# MATRIX AND GRAPH-THEORETICAL MODELING OF QUALITY FUNCTION DEPLOYMENT IN THE TEXTILE INDUSTRY

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**Abstract:** *The textile industry operates in a highly competitive environment in which product quality and customer satisfaction play a crucial role in achieving market success. Quality Function Deployment (QFD) is an effective methodology for translating customer requirements into technical characteristics and supporting product development and quality improvement processes. This paper presents the application of QFD in the textile industry, with particular emphasis on matrix-based and graph-theoretical modeling approaches. The relationships between customer requirements and technical characteristics are represented through weighted matrices and bipartite graphs, enabling clearer analysis, visualization, and prioritization of product attributes. A simplified QFD model is presented to demonstrate the calculation of technical importance ratings and the interpretation of customer–technical interactions. The study highlights the importance of integrating quality management methods with mathematical modeling in order to improve decision-making, optimize product development processes, and enhance competitiveness in the textile sector.*

**Keywords:** Quality Function Deployment (QFD), textile industry, graph theory, matrix modeling, customer requirements, product development.

# MATRIČNO I GRAFOVSKO-TEORIJSKO MODELIRANJE QFD METODOLOGIJE U TEKSTILNOJ INDUSTRIJI

**Apstrakt:** *Tekstilna industrija posluje u visoko konkurentnom okruženju u kojem kvalitet proizvoda i zadovoljstvo kupaca igraju ključnu ulogu u postizanju uspeha na tržištu. Raspoređivanje funkcije kvaliteta (QFD) je efikasna metodologija za pretvaranje zahteva kupaca u tehničke karakteristike i podršku procesima razvoja proizvoda i poboljšanja kvaliteta. Ovaj rad predstavlja primenu QFD-a u tekstilnoj industriji, sa posebnim naglaskom na pristupe modeliranja zasnovane na matricama i grafovima. Odnosi između zahteva kupaca i tehničkih karakteristika predstavljeni su kroz ponderisane matrice i dvodelne grafove, što omogućava jasniju analizu, vizuelizaciju i određivanje prioriteta atributa proizvoda. Predstavljen je pojednostavljeni QFD model kako bi se demonstriralo izračunavanje ocena tehničkog značaja i tumačenje interakcija kupac-tehnika. Studija ističe važnost integracije metoda upravljanja kvalitetom sa matematičkim modeliranjem kako bi se poboljšalo donošenje odluka, optimizovali procesi razvoja proizvoda i povećala konkurentnost u tekstilnom sektoru.*

**Ključne reči:** Raspoređivanje funkcije kvaliteta (QFD), tekstilna industrija, teorija grafova, matrično modeliranje, zahtevi kupaca, razvoj proizvoda.

## 1. INTRODUCTION

According to Hollander [1], clothing is considered fundamental to civilization. The type and style of clothing worn depend on both functional requirements, such as protection from environmental conditions or thermal comfort, and social and cultural factors. The required functionality may vary significantly depending on the intended end use [2].

Globalization and structural changes in the world economy have had a profound impact on the textile and apparel industries. The rapid growth of international competition has forced textile enterprises to adopt new management and production strategies in order to maintain competitiveness. Fashion and garment manufacturing represent dynamic sectors that integrate creativity, design, and production processes to meet increasingly complex consumer demands.

Quality plays a central role in this industry and includes multiple aspects such as material selection, workmanship, garment fit, comfort, and durability. According to the business dictionary, quality in manufacturing is defined as "a measure of excellence or a state of being free from defects, deficiencies, and significant variations, achieved through strict and consistent adherence to measurable and verifiable standards in order to attain uniform output that satisfies the specific requirements of customers or users." Quality assurance practices include material testing, compliance with industrial standards, systematic quality control throughout production, and the use of advanced technologies such as computer-aided design (CAD) for precise pattern making, marker planning, and other engineering operations. In addition, sustainable production practices and continuous improvement strategies are increasingly emphasized in order to maintain high-quality standards while reducing environmental impact.

At the same time, long-term business success in the twenty-first century depends on the ability of companies to effectively understand and respond to customer requirements. Quality Function Deployment (QFD) is a structured planning and development methodology that enables design teams to systematically identify customer needs and translate them into technical requirements. QFD is essentially a quality planning and management approach aimed at achieving optimal solutions for products and services [3–5]. One of its key advantages is that it improves communication within development teams by clearly defining the intent of new product development and structuring it into actionable steps. In today's rapidly changing markets, both large and small enterprises must continuously adapt their business models, organizational structures, and production systems. These changes can also be effectively planned and managed using QFD principles. A useful way to address such challenges is by aligning external market conditions, internal organizational processes, and financial objectives [6]. Recent studies confirm that QFD enhances customer-oriented product development, prioritization of technical characteristics, and overall competitiveness in apparel-related industries [7,8].

