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A Customer-Driven Supplier Evaluation Model Under Indeterminacy for Customizated Production

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Abstract: Due to the developing market conditions, changing customer expectations, and shortening of product life cycles, it is inevitable for companies to produce high-quality products that will meet customer requirements. Making the right decisions on issues such as working with right supplier, planning production correctly, ensuring effective stock management, and managing the cash flow are some of the factors that affect and change the expectations of the customers. In this study, hybrid quality function deployment (QFD) and analytical hierarchy process (AHP) methodology were used, focusing on supplier selection problems. The weights of the quality requirements (QRs) of the customers were determined by the neutrosophic AHP approach, and then the quality characteristics (QCs) were prioritized in the quality house, considering the relationship between the QRs and QCs. Finally, alternative suppliers were evaluated in terms of QCs using the NAHP method and the most suitable supplier was determined as the Austrian origin company.

Keywords: AHP; Furniture industry; Neutrosophic fuzzy sets; QFD; Supplier selection. Introduction.

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1. Introduction

With the changing and developing market conditions, more efficient use of existing resources, creation of alternative resources, and reaching the quality level expected by the customer requirements are achieved by giving importance to supplier selection. With the increase in competition, many businesses have to supply products that will meet the customer requirements in the most appropriate quality with the most optimum cost to maintain their existence. Correct supply chain management is one of the key objectives for both customer and product service quality. Most companies take advantage of all opportunities to reach the voice of the customer with their supply chain partners with whom they do business. Supplier selection includes a process that requires technical knowledge, finance, and human resources and provides the advantage of jointly managing company requests with the supplier (Chai & Ngai, 2020).

In supplier selection, criteria such as competitive prices, compliance with customer quality, short delivery time, communication, quality certification, and product technical suitability can be considered. In addition to the supplier selection criteria in the supply chain, quality raw materials and services contribute positively to product quality, and meeting customer needs must be analyzed according to the relationship between the criteria the customers, stakeholders, companies, and suppliers. Working with the right supplier or making the right evaluation of the existing suppliers are among the evaluations that the customer also needs (Sharma and Tripathy, 2023; Yazdani et al., 2017; Erdebilli et al., 2023).

When the decision models used for supplier selection practices, and modeling in the literature are examined, it is realized that supplier selection studies are generally modeled with multi-criteria decision-making (MCDM) methods. However QFD has been applied in very few supplier selection studies, and in some of these studies, both QFD and MCDM methods have been used as a hybrid. Since QFD is a systematic and customer-focused approach, it is appropriate to use it to prioritize customer needs. As a supplier's customer, customer complaints and supply chain process design needs can be easily determined with QFD (Tayyar and Soltani, 2023; de Araújo Souza et al., 2022; Bao and Li, 2021). In addition, it enables the evaluation of the criteria to be used in supplier selection from various perspectives, by supporting the cooperation between the supplier and the company. In this way, it supports the achievement of more competitive results by improving the cooperation and decision-making process, while focusing on the most important criterion in supplier selection, increasing customer satisfaction in future studies. QFD is a method based on data and feedback from experts, market research, and other external sources. This data-driven approach helps reduce bias and ensures that decisions are based on concrete information.

In our study, we used neutrosophic AHP to find the QR weights

In the following statements, we have presented the background, motivation, purpose, findings, and contribution of our study:

The ***background*** of our study, we have handled supplier selection problems for modular kitchen producers. The organization, in which we analyzed this problem, had difficulties in managing its supply chain processes especially in managing suppliers' raw material delivery process. So, a solution/ strategy for this organization was needed.

The primary ***motivation*** of our study is to analyze supplier selection criteria and alternative suppliers with a hybrid methodology that considers customers' requirements. By this methodology, we aim to develop a supplier selection model for organizations which will be a strategy for.

The ***gaps*** which we considered are;

- Neutrosophic AHP and QFD were not used in supplier selection for the customer-oriented companies.
- The number of supplier selection studies focusing on customer expectations is low, evaluations regarding sub-criteria that also take customer feedback into consideration are not investigated a lot and uncertainties in the supply chain process and supplier selection criteria are not considered too much.
- Customer requirements and expert opinions are planned at the same stage and therefore a strategic decision is made.

The ***purpose*** of this study is summarized as follows: The supplier selection problems involve criteria at different levels. The most important criteria for supplier selection include price, discount, quality, information management, and delivery time. It is considered appropriate to apply QFD in the study due to its methodological approach, focusing on the needs of the customers, and prioritization of those requirements. Customer complaints and requirements for supply chain process design are basically implemented with QFD as a supplier's customer. It allows the criteria to be used in supplier selection to be evaluated from several perspectives by encouraging cooperation between the supplier and the company. Therefore, through enhancing collaboration and decision-making, more competitive results are obtained. By focusing on the most important consideration in supplier selection, it enhances customer satisfaction in the future. QFD relies on information and opinions from professionals, market analysis, and other outside sources. This data-driven strategy guarantees that decisions are based on factual information and reduces bias. In the process of selecting a supplier, there are numerous criteria and potential uncertainties. The objective of implementing neutrosophic AHP-QFD is to ease the role of experts and model uncertainty more effectively than with other methods. The use of AHP is more appropriate for evaluation since the criteria in this study have more sub-criteria than the articles examined. The purpose of the study is to determine how to prioritize the criteria to select a more thorough and long-term supplier. With QFD, it can compare the qualities of suppliers and how they relate to one another. The neutrosophic AHP-QFD guarantees that the supplier selection meets customer requirements. This customer-oriented mindset significantly leads to enhanced fulfillment and lasting relationships in business. Alternatives are chosen more precisely by offering innovation and utilizing a more customer-oriented multi-criteria decision-making approach.

The ***findings*** of our study are explained in the following: The importance levels of the criteria and CRs identified in the study's initial phase were ascertained using the neutrosophic AHP. The QRs required to satisfy customer needs were identified in the second phase, and the QFD approach was used to calculate the weights of the QRs. Using the weights of the established quality standards, the neutrosophic AHP technique was once more employed in the third phase to assess potential substitute providers. Consequently, here is how the alternatives were ranked: Turkey, Italy, Germany-1, Germany-2, and Austria. A systematic and thorough approach to supplier evaluation is demonstrated using neutrosophic AHP to evaluate the relative importance of criteria and CRs, as well as the use of the QFD technique to define QRs. The study's findings, which placed Austria as the top supplier and Germany-2 and Germany-1 closely behind, offer the company under review useful information.

The ***contributions*** of our study are listed as follows:

- In this study, the methodology considers customer requirements. The organization which produces modular kitchen furniture must be aware of the needs of their customers' needs. These are also the requirements of the company which is the customer of its suppliers.
- In the literature, according to our research, there is not any study that investigates furniture industry supplier selection problems.
- A performance analysis model for suppliers is presented both to analyze suppliers' performances and supplier selection criteria performances for each alternative.

In our study, we outline a systematic exploration of the customer-oriented supplier selection process in the kitchen furniture industry. The methodology is structured into three main phases, each contributing to a holistic understanding of the proposed model. In the initial phase, we research the application of neutrosophic AHP to ascertain the importance levels of criteria and customer requests. The subsequent section focuses on the determination of QRs necessary to meet customer demands, employing the QFD approach. The third and final phase involves the application of neutrosophic AHP once again, this time to evaluate alternative suppliers based on the determined QRs. The systematic progression through these phases allows for a comprehensive examination of the supplier selection process, ultimately in a ranked list of alternatives. This structure facilitates a clear and in-depth presentation of our research methodology and findings, contributing to the overall coherence of this study. The organizational structure of our study is as follows: In the second section, the literature review is presented. In the third section, the details of the methodology are explained. In the fourth section, the application is presented and in the last section, the results of our research and contribution are provided.

1. Literature Review

In our study, we have conducted a literature review with the keywords "supplier selection", "multi-criteria decision making" and "QFD". According to our research, some of the studies which integrate these techniques are summarized below:

