-making system that uses the FAHP algorithm to analyze gem quality.

Abadi et al. (2018), focus on the process of selecting notebook brands among consumers in their study. Thanks to Fuzzy AHP (Analytical Hierarchy Process) to assist decision support system in the option of Notebook from decision support systems framed to aggrandizement all decision-process through assigning problems, choosing proper data, and defining the approaches were used to appraise the selection of options in the decision-making process.

The Analytical Hierarchy Process (AHP) could be a multi-criteria decision-making approach (MCDMA) that can be utilized to unravel complex choice issues. This ponders pointed to utilizing these objective applications to construct suppliers' choice demonstrate, utilizing competitive needs "quality, taken a toll, conveyance and adaptability" as an assessment and determination criteria. In the light of what the consider has concluded, the analyst prescribed the need of utilizing the Analytical Hierarchy process in making choices of selecting providers, particularly in chemical businesses segment, and other mechanical divisions as well, due to what this approach has of focal points and highlights for making complex choices (Hajar 2016).

One of the most important activities in supply chain management is supplier selection (SCM). Choosing the ideal supplier is a challenge for most small and medium-sized enterprises (SMEs) that use traditional approaches. A mixed multiple-criteria decision-making (MCDM) approach has been proposed to identify suppliers. This proposed system coordinates the Delphi method as a data acquisition tool with the analytic hierarchy process (AHP) as an MCDM strategy for information review. Both were used to select a successful supplier. This extension applies a Delphi strategy that allows specialists to choose most criteria and compares the trade-offs between available options according to most criteria. The criteria chosen were cost, transit time, online positioning, churn rate, and adaptability. Using the AHP approach, the criteria weights were acceptable at this point (Al Hazza, Abdelwahed, and Sidek 2022).

Design optimization is important in the improvement of efficient engineering products because using engineering judgment in the design and production of quality products is inevitable. Systems can show lots of failures because of lacking significant design criteria and lacking forecasting of their associated significance in the design and development of engineering. For vital design criteria of an engineering product need to be determined and their various level of importance (i.e. weights) defined using powerful engineering tools, Analytical Hierarchy Process (AHP) methodology was used (Nwaoha and Ashiedu 2015).

Supplier Evaluation is of expanding significance for companies and encourages trade advancement due to the truth that companies are concentrating on their center competencies. Following that, a prominent supplier assessment comprises all inside offices and their input approximately the supplier's execution to get an entire picture of the supplier's potential. This means that distinctive individuals are assessing suppliers due to their obligation which needs requires an organized handle for supplier assessment. Precisely this part is captured by AHP which guarantees that every single assessment for a supplier is embroiled within the add-up to picture assessment. The commonsense utilization of AHP in supplier assessment and determination is displayed with an expanded commerce illustration of Henkel in Germany upgraded by current trade patterns like hazard administration and the advantage to recognize best-in-class suppliers out of the supplier portfolio in a comparative approach (Politis, Klumpp, Celebi 2010).

4 Modeling and Solution Methodology

The steps of the Fuzzy Analytical Hierarchy Process are listed below (Polat, T.K., & Kaçmaz):

- As in the AHP method, determining the main and, if any, sub-criteria, with the support of experts and creation of the hierarchical model,
- Determination of pairwise comparisons of main and sub-criteria and the corresponding fuzzy numbers for these comparisons,
- Calculation of fuzzy importance weights of sub-criteria,
- Evaluation of alternatives using linguistic variables of each sub-criterion,
- Multiplying the fuzzy weights of the sub-criteria with the fuzzy evaluations of the alternatives and adding them to find the total score of each alternative,

- Clarifying the total scores of the alternatives.

Step 1. According to Saaty Scale Table 1, decision-maker class with criteria (suppliers) according to linguistic terms (Ayhan 2013).

Table 1. Saaty scale

Saaty scale	Definition		Fuzzy Triangular Scale		
1	Equally important	(Eq. Imp.)	(1,	1,	1)
3	Weakly important	(W. Imp)	(2,	3,	4)
5	Fairly important	(F. Imp.)	(4,	5,	6)
7	Strongly important	(S. Imp.)	(6,	7,	8)
9	Absolutely important	(A. Imp.)	(9,	9,	9)

The pairwise addition matrix is indicated in Eq. 1, where $\tilde{f}_{ij}^{k}$ demonstrates the k^{th} decision-maker's prediction of k i the criterion over j^{th} criterion, via fuzzy triangular numbers.

$$\tilde{M}^{k} = \begin{pmatrix} \tilde{f}_{11}^{k} \cdots \tilde{f}_{1n}^{k} \\ \tilde{f}_{21}^{k} \cdots \tilde{f}_{2n}^{k} \\ \tilde{f}_{n1}^{k} \cdots \tilde{f}_{nn}^{k} \end{pmatrix} \tag{1}$$

Step 2. If there is more than one decision maker, predilections of each decision maker $(\tilde{f}_{ij}^{k})$ are averaged and $(\tilde{f}_{ij}^{n})$ is computed as in the Eq. 2.

$$\tilde{f}_{iJ} = \frac{\sum_{k=1}^{k} \tilde{f}_{ij}^{k}}{k} \tag{2}$$

Step 3. Thanks to averaged predilections, pair wise addition matrix is updated as demonstrated in Eq. 3.

$$\tilde{M} = \begin{pmatrix} \tilde{f}_{11} \cdots \tilde{f}_{1n} \\ \cdots \\ \tilde{f}_{n1} \cdots \tilde{f}_{nn} \end{pmatrix} \tag{3}$$

Step 4. The geometric mean of fuzzy comparison values of each criterion is computed as demonstrated in Eq. 4. $\tilde{t}_i$ still symbolizes triangular values.

$$\tilde{t}_i = \left(\prod_{j=1}^{n} \tilde{f}_{ij} \right)^{1/n} \quad i = 1, 2, \ldots, n \tag{4}$$

Step 5. The fuzzy weight for each criterion can be found in Eq. 5 by integrating the following three substeps.

