

# A Hybrid QFD-based Decision-Making Model for Prioritizing Supplier Selection-Economic Indicators in a Furniture Company

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## Research Article



**Abstract** – In this study, a hybrid quality function deployment (QFD)-based decision-making model was proposed to prioritize economic indicators of supplier selection in a furniture company. The hybrid model is designed to prioritize economic indicators in the furniture company by measuring the influence of decision-makers through expert order weights and to ensure the effective use of step-wise weight assessment ratio analysis (SWARA) and the technique for order preference by similarity to ideal solution (TOPSIS) within the evaluation processes of a QFD-based decision mechanism. This hybrid QFD-based model has three main phases: i) Determining conceptual inputs of QFD-main structure, ii) Creating experts-weighted decision matrices, iii) Prioritizing/ranking/selecting supplier selection (SS)-economic indicator-alternatives. In the first phase, a QFD-team was formed with influential decision makers (experts) in the company's supply chain evaluations. Then, the two main QFD-conceptual inputs, customer needs (CNs) and supplier characteristics (SCs), were identified. The G1-order weights of experts were calculated using G1-order relation analysis. In the second phase, experts' G1-weighted CN-importance values were computed through SWARA method. Also, experts' G1-weighted CN-SC relationship evaluations-based decision matrices were obtained in this phase. Prioritizing/ranking/selecting SS-economic indicator-alternatives were executed in the third phase. The indicator-alternatives were prioritized by their closeness degrees calculated through TOPSIS. Consequently, *financial capability*, *competative cost/price*, and *quality* were determined as the most important indicator-alternatives for the furniture company using Pareto analysis.

**Keywords** – QFD, multi-criteria decision-making, Pareto analysis, SS-economic indicator, furniture industry

## Bir Mobilya Firmasında Tedarikçi Seçimi-Ekonomik Göstergelerinin Önceliklendirilmesi için Hibrit bir KFY-temelli Karar Verme Modeli

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## Araştırma Makalesi

**Öz** – Bu çalışmada, bir mobilya firmasında tedarikçi seçiminde ekonomik göstergelerin önceliklendirilmesi için hibrit bir kalite fonksiyon yayılımı (KFY) tabanlı karar verme modeli önerilmiştir. Hibrit model, karar vericilerin etkisini uzman sıra ağırlıkları ile ölçerek mobilya firmasında ekonomik göstergelerin önceliklendirilmesini ve KFY tabanlı bir karar mekanizması içinde adım adım ağırlık değerlendirme analizi (SWARA) ve ideal çözüme yakınlık tekniği (TOPSIS) yöntemlerinin etkin kullanımını sağlamayı amaçlamaktadır. Bu hibrit KFY tabanlı model üç ana aşamadan oluşmaktadır: i) KFY ana yapısının kavramsal girdilerinin belirlenmesi, ii) Uzman ağırlıklı karar matrislerinin oluşturulması, iii) Tedarikçi seçimi (TS) ekonomik gösterge alternatiflerinin önceliklendirilmesi / sıralanması / seçilmesi. İlk aşamada, firmanın tedarik zinciri değerlendirmelerinde etkili karar vericilerden (uzmanlardan) oluşan bir KFY ekibi oluşturulmuştur. Ardından, iki ana KFY kavramsal girdisi olan müşteri ihtiyaçları (Mİ'ler) ve tedarikçi özellikleri (TÖ'ler) belirlenmiştir. Uzmanların G1-sıra ağırlıkları, G1-sıra ilişkisi analizi kullanılarak hesaplanmıştır. İkinci aşamada, uzmanların G1 ağırlıklı Mİ-önem değerleri SWARA yöntemi ile hesaplanmıştır. Ayrıca, uzmanların G1 ağırlıklı Mİ - TÖ ilişki değerlendirmelerine dayalı karar matrisleri bu aşamada elde edilmiştir. Üçüncü aşamada, tedarikçi seçimi ekonomik gösterge alternatiflerinin önceliklendirilmesi / sıralanması / seçilmesi gerçekleştirilmiştir. Alternatifler, TOPSIS ile hesaplanan yakınlık derecelerine göre önceliklendirilmiştir. Sonuç olarak, Pareto analizi kullanılarak, mobilya firması için *finansal yetenek*, *rekabetçi maliyet/fiyat* ve *kalite* en önemli gösterge alternatifleri olarak belirlenmiştir.

**Anahtar Kelimeler** – KFY, çok-kriterli karar-verme, Pareto analizi, TS-ekonomik göstergesi, mobilya sektörü

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## 1. Introduction

In the face of globalization and changing consumer demands, organizations need to accurately analyze customer expectations and accelerate their efforts to develop/improve the necessary technical requirements/attributes in their production/service processes. Businesses focus on creating a decision-making mechanism based on scientific techniques and integrating it into their business processes to keep up with the changing and developing competitive environment. In this context, quality function deployment (QFD) is a critical approach that systematically transfers customer voice/expectations to technical characteristics. QFD in Figure 1, which has been demonstrated with various industrial benefits and is frequently used in individual and/or organizational decision-making processes today, was incorporated into the literature by Akao (1990; 1997) in the 1960s.