Asadabadi (2017) applied the analytical network process (ANP), QFD, and Markov chains in his study, taking into account the dynamic customer needs as the determining factor in customer-oriented supplier selection and decided that long-term cooperation can be supported by supplier selection. Babbar and Amin (2018) applied a two-stage QFD method and multi-objective stochastic mathematical model in their study for green supplier selection in which the uncertainties in the supply process in the beverage sector are managed with the stochastic approach, and the uncertainties in the opinions of the people are handled with the fuzzy QFD method. Bhattacharya et al. (2010) investigated the selection of suppliers from alternative suppliers by a hierarchical approach, in which AHP, QFD, and cost factor measures are combined, to consider engineering and customer needs. Chen et al. (2021) proposed a new QFD model, which uses DEMATEL, MULTIMOORA, unstable fuzzy linguistic term set, for the design of CNC machine tools. Haiyun et al. (2021) with the help of QFD, analyzed the innovation strategies multi-dimensionally by using a hybrid structure consisting of the interval-valued intuitionistic fuzzy DEMATEL and MULTIMOORA for green supply chain management. Jain and Singh (2020) aimed to make sustainable and stable supplier selection with a two-stage decision model by using a fuzzy inference system and fuzzy Kano model for the iron and steel industry. Karsak and Dursun (2014) proposed a new fuzzy MCDM method for supplier selection by using QFD and data envelopment analysis (DEA) together in a private hospital in Istanbul. Khan et al. (2022) included a full consistency method and fuzzy QFD hybrid model which will provide resilience in the health system during the COVID-19 pandemic and future pandemics. Lima-Junior and Carpinetti (2016) aimed to propose a new MCDM method with fuzzy QFD for supplier selection in the automotive sector in their study. Liu et al. (2019) used the Bonferroni test for green supplier selection in their study and divided them into several clusters to find the relationship between those in the same cluster. In addition, they applied QFD which uses preference values handled in the Bonferroni tests as customer needs importance values and the relationships between customer needs and technical criteria. Rajesh and Malliga (2013) developed a strategic supplier selection model for a high-pressure die-casting company by applying hybrid AHP and QFD methodology to analyze determined criteria. Sharma and Tripathy (2022) proposed an integrated QFD model with fuzzy TOPSIS for supplier selection and evaluation in their study. Singh and Kumar (2021) proposed an MCDM method integrated into the QFD model for social media usage by applying an image fuzzy set and a real case study was conducted with users of Facebook, Instagram, WhatsApp, and Twitter. Wang et al. (2022) included the use of TOPSIS and QFD and the hybrid interval-valued fuzzy sets in the evaluation of service performance for international container ports. Yazdani et al. (2017) organized their research by connecting DEMATEL for green supplier selection with customer needs. The relationship between the supplier selection pair and the needs of the customer was identified by applying the QFD. The complicated proportional assessment (COPRAS) lists alternative suppliers. In this section, there are studies used in traditional supplier selection and innovative supplier selection studies that also include the customer's requirements. Öztürk and Paksoy (2020) studied the green supplier selection problem in their studies considering customers' needs by using DEMATEL-QFD interval type-2 fuzzy AHP methods. Zhang et al. (2019) proposed a neighborhood-rough set-based QFD model for green building material supplier selection in their study in which technical specifications are determined by a decision-making group. Tayyar and Soltani (2020) proposed a method that decreases the cost of inappropriate supplier selection by choosing appropriate evaluation criteria with QFD-AHP. Liu et al. (2020) used QFD, best and worst method (BWM), VIKOR, and DEMATEL methods for supplier selection in blockchain tracing anti-fraud platforms. Chen (2020) included a study in which the entropy weight was collected using both AHP and TOPSIS instead of subjective weights for appropriate supply selection. Dang et al. (2022) solved a supplier selection problem under uncertainty using spherical fuzzy AHP and grey COPRAS in the automotive industry in Vietnam considering sustainable criteria. Seifbarghy and Hamidi (2025) proposed a hybrid fuzzy DEMATEL, neutrosophic SWARA, and neutrosophic MOORA framework based on the 10 C model for supplier selection.

One of the studies methodologically closest to the proposed approach is Karasan et al. (2022), who developed a neutrosophic Quality Function Deployment (QFD) methodology grounded in neutrosophic Analytic Hierarchy Process (AHP) and neutrosophic DEMATEL, applying it to the customer-oriented design of an automobile seat. In their study, customer requirements were weighted using neutrosophic AHP, while the interrelationships among technical characteristics were determined via neutrosophic DEMATEL. Furthermore, the robustness of the resulting priorities was tested through comparisons with alternative methods in the literature as well as comprehensive sensitivity analyses.

Although that study shares a similar neutrosophic AHP-QFD backbone with the present research, it addresses a product design problem. In contrast, the current study focuses on a supplier selection problem where, following the QFD phase, alternative suppliers are further evaluated through a second application of neutrosophic AHP based on the weighted quality characteristics. This structural distinction positions the present study as the first to extend the neutrosophic AHP-QFD approach to a customer-oriented supplier evaluation problem within the customized furniture industry.

In addition, in Table 1, we presented studies that deal with supplier selection problems and summarized them according to the scope and techniques applied. In Table 2, we have analyzed the studies that include NAHP in their studies according to their scope and all other techniques.

Table 1. *Techniques used for supplier selection*

References	**Scope**	**Method**
Lima-Junior and Carpinetti (2016)	*Application in the automotive industry by dividing priority, critical, complementary, and costly groups for supplier selection*	*Fuzzy QFD*
Rajesh and Malliga (2013)	*Strategic supplier selection proposal for high-pressure die-casting company*	*AHP; QFD*
Karsak and Dursun (2014)	*A private hospital application in Istanbul for supplier evaluation and selection*	*QFD; DEA; FWA*
Yazdani et al. (2017)	*Supplier evaluation and selection for environmental protection and sustainable development*	*QFD; DEMATEL; COPRAS*
Bhattacharya et al. (2010)	*Selection of suppliers to meet engineering and customer needs*	*AHP; Hierarchical QFD; CFM*
Haiyun et al. (2021)	*Developing an innovation strategy for green supply chain management in the energy sector*	*QFD; IVIF MOORA; DEMATEL*
Liu et al. (2019)	*Green supplier selection for bike rental case study*	*QFD; IT2FPBM; T2FWPBM*
Asadabadi (2017)	*Customer-oriented supplier selection*	*ANP; QFD; Markov Chain*
Tang and Yang (2021)	*Supplier selection for e-bike sharing*	*Interval-valued Pythagorean fuzzy preference relation*
Hendiani et al. (2020)	*Sustainable supplier selection for refinery in Southern Iran*	*Fuzzy best-worst method*

References	Scope	Method
Dursun and Karsak (2013)	*Determination and evaluation of supplier selection criteria*	*Fuzzy weighted average; QFD*
Bevilacqua et al. (2006)	*Supplier selection for the medium-sized clutch fittings industry*	*Fuzzy QFD*
Sharma and Tripathy (2022)	*Supplier evaluation and selection*	*QFD; Fuzzy TOPSIS*
Zheng et al. (2023)	*New energy vehicles supplier selection*	*QFD; Case-based reasoning*
Khorram et al. (2024)	*Supplier selection*	*Fuzzy DEMATEL; fuzzy QFD; fuzzy TOPSIS; and fuzzy VIKOR*
Koirala, and Shabbiruddin (2023)	*Sustainable battery supplier selection*	*QFD; Fuzzy COPRAS*
Deivanayagampillai et al. (2026)	*Robust green supplier selection in sustainable supply chain management under dynamic uncertainty*	*Adaptive Neutrosophic Decision-Making (ANDM); Neutrosophic Entropy; DHFWDHM; Adaptive TOPSIS*
Yang (2025)	*Building material supplier selection*	*2-Tuple Linguistic Neutrosophic Set (2TLNNS); Combined Grey Relational Analysis (2TLNN-CGRA); Shannon Entropy*
Ambilkar et al. (2024)	*Sustailient supplier selection in the additive manufacturing (AM) sector for trinket manufacturing*	*Fuzzy Delphi Method (FDM) and Neutrosophic Best-Worst Method (N-BWM)*

Table 2*. The literature studies with Neutrosophic AHP*

References	Scope	Method
Karamaşa et al. (2021)	Evaluating the optimal training aircraft selection.	NAHP, MULTIMOORA
Bilandi et al. (2020)	Wireless body area networks relay node selections for the medical health system.	NAHP
Başhan et al. (2020)	Maritime risk evaluation to optimize safety control, preventing crew and potential environmental impacts.	NAHP, fuzzy TOPSIS

References	Scope	Method
Reig-Mullor et al. (2022)	Sustainability reports of environmental, social, and governance.	NAHP-TOPSIS
Harnpornchai and Wonggattaleekam (2021)	Relative importance assignment for the real world.	NAHP
Akman et al. (2022)	E-commerce selections during the pandemic crisis.	Neutrosophic fuzzy AHP; EDAS
Kahraman et al. (2022)	Fuzzy extensions of AHP for INFUS conferences.	Intuitionistic fuzzy AHP; picture fuzzy AHP; NAHP; spherical fuzzy AHP; Pythagorean fuzzy AHP; q-rung orthopair fuzzy AHP
Vafadarnikjoo and Scherz (2021)	Sustainable, agility evaluations in the Iranian steel industry.	Neutrosophic-Grey AHP
Navarro et al. (2021)	Sustainable design.	NAHP, DEMATEL
Junaid et al. (2020)	Supply Chain Risk Assessment in Automotive Industry of Pakistan.	NAHP-TOPSIS
Karuppiah et al. (2021)	Sustainable humanitarian supply chain management.	NAHP, TODIM
Navarro et al. (2019)	Sustainable design assesment of concrete bridge.	NAHP, TOPSIS
Chakrabortty et al. 2023	Chatbot selection in the telecommunication industry.	Combined Compromise Solution (CoCoSo), NAHP
Singh et al. (2021)	Evaluating total transportation cost.	Trapezoidal neutrosophic fuzzy AHP, Artificial neural network
Alzahrani et al. (2023)	Selecting women's university sites in the state of West Bengal, India.	Neutrosophic number TRNN, AHP, TOPSIS, COPRAS
Rahman et al. (2022)	The causes of boiler accidents in Bangladesh.	NAHP
Tuan et al. (2020)	Lecturers' research productivity evaluation.	Interval-valued Neutrosophic AHP
Abdel-Basset et al. (2020)	Professional selection in Egypt.	Neutrosophic ANP, TOPSIS, AHP, MOORA
Vafadarnikjoo et al. (2023)	Blockchain technology adoption in manufacturing supply chains.	NAHP

References	Scope	Method
Ye et al. (2023)	Fashion culture communication and marketing in China.	Interval-valued Neutrosophic AHP
Yiğit (2023)	Evaluating trainers in organizations.	Interval-valued Neutrosophic AHP, Fuzzy C-Means (FCM).
Ayyildiz et al. (2023)	Evaluate universities based on student perspective.	IVN-AHP, VIKOR
Hezam et al. (2021)	Determining the priority groups for COVID-19 Vaccine.	NAHP, TOPSIS
Sánchez-Garrido et al. (2021)	The sustainability among design alternatives for a single-family home.	Neutrosophic group AHP, VIKOR
Karamaşa et al. (2020)	Selecting the right logistics service provider	NAHP
Seifbarghy and Hamidi (2025)	Supplier selection in the automotive parts supply chain based on the 10 C model	Fuzzy DEMATEL, Neutrosophic SWARA, Neutrosophic MOORA

2. Methodology

In this study, we propose a methodology that integrates NAHP and NQFD approaches to determine the best alternative by considering both the QRs of customers and the QCs of products. Many criteria and alternatives in supplier selection involve uncertainty. Using neutrosophic AHP-QFD is aimed to facilitate the work of experts, and uncertainty is modeled more effectively compared to other methods (Karasan et al., 2022). The prioritization of the criteria and the selection of more comprehensive and long-contract suppliers are the motivations of this study. The comparison of supplier qualifications and the relationship between suppliers is possible with QFD. The neutrosophic AHP-QFD ensures that supplier selection is aligned with customer requirements. This customer-oriented approach makes a significant contribution to increased satisfaction and long-term business relationships.