Recent research by the authors has focused on advanced approaches in textile and garment design, including futuristic modeling, CAD-based pattern development, and 3D virtual fitting systems [9-14]. These studies demonstrate the importance of integrating digital technologies and structural design principles to improve garment functionality, aesthetics, and user satisfaction. Such developments are highly relevant for customer-oriented methodologies such as QFD, which aims to systematically align product design with user requirements.

The challenges faced by individual companies vary; however, most organizations must compete in terms of value creation, value delivery, and value management to achieve both short-term and long-term success. Value creation involves not only the development of new products and services but also the continuous improvement of existing ones. Therefore, the aim of this study is to demonstrate how the QFD approach can be applied in the textile and apparel sector to improve product quality, enhance customer satisfaction, and strengthen competitive performance.

In addition to its practical contribution, this study introduces a mathematical interpretation of QFD using matrix-based and graph-theoretical models within the framework of applied mathematics. The originality of this research lies in the integration of matrix representations and graph theory to model customer–technical relationships in textile product development.

The scientific contribution of this study is the development of a formal analytical framework for QFD based on weighted matrices and bipartite graph structures. This approach enables clearer prioritization of technical characteristics, improved visualization of customer requirements, and enhanced decision-making in product design and quality management processes.

# 2. THEORETICAL BACKGROUND AND METHODOLOGY

## 2.1. Research Methodology

This study is based on a theoretical and analytical research approach focused on the application of Quality Function Deployment (QFD) in the textile industry. A systematic review of scientific literature related to quality management, textile product development, customer-oriented design, and QFD methodologies was conducted in order to identify the most relevant concepts and applications.

In addition to the literature analysis, matrix-based mathematical modeling and graph-theoretical representation were applied to describe the relationships between customer requirements and technical characteristics within the QFD framework. A simplified House of Quality model was developed to demonstrate the calculation of technical importance ratings and the interpretation of customer–technical interactions through weighted matrices and bipartite graphs.

The proposed approach combines principles from quality management, applied mathematics, and graph theory in order to provide a clearer analytical interpretation of QFD implementation in textile product development.

## 2.2. Quality Management in the Textile Industry

Management is defined as a universal process of performing work effectively and efficiently through other people—managers—and by engaging resources in achieving the previously defined goals of the enterprise. Thus, management science is a fundamental characteristic of an industrial, innovative, global, and modern society [15]. Garment companies face major challenges in maintaining production goals and standards, primarily due to the instability and variability of products, which represent a complex range of styles, seasons, different life cycles, and similar factors. Today, there is no single universal definition of quality. According to some views, quality means "performance according to standards." Others consider it to be "meeting customer needs." Therefore, in order to remain competitive in the mainstream of global competition, manufacturers must produce goods of good quality [16, 17]. Achieving world-class quality is not merely another program; it is a continuous process. However, since quality is directly related to profitability, emphasis on quality must begin at the very start, namely in the product or process design phase, and then continue throughout the production stage. This is particularly important in garment manufacturing, since clothing quality is reflected not only through the materials used (their basic characteristic properties, functionality, aesthetics, etc.), but also through the quality of the production process [18, 19]. Therefore, quality awareness should be integrated into every activity, from design to delivery. In this regard, quality requirements should be approached from a case-study perspective, as a puzzle that needs to be solved. Thus, the strategy for dealing with production quality should contain the following basic components:

- Definition of clothing quality characteristics in accordance with the specifications set by the manufacturer and the expectations of the customer;
- Clearly defined product quality requirements, with specified tolerances;
- Clearly defined quality requirements for which no tolerances are permitted;
- Clearly defined quality requirements in the implementation of quality control;
- Investment in prevention.

Considering that quality is not a static but a dynamic concept, it is complex and raises an important question: does ensuring and improving product quality cost money, or does it save money? One of the critical factors that can influence quality is the identification of problems and the determination of their causes. Specifications are considered a means of developing internal quality processes to ensure that quality complies with the required standard, also known as internal characteristics [20]. On the other hand, quality control is described as "a series of inspections and tests to ensure that the planned quality has actually been achieved" [21, 22].