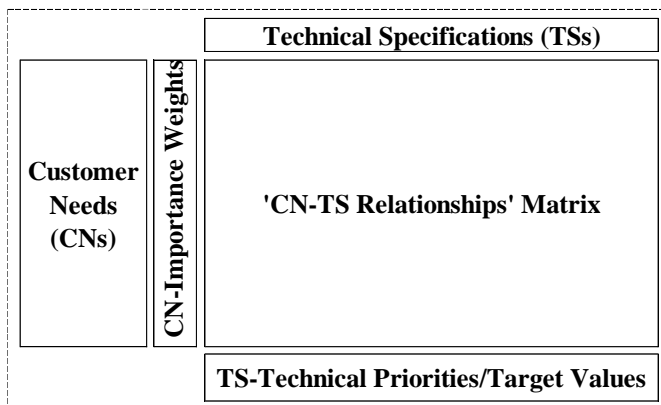


Figure 1. QFD-main structure

QFD is a design and quality management tool used in various functional areas such as planning, product design, management, product/service development, customer needs analysis, engineering, supply chain, pricing, and scheduling (Chan and Wu, 2002; Baskir et al., 2017). The process of translating customer voice (expectations/needs/requirements) into technical characteristics (attributes/specifications) using QFD involves the identification and evaluation of various criteria and alternatives. QFD has three main objectives: i) Identifying and prioritizing customer needs, ii) Evaluating the relationships between customer needs (CNs) and technical specifications (TSs), and iii) Determining target values/prioritizing TSs. QFD-based identification/evaluation is carried out with influential team members (experts) in the decision-making mechanism. Despite its widespread applications, QFD exhibits several limitations, including vagueness in capturing the customer's voice, challenges in handling linguistic data, ambiguity in assigning target values, differences in the influence of experts on decision-making, assigning weights to expert-assessments, and limitations of alternative comparisons (Bouchereau and Rowlands, 2000; Büyüközkan et al., 2007; Song et al., 2020; Baskir, 2023). There are numerous studies involving the integration of QFD and multi-criteria decision-making (MCDM) methods to address these limitations (Yazdani et al., 2016; Song et al., 2020; Baskir, 2023; Sharma and Tripathy, 2023; Sumrit and Keeratibhubordee, 2025). Two main focuses of MCDM-based implementations are related to prioritizing several alternatives and selecting the best alternative over various criteria. QFD-MCDM integration enhances decision-making by providing an objective, systematic, and transparent approach for prioritizing TSs and evaluating alternatives. Besides, this integration can reduce subjectivity and enable effective handling of complex and/or ambiguous data.

The furniture industry has a highly competitive structure in design, production, and supply of products that meet aesthetic and functional expectations. Companies operating in the furniture industry are responsible for making their sustainable supply strategies financially viable and ensuring operational efficiency. Determining and prioritizing economic indicators in supplier selection allows companies to achieve their sustainability goals in a balanced manner with profitability, resource optimization, and long-term competitive advantage. Thus,

determining/prioritizing SS-economic indicators are crucial for guiding strategic decision-making in the furniture industry. There are various QFD and/or MCDM integration-based furniture implementations in the literature (e.g., Kuang et al., 2013; Erdil, 2020; Yeşilkaya et al., 2022; İnce et al., 2023; Liu et al., 2025; Özden and Şenyiğit, 2025). Unlike previous studies, this study aims to prioritize SS-economic indicator-alternatives in a furniture company by employing a hybrid QFD-SWARA-TOPSIS model based on the G1-order weights of experts in the decision-making process.

In this study, a hybrid QFD-based decision-making model is proposed to prioritize SS-economic indicator-alternatives in a furniture company. The five components of the hybrid model involve: identifying customer needs (CNs) and supplier characteristics (SCs); determining QFD-experts; calculating the order weights of the QFD-experts in the decision-making process using the order relation analysis (G1-method); determining CN-weights combined with expert-weights through SWARA; and prioritizing the SS-economic indicator-alternatives using TOPSIS. Subsequently, the highest-priority indicator-alternatives is determined through a Pareto analysis based on the SC-normalized closeness degrees generated by the hybrid model. The results of the proposed hybrid model for prioritizing economic indicators in the furniture company will be compared with those obtained from the version incorporating only the QFD-SWARA integration.

This study is organized as follows: Literature review on the integration of QFD with SWARA/TOPSIS and furniture industry-based QFD/MCDM implementations is given in a subsection of the Introduction. The hybrid QFD-based decision-making model is presented in Section 2. The implementation of the hybrid approach for prioritizing SS-economic indicator-alternatives in a furniture company is given in Section 3. The conclusion is summarized in Section 4.

## **1.1. Literature Review**

A literature review was conducted on two aspects: i) The integrated QFD and/or SWARA/TOPSIS approaches-based studies, ii) Furniture industry-based QFD and/or MCDM implementation-studies.

### **1.1.1. The Integration of QFD with SWARA/TOPSIS Approaches**

Kumaraswamy et al. (2011) proposed an integrated QFD-TOPSIS model to evaluate ten candidate suppliers based on eight criteria (i.e., delivery, quality, management, etc.). Cost factors (i.e., order management cost, transportation cost, etc.) for the supplier selection procedure were also investigated. The effectiveness of the purchasing decisions for SMEs was investigated using the integrated model.