In the first phase, we handle QRs' weights by conducting the NAHP method. In the second phase, we determine QCs to meet QRs and we execute the steps of QFD to handle the weights of QCs by considering the QRs' weights handled in the first phase. Then in the last phase, we identify alternatives and again we carry out NAHP steps to find the most appropriate alternative by taking into account the QCs weights handled in the second step. The proposed methodology is presented in Figure 1.

In this study, there are linguistic evaluations of decision-makers and uncertainties in QRs and QCs. Therefore, we need to use fuzzy logic to solve the problem and in our study, we used neutrosophic sets. The purpose of using neutrosophic sets in the evaluation of QRs and QCs for multiple alternatives is to appropriately represent unclear, inconsistent, or incomplete information. It is more suitable for human thinking with its membership functions of truth, indeterminacy, and falsity. It contains more information than classical fuzzy logic thanks to the "indeterminacy” membership function. In the following, we present the details of the methods used in this study.

2.1. Quality Function Deployment

QFD is a method of transferring customer requirements to the technical specifications of the product or process in order to meet customer demands and expectations of products or processes now and in the future. It is an effective method that can be used for the company, as it includes the "voice of the customer" in stages such as product and production planning and engineering (Cebi et al., 2009). In the QFD study; it is not only to meet the expectations of the customer, but also to provide the quality and best product/service. QFD is one of the methods used by companies to transform the quality product/service requirements of their customers, stakeholders, employees, and suppliers into quality characteristics (Babbar and Amin, 2018; Haiyun et al., 2021; Karasan et al., 2022; Khan et al., 2022; Lima-Junior et al., 2016; Singh and Kumar, 2021; Yazdani et al.,2017).

Traditional QFD has the following features:

- The middle part of the figure is the house of quality, showing the relationship between quality requirements (WHATs) and quality characteristics (HOWs).
- The left part of the house of quality contains the customer's quality requirement and degree of importance.
- The upper part of the House of Quality shows the framework of the technical specifications and the relations between the technical specifications.
- The right part of the house of quality shows the comparison matrix of the firm against its competitors.
- The lower part of the house of quality shows the grade of quality attributes targeting and evaluation process.

2.2. Neutrosophic Sets

Neutrosophic sets refer to sets developed to portray uncertain, incomplete, and meaningless information, as a generalization of intuitive fuzzy sets and introduced by Florentin Smarandache in the 1980s is represented by three membership values. NS studies the nature and scope of impartiality, as well as their interactions with different intellectual diversity. NS uses indeterminacy as an independent measure of the membership and non-membership information. Hence the concept of NS is considered as a generalization of FS, IFS, and interval-valued sets (Das et al., 2020; Kaya et al., 2022; Junaid et al., 2020).

Definition 1: Let X and x∈X. Let X be a neutrosophic subset A in the universe. For subset A (Kaya et al., 2022);

The truth membership function is a subset of $T_A(x)$, $[0,1]$.

Indeterminacy membership function is a subset of $T_I(x)$, $[0,1]$.

Falsity membership is a subset of $T_F(x)$, $[0,1]$.

There are no restrictions on the sum of membership functions.

$$0^- \leq T_A(x) + T_I(x) + T_F(x) \leq 3^+ \quad (1)$$

Definition 2: If $N_1=(t_1, i_1, f_1)$ and $N_2=(t_2, i_2, f_2)$ are two different single-valued neutrosophic numbers, the calculations can be described in the section as follows (Kaya et al., 2022):

The sum of N_1 and N_2: $N_1 + N_2 = (t_1 + t_2 - t_1 t_2, i_1 i_2, f_1 f_2)$ (2)

The multiplication of N_1 and N_2: $N_1 \times N_2 = (t_1 t_2, i_1 + i_2 - i_1 i_2, f_1 + f_2 - f_1 f_2)$ (3)

The division of N_2 on N_1: $N_2/N_1 = (t_2/t_1, i_2 - i_1/1 - i_1, f_2 - f_1/1 - f_1)$ (4)

Definition 3: If $N_1=(t_1, i_1, f_1)$ is a single-valued neutrosophic number and A is an arbitrary positive real number, the multiplication of N1 and A can be described in the equation as follows (Kaya et al., 2022):

$$A \times N_1 = (1 - (1 - t_1)^A, i_1^A, f_1^A), \text{ where } A > 0 \quad (5)$$

Therefore, when $N_1=(t_1, i_1, f_1)$ is a single-valued neutrosophic number and A is an arbitrary positive real number, the division of N1 on A can be described as an equation as follows:

$$N_1/A = \left(1 - (1 - t_1)^{1/A}, i_1^{1/A}, f_1^{1/A}\right), \text{ where } A > 0 \quad (6)$$

Definition 4: If N_1 is a single-valued neutrosophic number, the score function is mapped N_1 into the single crisp output as S(N_1) follows (Kaya et al., 2022).:

$$S(N_1) = (3 + t_1 - 2i_1 - f_1)/4 \quad (7)$$

$t_{\tilde{a}}$ determines the maximum accuracy membership degree, $i_{\tilde{a}}$ and $f_{\tilde{a}}$ determine the minimum uncertainty and inaccuracy determines the degree of membership.

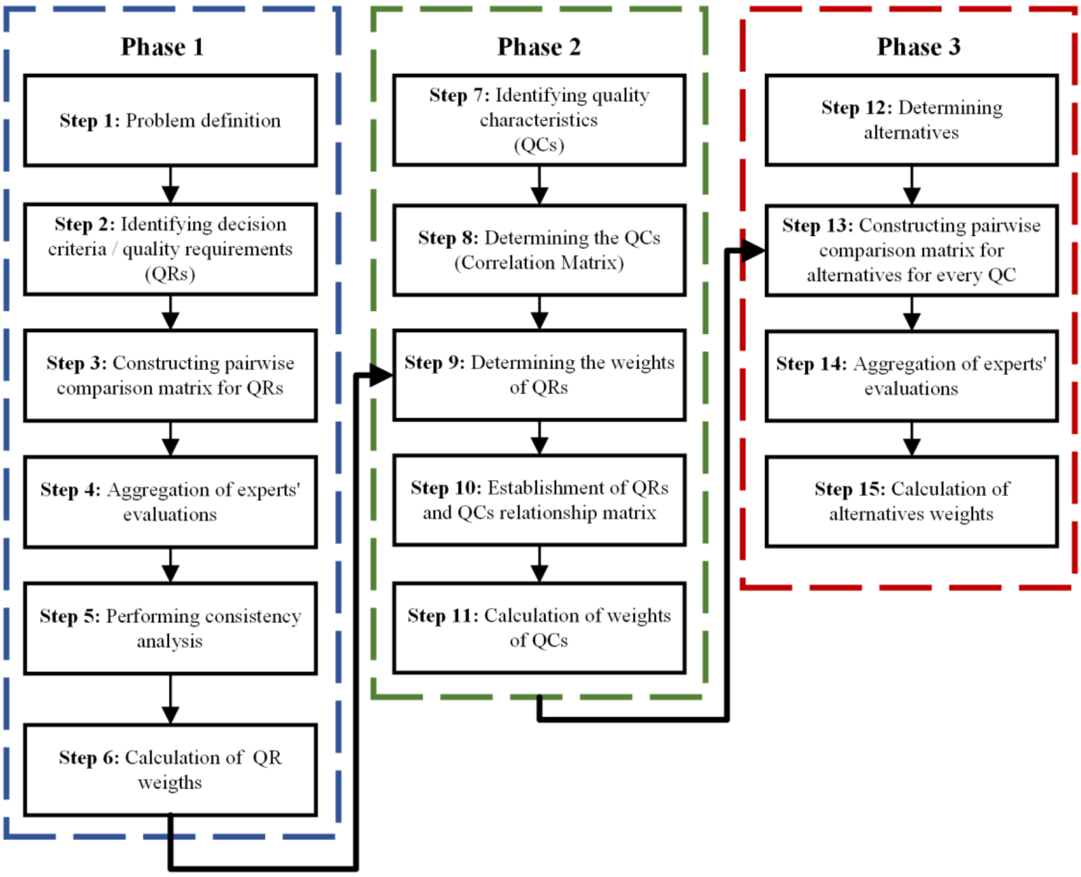

Figure 1. *Flowchart of the methodology*

2.3. Neutrosophic AHP (NAHP)

AHP is an MCDM approach that compares the importance of criteria and alternatives with pairwise comparisons. Since AHP does not deal with ambiguous situations in complex problems, it is used in most cases with fuzzy logic. In some real-life situations, this is not enough either. For this reason, evaluation with fuzzy numbers in decision problems provides more accurate decisions. In our study, we used neutrosophic fuzzy AHP to deal with this vagueness and find the weights of criteria and the best alternative.

The steps of the NAHP method used in this study are presented below:

Step 1: The criteria and sub-criteria of the problem and alternative suppliers to be selected are determined.

Step 2: A pairwise comparison is constructed for each criterion by the experts. Linguistic variables and importance weights are calculated based on neutrosophic values in Table 3 (Kaya et al., 2022).