## 2.3. Quality Measurement and Control Methods

In order to assess whether a particular product or service meets the specified requirements and can therefore be considered of acceptable quality, it is necessary to measure relevant characteristics and performance indicators. In this context, statistics plays a fundamental role in the field of quality assurance, since both basic and advanced statistical methods are widely applied in the pursuit of producing high-quality goods and services. Accordingly, the first rational step in any quality improvement project is to develop a thorough understanding of the current and desired configurations of the processes involved [23]. Effective measurement is also the foundation of efforts aimed at improving processes and products. If essential characteristics of a product or service cannot be measured reliably, there is no objective way to determine whether design requirements have been fulfilled or whether customer needs have truly been satisfied [24,25]. Once appropriate measurement systems are established, organizations can begin collecting meaningful data on process performance. What cannot be measured cannot be consistently guaranteed to the customer. For this reason, successful companies devote substantial resources to the development and maintenance of robust measurement systems [26]. Therefore, at the core of the House of Quality lies the measurement of defined and collected data related to business processes, with the purpose of understanding and controlling them, as well as gathering valuable information about products and services in order to improve quality and optimize operations [27,28]. The intensity and scope of measurement and control activities depend on the importance of the characteristics for quality and on the required level of accuracy. The design of an effective measurement system enables a systematic approach to the obtained results, including analysis and identification of critical points, determination of losses, problem-solving, and successful implementation of corrective actions [29].

## 3. RESULTS AND DISCUSSION

### 3.1. Quality Function Deployment (QFD)

Given the current business environment shaped by globalization and the free movement of goods, organizations must rapidly adapt their products and services to increasingly diverse customer demands in order to remain competitive. In the textile industry, continuous monitoring of market trends and alignment with customer requirements are essential for achieving sustainable competitive advantage. Quality Function Deployment (QFD) is a structured method that enables organizations to translate customer needs into technical specifications throughout the product development lifecycle [30]. In recent years, QFD has been enhanced through the integration of advanced techniques such as fuzzy logic, artificial neural networks, and statistical tools like the Taguchi method, improving decision-making and prioritization of customer requirements [31]. Additionally, Critical Parameter Management (CPM) complements QFD by monitoring key engineering relationships and performance metrics, ensuring that customer requirements are consistently met while accounting for variability in design, production, and supply processes [32]. Each word in the term Quality Function Deployment (QFD) carries a specific meaning:

**Quality** – Quality is determined by customer expectations; therefore, no product or service can be considered high quality without first identifying the customers and understanding their expectations.

**Function** – This refers to how customer expectations will be fulfilled, or how products and services will function in order to satisfy those expectations.

**Deployment** – This defines how the flow of development processes should be managed to ensure that customer expectations drive the development of new products and services.

Thus, QFD is a highly effective method that supports communication and decision-making in new product development by aligning products with actual customer requirements, while reducing design time and costs. The method was first implemented in 1972 at Mitsubishi Heavy Industries Kobe Shipyard [33] as a systematic approach for translating customer needs into technical specifications [34]. QFD provides a comprehensive view of the design and production process, helping to prevent manufacturing deficiencies early in the design stage. It also serves as a benchmarking tool for comparing products with competitors and defining priorities for improvement [35]. Based on two-dimensional matrices, QFD enables the calculation and graphical representation of key indicators, supporting informed decision-making [36,37].

### 3.2. Mathematical Representation of QFD

Quality Function Deployment (QFD) can be formally represented using matrix-based and graph-theoretical models, which makes it highly suitable for analysis within applied mathematics and graph theory frameworks.

Let the set of customer requirements be defined as:

$$CR = \{cr_1, cr_2, \dots, cr_n\} \quad (1)$$

and the set of technical characteristics as:

$$TC = \{tc_1, tc_2, \dots, tc_m\} \quad (2)$$

The relationship between customer requirements and technical characteristics is represented by a matrix:

$$R = [r_{ij}], \quad i = 1,2,\dots,n; \qquad j = 1,2,\dots,m \quad (3)$$

where:

- $r_{ij}$ denotes the strength of the relationship between customer requirement $cr_i$, and technical characteristic, $tc_j$
- the numerical scale 1–3–9 represents weak, moderate, and strong relationships respectively.

Let the importance weights of customer requirements be:

$$W = (w_1, w_2, \dots, w_n) \tag{4}$$

The importance score of each technical characteristic is calculated as:

$$I_j = \sum_{i=1}^{n} w_i \cdot r_{ij} \tag{5}$$

This formulation enables the prioritization of technical characteristics according to customer requirements.

## 3.3. Graph-Theoretical Interpretation

QFD can also be represented as a weighted bipartite graph:

$$G = (U, V, E) \tag{6}$$

where:

$U = \{cr_1, cr_2, \dots, cr_n\}$ represents customer requirements,

$V = \{tc_1, tc_2, \dots, tc_m\}$ represents technical characteristics,

$E \subseteq U \cdot V$ represents relationships between them.