Yang et al. (2013) showed that applying QFD to campus furniture design aligns user needs with wood material properties, improving product quality, reducing design flaws, shortening development time, and lowering production costs.

Li et al. (2014) developed a selection model by integrating intuitionistic fuzzy sets, QFD, and TOPSIS to carry out the selection of a knowledge management system (KMS) for the Aviation Design Institute in China. Four customer criteria (i.e., knowledge finding, knowledge sharing, etc.) and five system criteria (i.e., knowledge sharing, knowledge community, etc.) were identified to rank five KMS-alternatives.

Pramanik et al. (2016) proposed the integration of QFD, Analytic Hierarchy Process (AHP), and fuzzy TOPSIS to evaluate supplier performance in a manufacturing system and to identify a resilient supplier. Four decision makers with equal importance weight, three manufacturer-criteria (production-conformity, fitment, and mean-time between failures), and five resilience criteria (i.e., buffer capacity, re-engineering, adaptive capability, etc.) were determined to select the resilient supplier using the integrated approach.

Yazdani et al. (2016) presented a novel integrated QFD-SWARA-Weighted Aggregated Sum Product Assessment (WASPAS) method to implement supplier evaluation at the Iranian Steel Alborz Company. Seven

customer requirements (i.e., quality adoption, price, green design, etc.), and eight supplier characteristics (i.e., financial stability, quality control systems, reverse logistics, etc.) were determined to rank six green suppliers.

Van et al. (2018) proposed an interval neutrosophic set (INS)-based QFD to support green supplier evaluation in a transportation parts company. INS was used to assess product characteristics, supplier criteria, correlations, weights, and supplier impacts, while TOPSIS generated the final ranking of green suppliers.

Song et al. (2020) proposed a novel linguistic Z-numbers (LZNs)-based decision-making framework combining QFD, SWARA, and TOPSIS to prioritize engineering characteristics for a logistics service provider. Three QFD-team members with G1-based importance weights, six customer requirements (i.e., lead time, flexibility, reliability, etc.), and eight engineering characteristics (i.e., service-quality, just-in time, demand forecasting methods, etc.) were determined to rank the engineering characteristics using the proposed framework. The importance weights of QFD-team members were calculated using G1-relative relation analysis and the improved maximum consensus method and integrated into the proposed LZN-based decision-making framework.

Sharma and Tripathy (2023) proposed a combined QFD-fuzzy TOPSIS approach to prioritize electronic equipment suppliers and select the best supplier for an electronics company. Three decision makers with equal importance weight, seven customer needs (i.e., product quality, cost, delivery reliability, etc.), and eight supplier characteristics (i.e., financial position, the flexibility of responding to customer demand, supplier capacity, etc.) were determined to rank the suppliers using the combined approach.

Sumrit and Keeratibhubordee (2025) offered an integrated Fermatean fuzzy set-based QFD-SWARA approach to assess proactive risk mitigation strategies in recycling supply chain. Seven industrial experts, seven risk factors regarding incoming raw material, stakeholders collaboration, inventory, etc., and proactive risk mitigation strategies (PMSs) (i.e., buyer-supplier collaboration, supply chain information sharing, supply chain visibility, etc.) were identified to prioritize/rank the PMSs.

### **1.1.2. Furniture Industry-based QFD and/or MCDM Applications**

Kuang et al. (2013) analyzed QFD and Theory of Inventive Problem Solving (TRIZ) concepts, explored their link to furniture innovation, and proposed a QFD-TRIZ-based design model that translates user needs into a TRIZ contradiction matrix via HOQ. The usage of QFD-TRIZ methods in furniture design was executed for a small apartment furniture example.

Tekez and Bark (2016) applied a fuzzy TOPSIS approach for supplier selection at a furniture factory located in Sakarya. Five decision-makers selected six supplier selection criteria from the literature. Based on these six criteria, the ranking of 10 suppliers was carried out using the fuzzy TOPSIS approach.

Erdil (2020) proposed the integrated use of Pareto analysis and QFD as an effective approach to enhance product development and customer loyalty in the furniture industry, emphasizing the incorporation of the voice of the customer.

Yeşilkaya et al. (2022) conducted a potential analysis of provinces in Turkey based on industrial wood production using TOPSIS and Vİekriterijumsko KOMPromisno Rangiranje (VIKOR). Different wood types were considered as criteria and provinces as alternatives. The results from both methods were compared and visualized on a map.

Ince et al. (2023) addressed the lean and sustainable supplier selection problem of a large-sized wood-panel-based furniture manufacturer through a systematic approach. They integrated lean and sustainability key performance indicators (KPIs) into MCDM methods, evaluating 18 economic, environmental, and social criteria for supplier suitability. Criteria weights were assigned using the entropy method, and supplier options were compared via Fuzzy Additive Ratio Assessment (Fuzzy ARAS) and Fuzzy TOPSIS.