Table 3. Linguistic variables and weight of significance based on neutrosophic values

Linguistic Terms	**Neutrosophic sets**	**Linguistic Terms**	**Reciprocal Neutrosophic sets**
Extremely highly preferred (EHP)	(0.90, 0.10, 0.10)	Mildly lowly preferred (MLP)	(0.10, 0.90, 0.90)
Extremely preferred (EP)	(0.85, 0.20, 0.15)	Mildly preferred (MP)	(0.15, 0.80, 0.85)
Very strongly to extremely preferred (VSEP)	(0.80, 0.25, 0.20)	Mildly preferred to Very lowly preferred (MPVLP)	(0.20, 0.75, 0.80)
Very strongly preferred (VSP)	(0.75, 0.25, 0.25)	Very lowly preferred (VLP)	(0.25, 0.75, 0.75)
Strongly preferred (SP)	(0.70, 0.30, 0.30)	Lowly preferred (LP)	(0.30, 0.70, 0.70)
Moderately highly to strongly preferred (MHSP)	(0.65, 0.30, 0.35)	Moderately lowly preferred to lowly preferred (MLPLP)	(0.35, 0.70, 0.65)
Moderately highly preferred (MHP)	(0.60, 0.35, 0.40)	Moderately lowly preferred (MOLP)	(0.40, 0.65, 0.60)
Equally to moderately preferred (EMP)	(0.55, 0.40, 0.45)	Moderately to equally preferred (MEP)	(0.45, 0.60, 0.55)
Equally preferred (EQP)	(0.50, 0.50, 0.50)	Equally preferred (EQP)	(0.50, 0.50, 0.50)

Step 3: The aggregation of expert opinions is calculated with the neutrosophic weighted arithmetic mean addition operator.

$$F_w(A_1, A_2, \dots, A_n)\begin{cases}1-\prod_{j=1}^{n}\left(1-T_{A_j}(x)\right)^{w_j}\\ 1-\prod_{j=1}^{n}\left(1-I_{A_j}(x)\right)^{wj}\\ 1-\prod_{j=1}^{n}\left(1-F_{A_j}(x)\right)^{w_j}\end{cases} \tag{8}$$

$\boldsymbol{W} = (\boldsymbol{w_1}, \boldsymbol{w_2}, \dots \boldsymbol{w_n})$: weight vector $w_j \in [0,1]$ and $\sum_{j=1}^{n} w_j = 1$

Step 4: The consistency ratio (CR) is calculated for each pairwise comparison matrix. The method proposed by Xu and Liao (2014) will be used for CR calculation. The following calculations are used, with $(T'_{xk},\ I'_{xk},\ and\ F'_{xk})$ consistent neutrosophic values,

1. For $k > x+1$, $y = x+1$ $N_{xk} = (T'_{xk}, I'_{xk}, F'_{xk})$,

$$T'_{xk} = \frac{\sqrt[k-x-1]{T_{xy}*T_{yk}*T_{xk-1}*T_{k-1k}}}{\sqrt[k-x-1]{T_{xy}*T_{yk}*T_{xk-1}*T_{k-1k}}+\sqrt[k-x-1]{(1-T_{xy})*(1-T_{yk})*(1-T_{xk-1})*(1-T_{k-1k})}} \tag{9}$$

$$I'_{xk} = \frac{\sqrt[k-x-1]{I_{xy}*I_{yk}*I_{xk-1}*I_{k-1k}}}{\sqrt[k-x-1]{I_{xy}*I_{yk}*I_{xk-1}*I_{k-1k}}+\sqrt[k-x-1]{(1-I_{xy})*(1-I_{yk})*(1-I_{xk-1})*(1-I_{k-1k})}} \tag{10}$$

$$F'_{xk} = \frac{\sqrt[k-x-1]{F_{xy}*F_{yk}*F_{xk-1}*F_{k-1k}}}{\sqrt[k-x-1]{F_{xy}*F_{yk}*F_{xk-1}*F_{k-1k}}+\sqrt[k-x-1]{(1-F_{xy})*(1-F_{yk})*(1-F_{xk-1})*(1-F_{k-1k})}} \tag{11}$$

2. For $k = x+1$, $y = x+1$ $N_{xk} = (T_{xk}, I_{xk}, F_{xk})$
3. For $k < x$, $y = x+1$ $N_{xk} = (F'_{xk}, 1-I'_{xk}, T'_{xk})$

$$CR = \frac{1}{2(n-1)(n-2)}\sum_{x=1}^{n}\sum_{k=1}^{n}(|T'_{xk}-T_{xk}| + |I'_{xk}-I_{xk}| + |F'_{xk}-F_{xk}|) \tag{12}$$

*CR must be less than 0.1.

Step 5: The normalization method is applied for each criterion, and the normalization process is performed by dividing each row by the total of the column it belongs to.

Step 6: After the normalization process is done, the row totals are calculated and divided by the number of criteria, and the neutrosophic criteria weights are found.

Step 7: Neutrosophic criterion weights are clarified using Eq. (9).

$$S(N_i) = (3 + T_i - 2I_i - F_i)/4 \tag{13}$$

Step 8: The criteria weights are obtained so that the total weights are 1.

2.4. The Neutrosophic QFD (NQFD)

The grading of QRs as (1-5) or (1-9) by experts creates a negative situation in terms of subjectivity. Uncertainty, inconsistency, and disagreement of experts cause incomplete or inaccurate transmission of QRs in supplier selection problems. Relationship matrix values will be expressed with neutrosophic numbers. The relationships will be shown by $\tilde{\mathbf{9}}$**-** strong relationships, $\tilde{\mathbf{3}}$**-** average relationships, and $\tilde{\mathbf{1}}$**-** poor relationship.

In the QFD correlation matrix, (++) shows a strong positive correlation between QCs, (-) shows a negative correlation, and (--) shows a strong negative correlation. The weight of each QC (HOWs) is calculated by multiplying each relationship value by the corresponding QRs (WHATs) weight.

$$\omega(\boldsymbol{HOW})_{\boldsymbol{i}} = (\boldsymbol{HOW})_{\boldsymbol{i1}}\boldsymbol{relationship\ degree} \times \boldsymbol{\omega}(\boldsymbol{WHAT_1}) + \ldots + (\boldsymbol{HOW})_{\boldsymbol{in}}\boldsymbol{relationship\ degree} \times \boldsymbol{\omega}(\boldsymbol{WHAT_n}) \quad (14)$$

3. Application

In this study, an application is conducted by using the data of a customer-oriented and bespoke company in the kitchen furniture industry. The company, which provides modular facilities with different designs with an aesthetic, modern line, serves its domestic and international customers. Raw materials are procured from both domestic and foreign suppliers. The purpose of using QFD in the application is to meet customer needs with the voice of the customer and to develop a decision-making mechanism that allows harmony between the organization's characteristics and suppliers' characteristics. Evaluation is made by three experts working in the firm.

The application steps are as follows:

Phase 1/ Step 1: The problem handled in this study is to find the most appropriate supplier for the company.

Phase 1/ Step 2: In order to reveal the problem, the supplier selection criteria and sub-criteria of the company are classified in Table 4. We collected our criteria through a literature review and asked decision-makers to check whether they were suitable for supplier evaluation. These criteria are also considered as QRs of customers in the QFD phase. Some supplier selection criteria from the literature are included in this article. Certain criteria were developed by consulting the opinions of the purchasing and marketing departments because, in the furniture company where the application was conducted, design and consumer feedback are significant factors.

Table 4. *Supplier selection criteria*

Criteria	Sub-criteria	Relevant Literature
Order management (C1)	Order process (C11)	Karabayır and Botsalı, 2022
	Ordering/Portal login (C12)	Experts' opinion
Product and service marketing management (C2)	New product introduction (C21)	Galankashi et al., 2016; Wang et al., 2017
	Change in product (C22)	Wang et al., 2017
	The product is removed from the program (C23)	Wang et al., 2017
	Media management (C24)	Lahdhiri et al., 2022
	Product and service training (C25)	Galankashi et al., 2016, Wang et al., 2017
	Adapting to competitors (C26)	Karabayır and Botsalı, 2022
	Complaints management (C27)	Karabayır and Botsalı, 2022
	Identifying market-specific global trends (C28)	Karabayır and Botsalı, 2022; Wang et al., 2017
	Collaboration to improve existing service (C29)	Karabayır and Botsalı, 2022; Wang et al., 2017
	Quality (C210)	Galankashi et al., 2016; Lahdhiri et al., 2022; Wang et al., 2017
	Accurate and timely response to price offers (C211)	Karabayır and Botsalı, 2022
Logistics management (C3)	Notification of delivery dates (C31)	Galankashi et al., 2016; Wang et al., 2017
	Notification of minimum orders (C32)	Galankashi et al., 2016; Wang et al., 2017
	Material volume, package quantity, size notification (C33)	Galankashi et al., 2016; Wang et al., 2017
	Compliance with delivery dates (C34)	Galankashi et al., 2016
	Domestic franchise status (C35)	Expert opinion
Visit management (from company to supplier – from supplier to company) (C4)	Company presentation (C41)	Expert opinion
	Information sharing (C42)	Lahdhiri et al., 2022
	Workshop (C43)	Expert opinion
	Factory tour frequency (Digital & classic) (C44)	Lahdhiri et al., 2022

Criteria	Sub-criteria	Relevant Literature
Purchasing planning and control management (C5)	Price (C51)	Galankashi et al., 2016; Wang et al., 2017
	Compliance with the predictions (C52)	Galankashi et al., 2016; Wang et al., 2017

Phase 1/ Step 3: Table 5 was obtained by taking the opinions of 3 experts. The relationship matrix between the criteria and the sub-criteria is created according to their evaluations. The features of the experts are as follows:

- Expert 1: 13 years' experience as an Inventory Planning Executive
- Expert 2: 15 years' experience as Senior Purchase Representative
- Expert 3: 5 years' experience as a Purchase Representative

The values given in Table 5 and Table 6 show the pairwise comparisons of quality requirements both with linguistic terms and neutrosophic fuzzy sets.