Each edge ($cr_i$, $tc_j$) is weighted by , representing the strength of interaction.

This representation enables:

- network analysis,
- optimization,
- identification of critical technical characteristics,
- reduction of redundancy in product design.

## 3.4 Application Example of the QFD Matrix

A simplified QFD relationship matrix is presented in Table 1. Using the assigned customer importance weights for comfort, durability, and price, the calculated importance scores for the technical characteristics are 60 for TC1, 78 for TC2, and 44 for TC3. These results indicate that TC2 is the most critical technical characteristic and should therefore receive the highest priority in product development and design optimization.

**Table 1:** Simplified QFD relationship matrix between customer requirements and technical characteristics.

| Customer Requirements | Weight | TC1 | TC2 | TC3 |
|---|---|---|---|---|
| Comfort | 5 | 9 | 3 | 1 |
| Durability | 4 | 3 | 9 | 3 |
| Price | 3 | 1 | 9 | 9 |

Using the formula (5), the obtained results are:

$$I_1 = 5 \cdot 9 + 4 \cdot 3 + 3 \cdot 1 = 60$$
$$I_2 = 5 \cdot 3 + 4 \cdot 9 + 3 \cdot 9 = 78$$
$$I_3 = 5 \cdot 1 + 4 \cdot 3 + 3 \cdot 9 = 44$$

Figure 2 illustrates the calculated importance scores of technical characteristics derived from the QFD model. The results show that TC2 has the highest priority, followed by TC1 and TC3. This indicates that TC2 contributes most significantly to fulfilling customer requirements and should therefore be given the highest attention in product design and development within the textile industry.


**Figure 1**: Importance scores of technical characteristics calculated using the QFD model.

Based on the calculated importance scores, TC2 is the highest-priority technical characteristic, indicating that it has the strongest overall contribution to meeting customer requirements. In comparison, TC1 has moderate importance, while TC3 has the lowest priority among the three characteristics.

The relationships between customer requirements and technical characteristics can also be represented as a weighted bipartite graph, as illustrated in Figure 2.

This graph representation highlights the structure of QFD as a network, enabling the application of graph theory concepts such as centrality, connectiv-