Puspita Sari et al. (2024) focused on designing a pump-gallon product from wood waste using an integrated QFD-TRIZ approach. QFD was used to identify consumer needs and technical responses. TRIZ was used to resolve technical contradictions. An economic feasibility analysis based on the cost-benefit ratio was conducted, resulting in a multifunctional, modular gallon pump design.

Ince et al. (2025) investigated the production of outdoor wooden park benches, identifying lean wastes across seven operations within a sustainability framework. Eleven economic and environmental lean KPIs were used to prioritize 13 lean failure modes with risk priority numbers (RPNs) above 100, generating project proposals. Eighteen lean tools were ranked using Fuzzy QFD method.

Liu et al. (2025) integrated the Socialization, Externalization, Combination, and Internalization (SECI) model, text mining, and AHP-QFD to address bamboo furniture-issues, as a low-carbon industry that faces challenges in design clarity and user need quantification. SECI was used to structure the research process, Bidirectional Encoder Representations from Transformers Topic Model (BERTopic) was used to extract key user needs from online reviews, AHP was used to prioritize them, and QFD was used to convert them into weighted design elements and technical attributes.

Özden and Şenyiğit (2025) examined three spare part pricing methods (Coefficient-Based, Fixed-Ratio, and Hybrid) used by a furniture company, applying MCDM techniques with various weighting and ranking algorithms. The criteria weights for these methods were evaluated using TOPSIS, Stable Preference Ordering Towards Ideal Solution (SPOTIS), Multi-Attributive Border Approximation Area Comparison (MABAC), and Evaluation based on Distance from Average Solution (EDAS).

## 2. Material and Method

In this section, the methodological components of the hybrid model are presented as embedded within its procedural steps. The hybrid model has three phases: i) Conceptual planning, ii) Constructing decision matrices, and iii) Prioritizing procedures of supplier characteristics. The procedural execution of these phases takes place in a total of five steps. The flowchart of the hybrid model is illustrated in Figure 2.

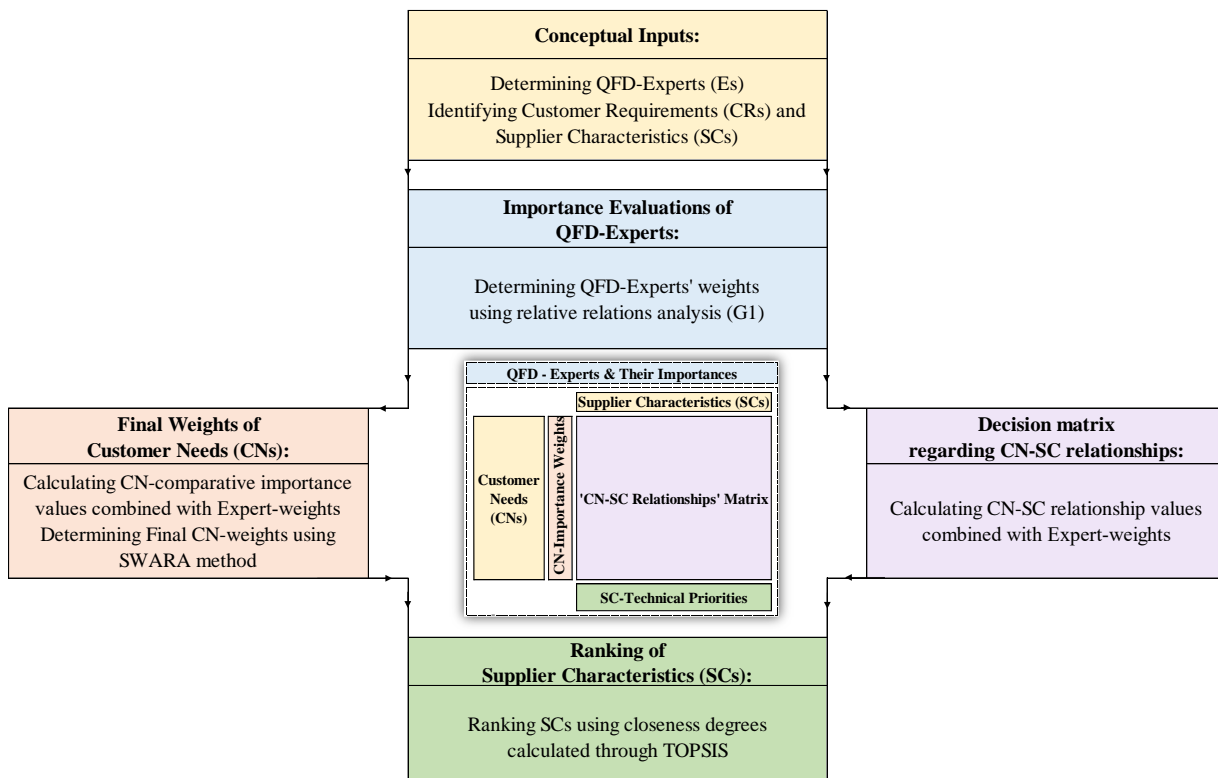


Figure 2. Flowchart of the hybrid QFD-based decision-making model.

The steps of the hybrid model are explained in the following sub-sections.