Table 5. *Comparison matrix with linguistic evaluations*

		C1	C2	C3	C4	C5
C1	Expert 1	EQP	MLP	MP	EQP	MLP
	Expert 2	EQP	MLP	MLP	EQP	MLP
	Expert 3	EQP	MLP	MLP	EQP	MLP
C2	Expert 1	EHP	EQP	EHP	EQP	SP
	Expert 2	EHP	EQP	EQP	VSP	VLP
	Expert 3	EHP	EQP	EQP	LP	MPVLP
C3	Expert 1	EP	MLP	EQP	EHP	EQP
	Expert 2	EHP	EQP	EQP	VSEP	MLP
	Expert 3	EHP	EQP	EQP	VSEP	MLP
C4	Expert 1	EQP	MLP	MLP	EQP	MLP
	Expert 2	EQP	VLP	MPVLP	EQP	MLP
	Expert 3	EQP	SP	MPVLP	EQP	MLP
C5	Expert 1	EHP	LP	EQP	EHP	EQP
	Expert 2	EHP	VSP	EHP	EHP	EQP
	Expert 3	EHP	VSEP	EHP	EHP	EQP

Table 6. *Neutrosophic fuzzy comparison matrix for QRs*

		C1	C2	C3	C4	C5
C1	Expert 1	(0.5, 0.5, 0.5)	(0.1, 0.9, 0.9)	(0.15, 0.8, 0.85)	(0.5, 0.5, 0.5)	(0.1, 0.9, 0.9)

	Expert 2	(0.5, 0.5, 0.5)	(0.1, 0.9, 0.9)	(0.1, 0.9, 0.9)	(0.5, 0.5, 0.5)	(0.1, 0.9, 0.9)
	Expert 3	(0.5, 0.5, 0.5)	(0.1, 0.9, 0.9)	(0.1, 0.9, 0.9)	(0.5, 0.5, 0.5)	(0.1, 0.9, 0.9)
C2	**Expert 1**	(0.9, 0.1, 0.1)	(0.5, 0.5, 0.5)	(0.9, 0.1, 0.1)	(0.5, 0.5, 0.5)	(0.7, 0.3, 0.3)
	Expert 2	(0.9, 0.1, 0.1)	(0.5, 0.5, 0.5)	(0.5, 0.5, 0.5)	(0.75, 0.25, 0.25)	(0.25, 0.75, 0.75)
	Expert 3	(0.9, 0.1, 0.1)	(0.5, 0.5, 0.5)	(0.5, 0.5, 0.5)	(0.3, 0.7, 0.7)	(0.2, 0.75, 0.8)
C3	**Expert 1**	(0.85, 0.2, 0.15)	(0.1, 0.9, 0.9)	(0.5, 0.5, 0.5)	(0.9, 0.1, 0.1)	(0.5, 0.5, 0.5)
	Expert 2	(0.9, 0.1, 0.1)	(0.5, 0.5, 0.5)	(0.5, 0.5, 0.5)	(0.8, 0.25, 0.2)	(0.1, 0.9, 0.9)
	Expert 3	(0.9, 0.1, 0.1)	(0.5, 0.5, 0.5)	(0.5, 0.5, 0.5)	(0.8, 0.25, 0.2)	(0.1, 0.9, 0.9)
C4	**Expert 1**	(0.5, 0.5, 0.5)	(0.1, 0.9, 0.9)	(0.1, 0.9, 0.9)	(0.5, 0.5, 0.5)	(0.1, 0.9, 0.9)
	Expert 2	(0.5, 0.5, 0.5)	(0.25, 0.75, 0.75)	(0.2, 0.75, 0.8)	(0.5, 0.5, 0.5)	(0.1, 0.9, 0.9)
	Expert 3	(0.5, 0.5, 0.5)	(0.7, 0.3, 0.3)	(0.2, 0.75, 0.8)	(0.5, 0.5, 0.5)	(0.1, 0.9, 0.9)
C5	**Expert 1**	(0.9, 0.1, 0.1)	(0.3, 0.7, 0.7)	(0.5, 0.5, 0.5)	(0.9, 0.1, 0.1)	(0.5, 0.5, 0.5)
	Expert 2	(0.9, 0.1, 0.1)	(0.75, 0.25, 0.25)	(0.9, 0.1, 0.1)	(0.9, 0.1, 0.1)	(0.5, 0.5, 0.5)
	Expert 3	(0.9, 0.1, 0.1)	(0.8, 0.25, 0.2)	(0.9, 0.1, 0.1)	(0.9, 0.1, 0.1)	(0.5, 0.5, 0.5)

Phase 1/ Step 4: Using Equation (4), expert opinions are used to calculate the neutrosophic weighted arithmetic mean (Table 7). The weights of all experts are equal, so w_j is 0,333. For example the calculation for $\tilde{r}_{42}$;

$$\tilde{r}_{42} = \begin{cases} 1-(1-0{,}1)^{0{,}333} \times (1-0{,}25)^{0{,}333} \times (1-0{,}7)^{0{,}333} \\ 1-(1-0{,}9)^{0{,}333} \times (1-0{,}75)^{0{,}333} \times (1-0{,}3)^{0{,}333} \\ 1-(1-0{,}9)^{0{,}333} \times (1-0{,}75)^{0{,}333} \times (1-0{,}3)^{0{,}333} \end{cases}$$

$$\tilde{r}_{42} = (0{,}413, 0{,}740, 0{,}740)$$

Table 7. Aggregated neutrosophic comparison matrix

	C1	**C2**	**C3**	**C4**	**C5**
C1	(0,50, 0,50, 0,50)	(0,10, 0,90, 0,90)	(0,12, 0,87, 0,89)	(0,50, 0,50, 0,50)	(0,10, 0,90, 0,90)
C2	(0,90, 0,10, 0,10)	(0,50, 0,50, 0,50)	(0,71, 0,39, 0,39)	(0,56, 0,52, 0,52)	(0,44, 0,65, 0,67)
C3	(0,89, 0,13, 0,12)	(0,39, 0,71, 0,71)	(0,50, 0,50, 0,50)	(0,84, 0,20, 0,17)	(0,26, 0,83, 0,83)
C4	(0,50, 0,50, 0,50)	(0,41, 0,74, 0,74)	(0,17, 0,82, 0,84)	(0,50, 0,50, 0,50)	(0,10, 0,90, 0,90)

C5	(0,90, 0,10, 0,10)	(0,67, 0,45, 0,44)	(0,83, 0,26, 0,26)	(0,90, 0,10, 0,10)	(0,50, 0,50, 0,50)

Phase 1/ Step 5: Equation 5-6-7 is used to calculate the consistency of the neutrosophic pairwise comparison matrix. The consistency ratio with equation (8) was found as CR=0.001.

Phase 1/ Step 6: In this step, the importance levels of the sub-criteria have been accepted as equal and are given in Table 8.

Table 8. *Selection criteria importance of degrees*

Main-criteria	**Sub-criteria**	**Weights ω**	**Criteria Importance Degree**	**Criteria Importance Degree (%)**
C1	Order process (C11)	9%	0,500	0,043
	Ordering/Portal login (C12)		0,500	0,043
C2	New product introduction (C21)	25%	0,091	0,023
	Change in product (C22)		0,091	0,023
	The product is removed from the program (C23)		0,091	0,023
	Media management (C24)		0,091	0,023
	Product and service training (C25)		0,091	0,023
	Adapting to competitors (C26)		0,091	0,023
	Complaints management (C27)		0,091	0,023
	Identifying market-specific global trends (C28)		0,091	0,023
	Collaboration to improve existing service (C29)		0,091	0,023
	Quality (C210)		0,091	0,023
	Accurate and timely response to price offers (C211)		0,091	0,023
C3	Notification of delivery dates (C31)	21%	0,200	0,043
	Notification of minimum orders (C32)		0,200	0,043
	Material volume, package quantity, size notification (C33)		0,200	0,043
	Compliance with delivery dates (C34)		0,200	0,043
	Domestic franchise status (C35)		0,200	0,043
C4	Company presentation (C41)	13%	0,250	0,033
	Information sharing (C42)		0,250	0,033
	Workshop (C43)		0,250	0,033

Main-criteria	Sub-criteria	Weights ω	Criteria Importance Degree	Criteria Importance Degree (%)
	Factory tour frequency (Digital & classic) (C44)		0,250	0,033
C5	Price (C51)	31%	0,500	0,157
	Compliance with the predictions (C52)		0,500	0,157

Phase 2 / Step 7: The quality characteristics (QCs) that the company must meet in order to meet the supplier selection criteria are determined by asking decision-makers and they are presented below:

- Number of patents (QC1)
- Reverse logistics rate (QC2)
- Experiences in the field (QC3)
- Quality certification systems (QC4)
- Location (QC5)
- Financial stability (QC6)
- Reliability of the raw material to the customer and manufacturing processes (QC7)
- Discount (QC8)
- Management and organizational culture (QC9)
- Compliance with environmental laws (QC10)
- Technical capacity (QC11)

Phase 2 / Step 8: The QCs' correlation matrix is constructed and presented in Table 9. The scale used to create the correlation matrix is as follows: ++ high positive correlation, + positive correlation, - negative correlation, -- high negative correlation.

Table 9. Correlation matrix

	QC1	**QC2**	**QC3**	**QC4**	**QC5**	**QC6**	**QC7**	**QC8**	**QC9**	**QC10**	**QC11**
QC1											**++**
QC2											
QC3											
QC4										**+**	
QC5						**-**					
QC6					**-**						
QC7											**+**
QC8											
QC9											

QC10				+							
QC11	++						+				

Phase 2 / Step 9: The QR weights are handled from Phase 1/Step 6.

Phase 2 / Step 10: A relationship matrix is created between WHATs and HOWs. The relationship between QRs and QCs will be shown with neutrosophic values of $\tilde{9}, \tilde{3}, \tilde{1}$*. Table 10 includes the neutrosophic scale for QRs and QCs relationship matrix and Table 11 shows the relationship matrix between the QRs and QCs.