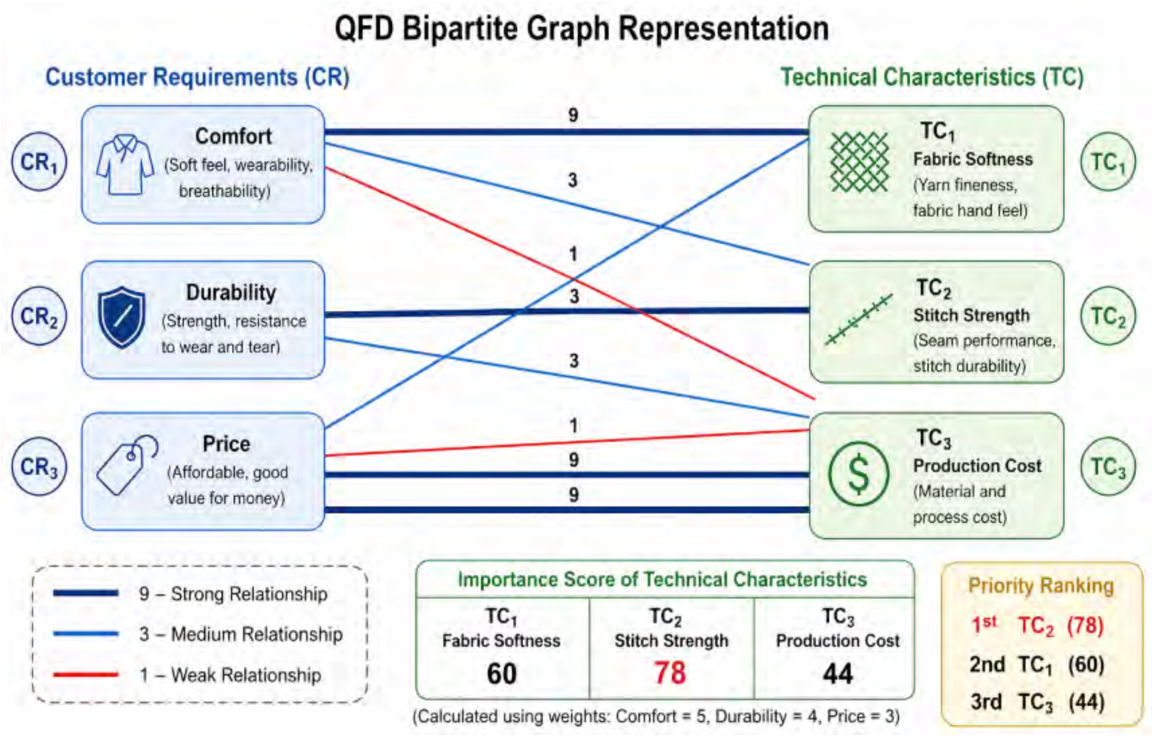


**Figure 2:** Bipartite graph representation of Quality Function Deployment (QFD), illustrating relationships between customer requirements and technical characteristics.

ity, and optimization. This representation allows the application of graph-theoretical measures such as node centrality and edge weighting for optimizing product design decisions.

## 3.5. Applications of QFD in the Textile Industry

As previously noted, research [38-41] highlights that QFD aims to identify key service and product characteristics necessary to meet customer requirements, ensuring that the Voice of the Customer (VOC) is clearly understood. Another study used the House of Quality to support slow-fashion denim design and showed how consumer expectations and sustainability considerations can be integrated into jeans development [42]. In his research, Chen & Lei [43] studies personalized youth apparel design using QFD to translate user demand into clothing-design requirements, making it relevant for mass customization and demand-driven fashion development. Other studies confirm that QFD effectively translates VOC into technical and process requirements, often in combination with quality tools such as SERVQUAL and the Kano model [44-47]. The integration of these methods improves service and product design, leading to enhanced quality and customer satisfaction [48]. However, such integrations often rely on subjective judgments, which may introduce uncertainty and bias. To address these limitations, fuzzy methods have been applied to improve decision-making accuracy and support the integration of these tools [49,50]. Additionally, several studies [51] emphasize that QFD remains one of the most effective techniques for transforming customer requirements into technical specifications. In the study [52] combining Kano, QFD, and PUGH produced protective-clothing concepts with higher user satisfaction than traditional design approaches, while linking user requirements and design elements more explicitly and objectively. The Analytic Hierarchy Process (AHP) has also been integrated with QFD to support decision-making, particularly in maintenance systems. This integration led to the development of the Diagnostic Maintenance Function Deployment (DMFD) model, which has been successfully applied in modern textile industries, often in combination with Total Productive Maintenance (TPM), to better meet market demands [53]. QFD/HoQ was also useful for collaborative apparel platforms because it exposed gaps between customer and provider priorities and translated them into platform design features like mobile compatibility, secure payment, and review systems [54]. In home-textile manufacturing, QFD plus DMAIC and Monte Carlo simulation improved the mapping of customer requirements to technical actions and helped prioritize the most important production risks [55]. Overall, QFD serves as a powerful management tool that focuses development efforts on customer-valued features, reducing unnecessary costs, time, and resource waste. It improves design efficiency, minimizes redesign and warranty costs, and supports long-term cost savings. Despite requiring time and cross-functional collaboration, especially for organizations new to its application, QFD significantly enhances communication and decision-making by providing a structured framework for translating customer needs into technical solutions. In this regard, QFD improves communication by:

- Providing a standardized format for translating "Whats" into "Hows";
- Encouraging fact-based decision-making;
- Documenting decisions in matrices for review and continuous improvement.

For successful implementation, management must ensure proper team understanding, define roles and timelines, monitor progress, and support continuous communication and data collection throughout the QFD process.

## 4. CONCLUSION

The textile and apparel industry operates in a highly competitive and rapidly evolving environment, where customer-oriented quality management approaches are essential. Quality Function Deployment (QFD) has proven to be an effective tool for translating customer requirements into technical specifications, improving product quality, reducing waste, and enhancing overall efficiency. Applications of QFD in textile-related sectors confirm its practical relevance and adaptability. Furthermore, the integration of QFD with modern methodologies such as fuzzy logic, AHP, and statistical tools enhances its capability to support complex decision-making processes. From a mathematical perspective, QFD can be effectively modeled using matrix representations and bipartite graph structures, enabling quantitative analysis, optimization, and improved visualization of relationships between customer needs and technical characteristics. In conclusion, the combination of practical application and mathematical modeling makes QFD a powerful interdisciplinary tool, suitable for both industrial implementation and theoretical research within applied mathematics and graph theory. The graph representation enables the application of graph-theoretical methods for analyzing relationships and optimizing design decisions. Future research may include the application of fuzzy graph theory, weighted network algorithms, and machine learning techniques for advanced optimization of textile product development and customer-oriented quality management.

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