### 2.1. The Conceptual-Input Definitions for QFD Planning Procedures

The components of QFD (customer needs, supplier characteristics, QFD-team experts) are defined. Customer needs ( $CN_i, i = 1, 2, \dots, n; n: \# \text{ of CNs}$ ) and Supplier characteristics ( $SC_j, j = 1, 2, \dots, m; m: \# \text{ of SCs}$ ) are identified, and QFD-experts/team members ( $E_l, l = 1, 2, \dots, h; h: \# \text{ of experts}$ ) are determined.

### 2.2. Determining the Weights of Experts

The expert-weights (E-weights) regarding priorities/influences in decision-mechanism are determined using G1-order relations analysis (Ruan and Yang, 2014). The calculating procedures of G1 method are given in the following steps:

*Step G1.1:* A leader/an expert can determine the effects of experts (Es) on the decision-mechanism in descending order.

*Step G1.2:* Relative importance scales of the adjacent Es are given in Table 1. According to Table 1, relative importance scale can be defined by  $r_l = \frac{\theta_{l-1}}{\theta_l}, l = 2, 3, \dots, h$ .

Table 1

Importance scale of QFD-experts (Song et al., 2020)

$\theta_l$	Explanation
1.0	$E_{k-1}$ and $E_k$ have equal importance
1.2	$E_{k-1}$ is somewhat more important than $E_k$
1.4	$E_{k-1}$ is obviously important than $E_k$
1.6	$E_{k-1}$ is strongly more important than $E_k$
1.8	$E_{k-1}$ is extremely more important than $E_k$

*Step G1.3:* The E-weights are calculated as in Equations 1 and 2:

$$\lambda'_l = \left(1 + \sum_{l=2}^h \sum_{k=l}^h r_k\right)^{-1} \quad (1)$$

$$\lambda_{l-1} = r_l \lambda'_l \quad (2)$$

### 2.3. Creating Decision Matrices

CN-SC relationship-evaluation matrix of each QFD-expert  $U^l = [u_{ij}^l]_{n \times m}$  ( $l = 1, \dots, h$ ) is created, where  $u_{ij}^l$  is the  $l^{\text{th}}$  expert-evaluation for  $j^{\text{th}}$  SC in terms of the  $i^{\text{th}}$  CN. The decision matrix  $V = [v_{ji}]_{m \times n}$  (in Equation 3) is obtained by  $v_{ji} = (u_{ij}^l)' \lambda_l = u_{ji}^l \lambda_l$ .

$$V = [v_{ji}]_{m \times n} = \begin{bmatrix} v_{11} & \cdots & v_{1n} \\ \vdots & \ddots & \vdots \\ v_{m1} & \cdots & v_{mn} \end{bmatrix} = \begin{bmatrix} u_{11}^l \lambda_l & \cdots & u_{n1}^l \lambda_l \\ \vdots & \ddots & \vdots \\ u_{m1}^l \lambda_l & \cdots & u_{mn}^l \lambda_l \end{bmatrix} \quad (3)$$

### 2.4. Determining the Importance Weights of CNs

The relative importance weights of CNs are calculated using SWARA (Keršulienė et al., 2010) as follows:

*Step S.1:* QFD-experts rank CNs by the CN-relative importance values. As a result of the CN-ranking, the most important CN is listed first.

*Step S.2:* The comparative-importance value of the adjacent CNs ( $s_i^l, i = 2, 3, \dots, n; l = 1, 2, \dots, h$ ) are determined by each QFD-expert. The final comparative value of CNs ( $s_i$ ) is calculated as in Equation 4.

$$s_i = \sum_{l=1}^h \lambda_l s_i^l \quad (4)$$

*Step S.3:* The characteristics of  $x_i$ -comparative importance and  $y_i$ -recalculated weights are determined as in Equations 5 and 6, respectively.

$$x_i = s_i + 1 \quad (5)$$

$$y_i = \frac{y_{i-1}}{x_i} \quad (6)$$

*Step S.4:* The final weights of CNs ( $w_i, i = 1, 2, \dots, n$ ) are calculated as in Equation 7.

$$w_i = \frac{y_i}{\sum_{i=1}^n y_i} \quad (7)$$

## 2.5. Prioritizing the SCs

SCs are prioritized using the following steps of TOPSIS (Hwang and Yoon, 1981):

*Step T.1:* Positive/Negative ideal solutions are defined as in Equations 8 and 9, respectively ( $j = 1, 2, \dots, m; i = 1, 2, \dots, n$ ).

$$\text{Positive ideal solution: } v_i^+ = \max_j v_{ji} \quad (8)$$

$$\text{Negative ideal solution: } v_i^- = \min_j v_{ji} \quad (9)$$

*Step T.2:* The Euclidean distances between CNs and both positive and negative ideal solutions are computed as in Equations 10 and 11, respectively.

$$d_j^+ = \sum_{i=1}^n w_i d(v_{ji}, v_i^+) \quad (10)$$

$$d_j^- = \sum_{i=1}^n w_i d(v_{ji}, v_i^-) \quad (11)$$

where  $w_i$  is the  $i^{\text{th}}$  CN-final weight ( $i = 1, 2, \dots, n$ ).