Step 5a. Calculate the vector collection of each.
Step 5b. Calculate the (-1) power of collection vector. Change the fuzzy triangular number, to make it in an increasing order.
Step 5c. In order to calculate the fuzzy weight of criterion i ($\tilde{w}_i$), multiply each $\tilde{t}_i$ with this reverse vector.

$$\begin{aligned}\widetilde{w}_i &= \widetilde{t}_i \otimes (\widetilde{t}_1 \ \oplus \ldots\ldots\ldots \widetilde{t}_2)^{-1} \\ &= (lw_i, mw_i, uw_i)\end{aligned} \tag{5}$$

Step 6. Due to the fact that $\tilde{w}_i$ are still fuzzy triangular numbers, it needs to be defuzzy by the proposed centroid method.

$$\tilde{S}_i = \frac{lw_i + mw_i + uw_i}{3} \tag{6}$$

Step 7. $\tilde{S}_i$ is a non-fuzzy number but it needs to be normalized by following Eq. 7.

$$\widetilde{K}_i = \tilde{S}_i / \sum_{i=1}^{n} \tilde{S}_i \tag{7}$$

Normalized weights for both the criteria and the alternatives are determined using these seven methods. Then generate the score for each choice by multiplying it by the criteria associated with the weight of each choice. Based on these results, the decision maker recommends the option with the highest score.

Excel program was used for calculations and operations. First, 5 evaluation criteria were evaluated with each other according to the Saaty Scale. You can see the calculated geometric averages in Table 2. In Table 3, the fuzzy weights of the criteria examined for the company were found. Values are normalized.

Table 2. Criteria with geometric mean

Quality	Geometric Mean		
	2.1689	2.5365	2.8619
Proximity	1	1.3099	1.6054
Price	0.8027	1	1.4309
On-time Delivery	0.5296	0.6443	0.8218
Quality Document Status	0.4013	0.4670	0.5743
Total	4.9026	5.9579	7.2946
Inverse	0.2039	0.1678	0.1370
Increasing Order	0.1370	0.1678	0.2039

Table 3. Fuzzy weights

Quality	Fuzzy Weight			(Average)	Normalized
	0.2973	0.4257	0.5837	0.4356	0.4135
Proximity	0.1370	0.2198	0.3274	0.2281	0.2165
Price	0.1100	0.1678	0.2918	0.1899	0.1803
On-time Delivery	0.0726	0.1081	0.1676	0.1161	0.1102
Quality Document Status	0.0550	0.0783	0.1171	0.0835	0.0792
Total				1.0533	1

5 Result and Discussion

Table 4 and Table 5 fuzzy AHP steps were applied according to criteria and suppliers. The order of suppliers to be selected by the firm according to the fuzzy AHP is as follows: supplier 1, supplier 2, supplier 3, supplier 4, and supplier 5. According to the result, the best supplier was determined as 1. According to the results, the best supplier 1 was determined, but when the purchase rates of the company in the previous year are examined, it has been observed that the highest number of suppliers has been worked with 3 so far.

Table 4. Weights according to criteria and suppliers

	Weights	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Quality	0.4135	0.3945	0.3258	0.1886	0.0622	0.0286
Proximity	0.2165	0.5841	0.1563	0.1486	0.0804	0.0303
Price	0.1803	0.3606	0.3858	0.1516	0.0707	0.0310
On-time Delivery	0.1102	0.4061	0.2659	0.1819	0.1191	0.0267
Quality Document Status	0.0792	0.3846	0.3726	0.1532	0.0610	0.0283

Table 5. Results

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Quality	0.1631	0.1347	0.0780	0.0257	0.0118
Proximity	0.1265	0.0338	0.0321	0.0174	0.0065
Price	0.0650	0.0695	0.0273	0.0127	0.0056

(*continued*)

Table 5. (*continued*)

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
On-time Delivery	0.0447	0.0293	0.0200	0.0131	0.0029
Quality Document Status	0.0304	0.0295	0.0121	0.0048	0.0022
Sum	0.4299	0.2970	0.1697	0.0739	0.0292

6 Conclusion

In this study, firstly general information about the company is given. While examining the general information about the company, the stages of the company in the supply chain were observed. The focus is on supplier selection, which is one of the most important. Subsequently, the literature search continued. The first step of the literature research, started by examining the supplier selection criteria, which are important for companies. Considering the literature research, after examining many different criteria, the firm's quality department focused on 5 criteria (quality, proximity, on-time delivery, price, and quality document status). Afterward, the literature research focused on the fuzzy AHP part. Fuzzy AHP has been used in supplier selection because it is a method that determines the best for all criteria, transforms verbal uncertainty into numerical data, and determines the best alternative in the light of these numerical data. Applied to fuzzy AHP steps. Necessary calculations were made in the Excel program for the criteria examined. As a result of the calculations, the best supplier was determined as the 1st supplier.

For future studies, it is aimed to create a simulation by combining the Arena (Rockwell Arena) software with the evaluation criteria in other parts of the production and extending the fuzzy logic of the data type I am working with. Arena (Rockwell Arena) software will be a good evaluation tool in conjunction with fuzzy AHP as it allows comparisons for various scenarios in different production areas.

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