Phase 2 / Step 11: The aggregated relationship matrix is presented in Table 12 and the weights of QCs are calculated via Eq. (4).

Table 10. The neutrosophic scale for QRs and QCs relationship matrix

Relationship	**Neutrosophic fuzzy numbers**		
$\tilde{1}$ - poor relationship	0.1	0.9	0.9
$\tilde{3}$ - moderate relationship	0.5	0.5	0.5
$\tilde{9}$ - strong relationship	0.9	0.1	0.1

*$\tilde{9}$ strong relationships (S), $\tilde{3}$ moderate relationships (A), $\tilde{1}$ poor relationship (P)

Table 11. Relationship matrix

QRs	**Expert #**	**QR Weights**	**QC1**	**QC2**	**QC3**	**QC4**	**QC5**	**QC6**	**QC7**	**QC8**	**QC9**	**QC10**	**QC11**
C11	**Expert 1**	**0,043**			A		S				A		P
	Expert 2				A		S				A		P
	Expert 3				A		S				A		P
C12	**Expert 1**	**0,043**			A						S		S
	Expert 2				A						S		S
	Expert 3				A						S		S
C21	**Expert 1**	**0,023**	A		A	A					S	S	S

QRs	Expert #	QR Weights	QC1	QC2	QC3	QC4	QC5	QC6	QC7	QC8	QC9	QC10	QC11
	Expert 2		A		P	A					S	S	S
	Expert 3		A		P	A					S	S	S
C22	Expert 1	0,023	S	P	S	S			S		S	S	S
	Expert 2		S	P	S	S			S		S	S	S
	Expert 3		S	P	S	S			S		A	S	A
C23	Expert 1	0,023		S	A						S	S	S
	Expert 2			S	A						S	S	S
	Expert 3			S	A						S	S	S
C24	Expert 1	0,023			S	S		S			S		
	Expert 2				S	S		S			S		
	Expert 3				S	S		S			S		
C25	Expert 1	0,023	P		S								
	Expert 2		P		S								
	Expert 3		P		S								
C26	Expert 1	0,023											
	Expert 2												
	Expert 3												
C27	Expert 1	0,023		S	P				A		S		S
	Expert 2			S	P				A		S		S

QRs	Expert #	QR Weights	QC1	QC2	QC3	QC4	QC5	QC6	QC7	QC8	QC9	QC10	QC11
	Expert 3			S	P				A		S		S
C28	Expert 1	0,023	S		A	S		S			S		S
	Expert 2				A	S		S			S		S
	Expert 3					S		S			S		
C29	Expert 1	0,023	S		A		A	A	A		A		A
	Expert 2		S		A		A	A	A		A		A
	Expert 3		S		A		A	A	A		A		A
C210	Expert 1	0,023	S	S	A	S			S		A		A
	Expert 2		S	S	A	A			S		A		A
	Expert 3		S	S		S			S		A		A
C211	Expert 1	0,023			A		P	S		P	P		A
	Expert 2				A		P	S		P	P		A
	Expert 3				A		P	S		P	P		
C31	Expert 1	0,043									A		
	Expert 2										A		
	Expert 3										A		
C32	Expert 1	0,043									A		
	Expert 2										A		
	Expert 3										A		

QRs	Expert #	QR Weights	QC1	QC2	QC3	QC4	QC5	QC6	QC7	QC8	QC9	QC10	QC11
C33	Expert 1	0,043											
	Expert 2										A		
	Expert 3										A		
C34	Expert 1	0,043									A		
	Expert 2										A		
	Expert 3										A		
C35	Expert 1	0,043		P			A						
	Expert 2			P									
	Expert 3			P			A						
C41	Expert 1	0,033	S			S	S	S					
	Expert 2					S	S	S					
	Expert 3					S	S	S					
C42	Expert 1	0,033											
	Expert 2												
	Expert 3												
C43	Expert 1	0,033	S										
	Expert 2		A										
	Expert 3		A										
C44	Expert 1	0,033					S						

QRs	Expert #	QR Weights	QC1	QC2	QC3	QC4	QC5	QC6	QC7	QC8	QC9	QC10	QC11
	Expert 2						S						
	Expert 3						A						
C51	Expert 1	0,157						S		S			
	Expert 2							S		S			
	Expert 3							S		S			
C52	Expert 1	0,157							S		S		S
	Expert 2								S		S		S
	Expert 3								S				S

Table 12. Aggregated relationship matrix

		QCs (HOWs)										
QRs (WHATs)	**QRs weights**	**QC1**	**QC2**	**QC3**	**QC4**	**QC5**	**QC6**	**QC7**	**QC8**	**QC9**	**QC10**	**QC11**
C11	0,04			0,50		0,90				0,50		0,10
C12	0,04			0,50						0,90		0,90
C21	0,02	0,50		0,26	0,50					0,90	0,90	0,90
C22	0,02	0,90	0,10	0,90	0,90			0,90		0,83	0,90	0,83
C23	0,02		0,90	0,50						0,90	0,90	0,90
C24	0,02			0,90	0,90		0,90			0,90		
C25	0,02	0,10		0,90								
C26	0,02											
C27	0,02		0,90	0,10				0,50		0,90		0,90
C28	0,02				0,90		0,90			0,90		
C29	0,02	0,90		0,50		0,50	0,50	0,50		0,50		0,50
C210	0,02	0,90	0,90		0,83			0,90		0,50		0,50
C211	0,02			0,50		0,10	0,90		0,10	0,10		
C31	0,04									0,50		
C32	0,04									0,50		

		QCs (HOWs)										
QRs (WHATs)	**QRs weights**	**QC1**	**QC2**	**QC3**	**QC4**	**QC5**	**QC6**	**QC7**	**QC8**	**QC9**	**QC10**	**QC11**
C33	0,04											
C34	0,04									0,50		
C35	0,04		0,10									
C41	0,03				0,90	0,90	0,90					
C42	0,03											
C43	0,03	0,71										
C44	0,03					0,83						
C51	0,16						0,90		0,90			
C52	0,16							0,90				0,90
Total	1,00	4,01	2,90	5,56	4,93	3,23	5,00	3,70	1,00	9,33	2,70	6,43
Weights of QCs		**8%**	**6%**	**11%**	**10%**	**6%**	**10%**	**7%**	**2%**	**19%**	**5%**	**13%**

According to Table 12, management and organizational culture, technical capacity, experience in the field, quality and certification systems, and financial stability are important characteristics, and quality requirements to be followed for alternative supplier selection. In addition, we show the quality requirements which have the highest effect on quality characteristics in Table 13. According to this table, it is realized that to provide efficient management, have an effective organizational culture (QC9), and increase its technical capacity (QC11), the organization must manage its ordering, product, and service marketing processes successfully. And like these, to increase the experience in their field (QC3), the organizations must focus on their product and service marketing activities. In the production field, quality certification systems (QC4) are required by all parties of customers. So, to have integrated quality systems and to benefit from them, organizations must be aware of the market requirements and must have high interaction with their suppliers. The organizations aim to be financially stable have a high market share and increase their profitability, therefore they have to increase their marketing operations efficiency, they have to develop the right communication skills with their suppliers and they have determined the right price for their products and services.

Phase 3 / Step 12: The alternative suppliers list is determined. In order to create an alternative supplier list, the company has proposed five alternative suppliers: Turkey (TR), Germany (DE1, DE2), Austria (AT), and Italy (IT). The qualifications of suppliers are presented in Table 14.

Table 13. The QR/QC relationship analysis

Management and organizational culture (QC9)	**Technical capacity (QC11)**	**Experiences in the field (QC3)**
Ordering/Portal login (C12) New product introduction (C21) Change in product (C22) The product is removed from the program (C23) Media management (C24) Complaints management (C27) Identifying market-specific global trends (C28)	Ordering/Portal login (C12) New product introduction (C21) Change in product (C22) The product is removed from the program (C23) Complaints management (C27) Collaboration to improve existing service (C29)	Change in product (C22) Media management (C24) Product and service training (C25)
Quality certification systems (QC4)	**Financial stability (QC6)**	
Change in product (C22) Media management (C24) Identifying market-specific global trends (C28) Quality (C210) Company presentation (C41)	Media management (C24) Identifying market-specific global trends (C28) Accurate and timely response to price offers (C211) Company presentation (C41) Price (C51)	

Table 14. Alternatives qualifications

Alternative suppliers	**Experience**	**Number of trading countries**	**Franchise status**
TR (Turkey)	50 years	More than 80 countries	Existing
DE1 (Germany-1)	100 years	More than 150 countries	Existing
DE2 (Germany-2)	135 years	More than 100 countries	Existing
AT (Austria)	70 years	More than 120 countries	Existing
IT (Italy)	24 years	More than 70 countries	Existing

Phase 3 / Step 13: Score is calculated for suppliers by using NAHP. A neutrosophic comparison matrix was prepared for each criterion, and a comparison matrix for the first criterion (QC1) is given in Table 15 as an example.