*Step T.3:* The prioritizing/ranking SCs is executed by the closeness degrees ( $C_j, j = 1, 2, \dots, m$ ) in Equation 12.

The SC with the highest closeness value is considered the top priority.

$$C_j = \frac{d_j^-}{d_j^- + d_j^+} \quad (12)$$

The min-max normalization method can be used to normalize the relevant variables of the hybrid model (i.e., decision matrix, closeness degree, etc.).

## 3. Results and Discussion

This section presents the hybrid model's conceptual preparation, evaluation procedures, and comparative results under three subheadings.

### 3.1. Conceptual Preparations of Case Study

The hybrid QFD-based decision-making model was applied to prioritizing the economic characteristics of suppliers in a furniture company. QFD-conceptual inputs (customer needs and supplier characteristics) and evaluations were executed by three QFD-experts. The QFD-team (QFD-experts) consisted of the general manager (E1), the purchasing manager (E2), and the quality manager (E3) in the furniture company. The relevant customer needs (CNs) and supplier characteristics (SCs) were determined by the most frequent SS-economic

indicators (Zhou and Xu, 2018) and QFD-expert opinions. The CNs and SCs are given in Table 2 and 3, respectively.

Table 2  
The CNs and their explanations

Customer Need (CN)	Explanation
CN1: Affordable price advantage	Price advantage over competitors fulfills long-term cost management.
CN2: On-time delivery reliability	On-time delivery is necessary/vital for production planning.
CN3: Continuous supply capability	It is necessary to ensure supply continuity and reduce the stock-out risk.
CN4: Rapid adaptation to demand changes	It is necessary to meet new product/service change demands and ensure production adaptation.
CN5: Quality guarantee	Product quality and error-free delivery are critical for customer satisfaction and cost control.

Table 3  
The SCs and their explanations

Supplier Characteristic (SC)	Explanation
SC1: Competitive cost/price	To achieve cost efficiency and competitive advantage from the perspective of the company or customer.
SC2: Delivery time	The capability to transport the product to the predefined location
SC3: Quality	The performance of purchased materials to meet the expectations for the committed service or product.
SC4: Financial capability	The capital capability needed to maintain business operations
SC5: Flexibility in responding to demand	Time/cost management flexibility in meeting product volume changes and integrating new product demand into existing production processes
SC6: Service capability	Rapid adaptation to operational situations such as changes in product volume and integrating new product demand into existing production processes

### 3.2. The Hybrid Model Evaluation-Procedures

The QFD-Experts were sorted by their task definitions and decision priority regarding supplier selection as follows:

E1 (general manager) and E3 (quality manager) represent the maximum and minimum weights, respectively. E2 (purchasing manager) accounts for medium weight and lies between E1 and E3. The relative importance value in Table 1 were assigned as  $\theta_2=1.2$  (E1 is somewhat more important than E2) and  $\theta_3=1.2$  (E2 is somewhat more important than E3). According to the G1 method, the E-weights were found as  $E1 \rightarrow \lambda'_1 = 0.39$ ,  $E2 \rightarrow \lambda'_2 = 0.33$ , and  $E3 \rightarrow \lambda'_3 = 0.28$ . These E-weights were used for the remaining steps of the hybrid model. The comparative-importance value (CIV) between adjacent CNs were determined by each expert (see Table 4).

Table 4  
Each expert's assessment of the CIV between adjacent CNs

Expert	Linguistic Importance Scale			
E1	$CN_{(5 \rightarrow 1)}: 0.10$	$CN_{(2 \rightarrow 5)}: 0.15$	$CN_{(3 \rightarrow 2)}: 0.25$	$CN_{(4 \rightarrow 3)}: 0.35$
E2	$CN_{(2 \rightarrow 1)}: 0.15$	$CN_{(3 \rightarrow 2)}: 0.25$	$CN_{(5 \rightarrow 3)}: 0.35$	$CN_{(4 \rightarrow 5)}: 0.5$
E3	$CN_{(1 \rightarrow 5)}: 0.20$	$CN_{(2 \rightarrow 1)}: 0.25$	$CN_{(3 \rightarrow 2)}: 0.40$	$CN_{(4 \rightarrow 3)}: 0.50$

$CN_{(i_1 \rightarrow i_2)}$ :  $CN_{i_1}$  is less important than or equal to  $CN_{i_2}$ .

CN-weights for each expert were calculated using SWARA, as shown in Table 5. The last row of Table 5 shows the final E-weighted CN-importance values. These final CN-weights (Es-weighted CN-importance values) were used when performing the TOPSIS steps for SCs-prioritization.

Table 5

The final E-weighted CN-importance values and their SWARA-calculations

E1	$s_j^1$	$x_j^1$	$y_j^1$	$w_j^1$	
CN1		1	1	0.26	
CN5	0.1	1.10	0.91	0.24	
CN2	0.15	1.15	0.79	0.21	
CN3	0.25	1.25	0.63	0.17	
CN4	0.35	1.35	0.47	0.12	
E2	$s_j^2$	$x_j^2$	$y_j^2$	$w_j^2$	
CN1		1	1	0.29	
CN2	0.15	1.15	0.87	0.26	
CN3	0.25	1.25	0.70	0.20	
CN5	0.35	1.35	0.52	0.15	
CN4	0.5	1.50	0.34	0.10	
E3	$s_j^3$	$x_j^3$	$y_j^3$	$w_j^3$	
CN5		1	1	0.30	
CN1	0.2	1.20	0.83	0.25	
CN2	0.25	1.25	0.67	0.20	
CN3	0.4	1.40	0.48	0.15	
CN4	0.5	1.50	0.32	0.10	
Overall Es ( $\lambda_1^1/\lambda_1^2/\lambda_1^3$ ): (0.39/0.33/0.28)	CN1	CN2	CN3	CN4	CN5
E-weighted CN-weights	0.27	0.22	0.17	0.11	0.23

Following the CN-SC relationship evaluations by QFD-experts using global weights (1: weak, 3: moderate, 9: strong relationship), the E-weighted CN-SC relationships-based decision matrices were generated by multiplying the CN-SC assessments of each expert with the respective E-weight. The E-weighted CN-SC relationships-based decision matrices are given in Table 6.

Table 6

The Es-weighted CN-SC relationships-based decision matrices

E1	CN1* $\lambda_1^1$	CN2* $\lambda_1^1$	CN3* $\lambda_1^1$	CN4* $\lambda_1^1$	CN5* $\lambda_1^1$
SC1	3.52	3.52	1.17	1.17	3.52
SC2	1.17	3.52	0.39	0.39	1.17
SC3	1.17	1.17	0.39	0.39	3.52
SC4	3.52	3.52	1.17	1.17	3.52
SC5	3.52	1.17	3.52	1.17	1.17
SC6	1.17	1.17	3.52	3.52	1.17
E2	CN1* $\lambda_1^2$	CN2* $\lambda_1^2$	CN3* $\lambda_1^2$	CN4* $\lambda_1^2$	CN5* $\lambda_1^2$
SC1	2.99	2.99	0.33	0.33	1
SC2	2.99	2.99	1	1	1
SC3	1	2.99	2.99	1	2.99
SC4	2.99	2.99	2.99	1	1
SC5	2.99	0.33	2.99	1	0.33
SC6	1	1	2.99	2.99	1
E3	CN1* $\lambda_1^3$	CN2* $\lambda_1^3$	CN3* $\lambda_1^3$	CN4* $\lambda_1^3$	CN5* $\lambda_1^3$
SC1	2.49	0.83	0.28	0.28	2.49
SC2	0.83	2.49	0.83	0.83	2.49
SC3	2.49	0.83	0.28	0.83	2.49
SC4	2.49	0.28	0.28	2.49	0.83
SC5	0.28	2.49	0.28	0.83	2.49
SC6	0.83	2.49	0.83	0.83	2.49

The final decision matrix was obtained by summing the CN-SC decision matrices calculated for each expert and multiplying the resulting overall decision matrix by the CN-weights. The final normalized decision matrix is given in Table 7. The normalization procedures were executed using min-max normalization method.

Table 7

The final normalized decision matrix

	CN1	CN2	CN3	CN4	CN5
SC1	1	0.67	0	0	0.6
SC2	0.33	1	0.08	0.08	0.13
SC3	0.28	0.2	0.34	0.08	1
SC4	1	0.56	0.48	0.52	0.27
SC5	0.63	0	0.9	0.22	0
SC6	0	0.13	1	1	0.13
CN-weights	0.27	0.22	0.17	0.11	0.23

The distances between CNs and both positive and negative ideal solutions, closeness degrees of SCs, and SC-rankings are given in Table 8.

Table 8

The closeness degrees of SCs and SC-rankings

SC	d+ (positive ideal solution)	d- (negative ideal solution)	Closeness	Normalize Closeness	SC-Ranking
SC1	0.23	0.34	0.59	0.99	2
SC2	0.33	0.24	0.42	0.30	4
SC3	0.3	0.25	0.45	0.43	3
SC4	0.22	0.32	0.59	1	1
SC5	0.34	0.23	0.4	0.21	5
SC6	0.39	0.21	0.35	0	6

The most critical indicator-alternatives were selected using Pareto analysis in Figure 3. According to Figure 3, the first three indicators (*SC4: Financial capability, SC1: Competitive cost/price, SC3: Quality*) account for 82.1% of the total weight. The furniture company can concentrate its limited resources on these critical indicator-alternatives, achieving more effective strategic decision-making results.