Table 15. Pairwise comparisons of alternative for QC1 criterion

		TR	**DE1**	**DE2**	**AT**	**IT**
TR	**Expert 1**	(0,5, 0,5, 0,5)	(0,1, 0,9, 0,9)	(0,1, 0,9, 0,9)	(0,1, 0,9, 0,9)	(0,3, 0,7, 0,7)
	Expert 2	(0,5, 0,5, 0,5)	(0,1, 0,9, 0,9)	(0,1, 0,9, 0,9)	(0,1, 0,9, 0,9)	(0,4, 0,65, 0,6)
	Expert 3	(0,5, 0,5, 0,5)	(0,1, 0,9, 0,9)	(0,1, 0,9, 0,9)	(0,3, 0,7, 0,7)	(0,3, 0,7, 0,7)
DE1	**Expert 1**	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,5, 0,5, 0,5)	(0,5, 0,5, 0,5)	(0,6, 0,35, 0,4)
	Expert 2	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,5, 0,5, 0,5)	(0,5, 0,5, 0,5)	(0,7, 0,3, 0,3)
	Expert 3	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,5, 0,5, 0,5)	(0,5, 0,5, 0,5)	(0,7, 0,3, 0,3)
DE2	**Expert 1**	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,5, 0,5, 0,5)	(0,1, 0,9, 0,9)	(0,6, 0,35, 0,4)
	Expert 2	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,5, 0,5, 0,5)	(0,1, 0,9, 0,9)	(0,6, 0,35, 0,4)
	Expert 3	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,5, 0,5, 0,5)	(0,1, 0,9, 0,9)	(0,6, 0,35, 0,4)
AT	**Expert 1**	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,9, 0,1, 0,1)
	Expert 2	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,9, 0,1, 0,1)
	Expert 3	(0,7, 0,3, 0,3)	(0,5, 0,5, 0,5)	(0,9, 0,1, 0,1)	(0,5, 0,5, 0,5)	(0,9, 0,1, 0,1)
IT	**Expert 1**	(0,7, 0,3, 0,3)	(0,4, 0,65, 0,6)	(0,4, 0,65, 0,6)	(0,1, 0,9, 0,9)	(0,5, 0,5, 0,5)
	Expert 2	(0,4, 0,65, 0,6)	(0,3, 0,7, 0,7)	(0,4, 0,65, 0,6)	(0,1, 0,9, 0,9)	(0,5, 0,5, 0,5)
	Expert 3	(0,7, 0,3, 0,3)	(0,3, 0,7, 0,7)	(0,4, 0,65, 0,6)	(0,1, 0,9, 0,9)	(0,5, 0,5, 0,5)

Phase 3 / Step 14-15: The suppliers are sorted. Finally, the values in Table 16 were obtained by multiplying the matrix with the weights. Accordingly, even if there are close values, the supplier in Austria will be selected. The order is AT, DE2, DE1, TR, IT and.

Table 16. The weights of alternatives

Quality Characteristics	**Weights**	**TR**	**DE1**	**DE2**	**AT**	**IT**
QC1	0,08	9%	22%	24%	34%	12%
QC2	0,08	10%	25%	25%	29%	12%
QC3	0,10	20%	20%	20%	20%	20%
QC4	0,11	13%	20%	25%	30%	12%
QC5	0,07	23%	20%	20%	20%	17%
QC6	0,13	15%	20%	24%	30%	12%
QC7	0,08	13%	20%	28%	22%	18%
QC8	0,03	30%	17%	14%	17%	22%

Quality Characteristics	Weights	TR	DE1	DE2	AT	IT
QC9	0,16	15%	20%	22%	25%	19%
QC10	0,05	8%	20%	24%	34%	14%
QC11	0,12	11%	19%	24%	30%	16%
Alternatives weights		14%	20%	23%	27%	15%

It is seen that AT is the most appropriate supplier. When we analyze the qualifications of this supplier, it is seen that it has experience in the kitchen furniture industry and it exports to more than 120 countries. In addition, having franchises in Turkey provides convenience in terms of getting support.

In our study, we also analyzed the supplier evaluation criteria or QCs for every alternative. The objective of doing this is to present the efficiencies of alternative suppliers according to QCs. We have used the performance analysis model which is proposed in Bilisik et al. (2012). The most important criteria are presented in the performance analysis matrix and the company proposes a strategy for their suppliers to increase their performances as a result of this approach. The criteria are explained below and they are presented in Figure 2:

- ***Strong and important criteria:*** The criteria that have high weights and high efficiency of alternatives are evaluated primarily.
- ***Secret criteria:*** The criteria that have high weights and low efficiency are evaluated in second place.
- ***Poor and unimportant criteria:*** The criteria that have low weights and low efficiency are not evaluated preferential.
- ***Standard criteria:*** These criteria which have low weights and high efficiency are open to improvement.

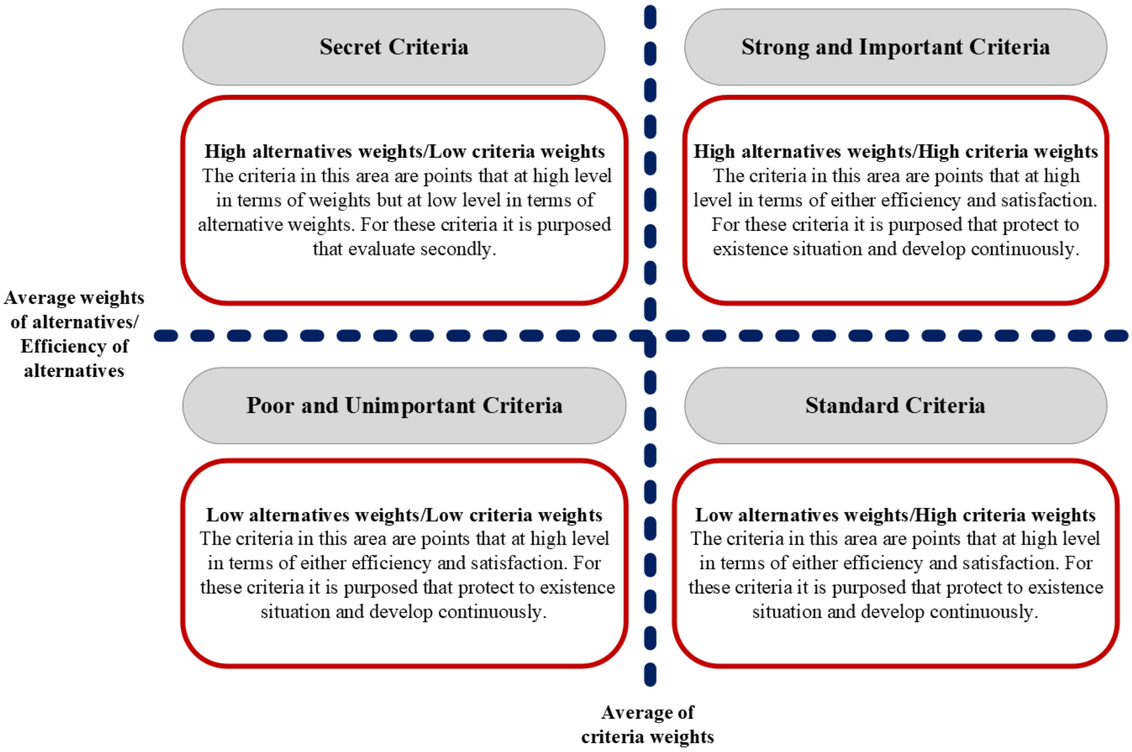

Figure 2. Performance analysis model for supplier selection criteria

The results of the performance analysis model for supplier selection criteria are shown in Figure 4. For the supplier from Turkey-***TR***, the highest QCs weights are handled as "Experiences in the field (QC3)", "Location (QC5), and "Discount (QC8)". They are QCs that must be followed and continued to increase. As seen from the matrix of TR, there are not any QC which is located in strong and important criteria areas. This means, the supplier must focus on standard criteria and increase the quality characteristics which are "Quality certification systems (QC4)", "Management and organizational culture (QC9)", "Financial stability (QC6)", "Reliability of the raw material to the customer and manufacturing processes (QC7)" and Technical capacity (QC11)". For the first supplier from Germany-***DE1***, "Number of patents (QC1)" and "Reverse logistics rate (QC2)" have the highest importance weights and these must be continuously followed and increased. In addition, "Financial stability (QC6), "Reliability of the raw material to the customer and manufacturing processes (QC7)", "Management and organizational culture (QC9)" and "Technical capacity (QC11)" criteria/QCs have lower efficiency, so the suppliers must focus on them and increase the performance. The second supplier from Germany-***DE2*** has strong and important criteria which are "Quality certification systems (QC4)", "Financial stability (QC6)", "Reliability of the raw material to the customer and manufacturing processes (QC7)", "Management and organizational culture (QC9)" and "Technical capacity (QC11)". This company has the second highest average efficiency value and it must protect this strong qualification. Supplier from Austria-***AT*** is the best alternative according to criteria/QCs and the "Quality certification systems (QC4)", "Financial stability (QC6)" and "Technical capacity (QC11)" criteria are determined as strong and important criteria. The weights of criteria for this supplier according to criteria have the highest values and the company must protect and continuously improve their capabilities. Suppliers from Italy-***IT*** have three strong and important criteria which are "Reliability of the raw material to the customer and manufacturing processes (QC7)," "Management and organizational culture (QC9)", and "Technical capacity (QC11)". The company must protect this situation but it must increase the average efficiency value by developing criteria which are determined as standard and poor/unimportant criteria.

3.1. Sensitivity Analysis

In our study, we have determined the QRs' weights by using the NAHP technique and to show the sensitivity of our methodology we have compared the results by changing QRs' weights. In the first scenario, we considered equal QR weights, and in the second scenario, we asked experts to evaluate QRs' importance weights. In Table 17, the result of the sensitivity analysis is presented, and as can be seen in Figure 3, there is not any change in the ranking of alternatives. This can be interpreted as the weights of customer requirements do not influence the final rankings of alternatives.