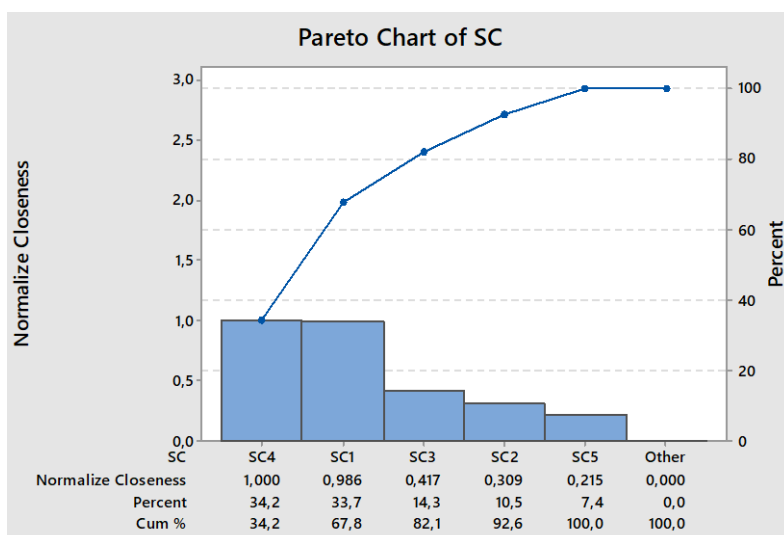


Figure 3. Pareto analysis for the SS-economic indicator-alternatives

### 3.3. Comparative Results

The hybrid model including QFD-SWARA-TOPSIS was compared with the QFD-SWARA. The expert decision weights (the E-weights) were included in the calculations in both models. The SC-rankings of the models are given in Table 9. According to Table 9, the first three (*SC4: Financial capability*, *SC1: Competitive cost/price*, *SC3: Quality*) and the last (*SC6: Service capability*) indicator-alternatives are same for both models. In the hybrid model, the indicator-alternative “*SC2: Delivery time*” ranks fourth, whereas in the QFD-SWARA model, this indicator-alternative ranks fifth. The indicator-alternative “*SC5: Flexibility in responding to demand*” ranks fifth in the hybrid model and fourth in the QFD-SWARA model. The normalized target values of the compared models are illustrated in Figure 4.

Table 9

Ranking-comparisons of the QFD-SWARA and the hybrid model

Economic indicator-alternative	QFD-SWARA Model	The Hybrid Model
SC1: Competitive cost/price	2	2
SC2: Delivery time	5	4
SC3: Quality	3	3
SC4: Financial capability	1	1
SC5: Flexibility in responding to demand	4	5
SC6: Service capability	6	6

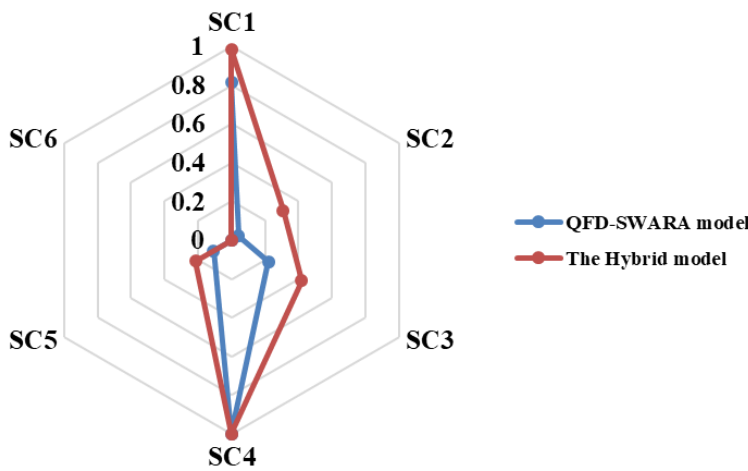


Figure 4. The target values of the compared models

### 4. Conclusion

This study aimed to develop a hybrid QFD-based decision-making model integrating QFD with SWARA and TOPSIS to prioritize SS-economic indicator-alternatives in a furniture company. The QFD experts’ importance weights in the decision-making process were also integrated across all evaluation layers of this hybrid model. This QFD-experts’ importance weighted hybrid model offers a rational solution approach for the identification and prioritization of SS-economic indicators to the stakeholders of the furniture company (managers, employees, and suppliers). Furthermore, this hybrid model integrates SWARA’s transparent, expert-driven weighting approach and TOPSIS’s ideal-solution-based ranking mechanism into the QFD-evaluations. After implementing this hybrid model to prioritizing/ranking furniture sector-based SS-economic indicators, the most important indicators were determined using Pareto analysis. The results revealed that *SC4: Financial capability*, *SC1: Competitive cost/price*, and *SC3: Quality* are the most critical SS-economic indicators, while *SC2: Delivery time*, *SC5: Flexibility in responding to demand*, and *SC6: Service capability* hold relatively

lower priority. Finally, when comparing the hybrid QFD-SWARA-TOPSIS model to the QFD-SWARA approach without TOPSIS, it was observed that the *SC2: Delivery time* and *SC5: Flexibility in responding to demand* indicators were ranked differently. In contrast, the other indicators maintained the same ranking in both models. This study demonstrates the applicability of the proposed hybrid method in an industrial context, providing a guiding framework for decision-making processes in various fields and for future research.

Future research could apply the hybrid QFD-based decision-making model to different manufacturing/service sectors and compare the results using QFD-based decision models integrated with alternative multi-criteria decision-making methods.

### Author Contributions

Mükerrem Bahar Başkır (Corresponding Author) conceptualized the study, designed the methodology, conducted the formal analysis, curated the data, wrote the original draft, and reviewed and edited the manuscript. Berna Bozkurt contributed to data curation, and participated in reviewing and editing the manuscript.

### Conflict of Interest

The authors declared no conflict of interest.

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