Table 17. Sensitivity analysis results

	Methodology	**Equal criteria weights**	**Experts' criteria evaluations**
TR	0.1417	0.1425	0.1420
DE1	0.2003	0.2022	0.2025
DE2	0.2350	0.2314	0.2319
AT	0.2658	0.2703	0.2702
IT	0.1571	0.1536	0.1534

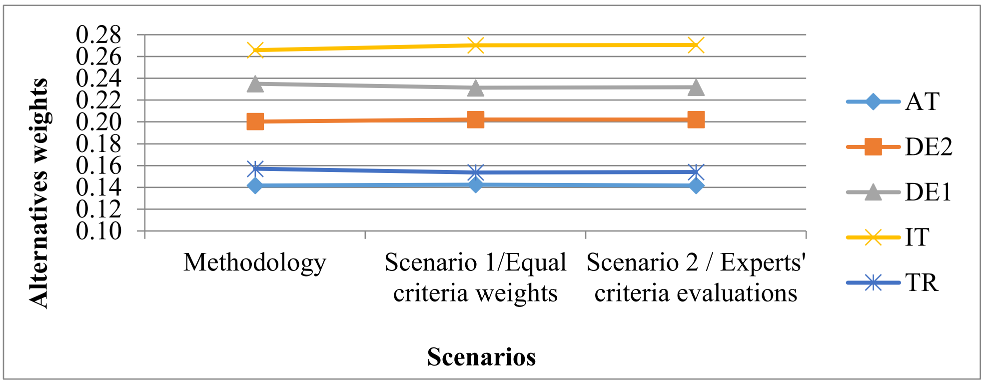

Figure 3. The ranking of alternatives

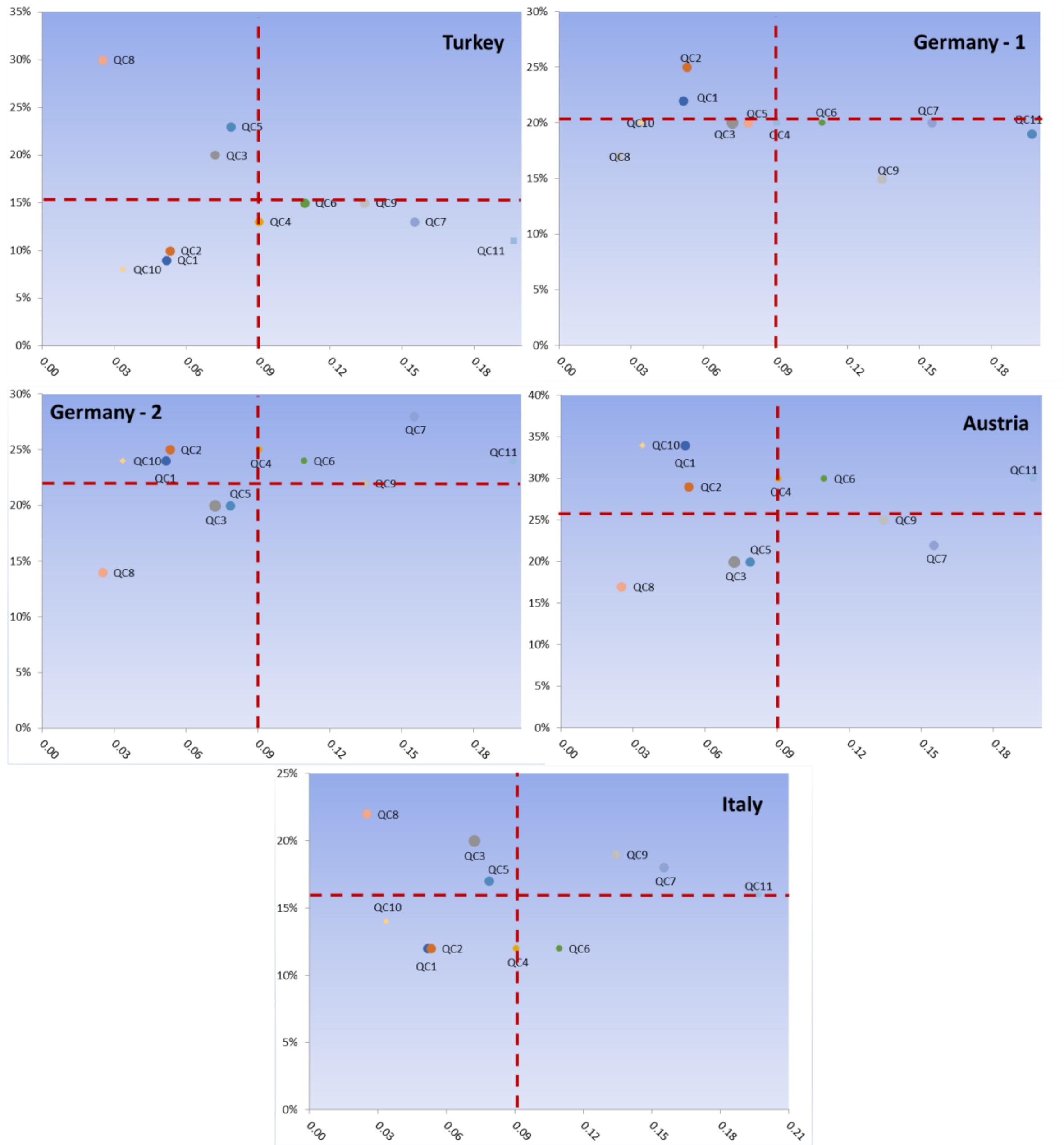

Figure 4. The result of criteria analysis for alternatives

4. Conclusion

Today, with the increase in challenging supply chain conditions for organizations, working with the most appropriate supplier gets more crucial. In addition, considering customers' expectations, needs and requirements is a necessity for organizations to survive for a long time. In our study, with awareness of the importance of these issues, we proposed a customer-oriented methodology to analyze QRs, QCs, and alternative suppliers. Supplier selection problems involve important strategic and operational decisions in a competitive environment with a short lifecycle and where the customer indirectly contributes to the product. In subsequent research, sustainability will play a significant role in the supplier selection process. Thus, customer-oriented supplier selection problems contribute to the literature by adding more environmentally friendly, social, and economic supplier selection criteria.

As a result of our research, although there are several publications that deal with the problem of supplier selection in a furniture production organization, no study has been found that deals with the problem of customer-oriented supplier selection with the QFD and AHP hybrid methodology. In addition, since the evaluators did not have precise information and made their evaluations with linguistic expressions, the evaluation was made with the neutrosophic sets. The business discussed in this study is a company that has customer-oriented production and designs serving in the kitchen furniture sector. For this reason, a model has been proposed in the study to make the most suitable supplier selection considering the requirements of the customers. The theoretical advancement and practical implications according to problem, methodology, and application are given in Table 18.

Table 18. *The theoretical advancements and practical impacts of key categories of this study*

Key Categories	Theoretical Advancements	Practical Impacts
Customer-oriented supplier selection	When the literature is investigated, it is realized that there is not any study about customer-oriented supplier selection for modular kitchen furniture production organization. This study is a novel application, and it will help decision-makers deal with this problem.	With the increase in demand in the kitchen furniture sector, it gets harder to be customer-oriented and to work with the most convenient suppliers. So this study will help sector professionals to manage their end-to-end supply chain process efficiently.
Neutrosophic AHP-QFD	The theory is advanced by applying the methodology to a totally new problem in the literature.	Experts in other industries can apply this methodology to determine the most appropriate suppliers to work with.
Application	This application contributes to the furniture production supply chain theory.	The application conducted is for modular kitchen furniture producers and when the

	literature is researched, it is found that there is not any study that handles this problem.

Neutrosophic AHP was applied to determine the importance levels of the criteria/customer requests determined in the first phase of the study. In the second phase, the quality requirements necessary to meet the customer demands were determined and the weights of the quality requirements were found with the quality function deployment approach. In the third phase, the neutrosophic AHP technique was used again to evaluate alternative suppliers, taking into account the weights of the determined quality requirements. As a result, the ranking of the alternatives was obtained as follows: Austria, Germany-2, Germany-1, Italy, and Turkey. The application of neutrosophic AHP in determining the importance levels of criteria and customer requests, coupled with the integration of the quality function deployment approach in defining quality requirements, demonstrates a comprehensive and systematic methodology for supplier evaluation. The results of the study, which ranked Austria as the top supplier, Germany-2 and Germany-1 following closely, provide actionable insights for the company under consideration.

Our research has made a significant contribution to the field of supplier selection in the context of customer-oriented production within the kitchen furniture sector. The absence of prior studies addressing the specific problem of customer-oriented supplier selection using the AHP hybrid methodology highlights the novelty and importance of this research. The introduction of the neutrosophic sets in the evaluation process, particularly due to evaluators relying on linguistic expressions, adds a considerable dimension to the study. The proposed model aims to optimize supplier selection by considering customers' preferences, experts' opinions, and design-oriented suppliers.

The limitations of our study can be explained as follows: Because this methodology is applied in the kitchen furniture industry, the number of experts is limited. We have asked three experts for their evaluations. Increasing the number of organizations and sector experts may provide more holistic results but this process will take a longer time and be harder. In addition, the evaluations are made using neutrosophic AHP-QFD hybrid methodology. The neutrosophic fuzzy sets are used in all phases and this increases the complexity of the methodology.

This study will give insight to managers to evaluate the performance of suppliers and select the most suitable supplier who is more customer-focused. In the proposed method, we determine supplier selection criteria weights via the neutrosophic AHP technique and we related these criteria with QCs via the neutrosophic QFD approach to find the most appropriate supplier. While evaluating suppliers, using this hybrid decision-making approach will provide organizational efficiency by considering qualitative and quantitative criteria. Additionally, the performance analysis model used provides a decision support structure for managers. Thanks to this model, managers will be able to see the level of fulfillment of the criteria and enable action plans to be made regarding them.

In future studies, solutions can be developed by using different solution methodologies for customer-oriented supplier selection. Applications of the methodology used in this study in different sectors can be examined. In addition, while choosing a supplier, the criteria can be updated with a sustainability-oriented approach as well as a customer-oriented approach. Future studies could explore alternative solution methodologies for customer-oriented supplier selection and investigate the applicability of the proposed model in diverse industry sectors. Additionally, there is potential to update supplier selection criteria with a sustainability-oriented approach, aligning with the growing importance of environmentally conscious practices in contemporary business operations. Overall, this research lays the foundation for further advancements in the strategic process of supplier selection, emphasizing the need for ongoing innovation and adaptation in response to evolving business landscapes.

Data availability statement

Authors can be contacted if any other data related to the study is required.

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