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Research Article

Analyzing and Dealing with the Distortions in Customer Requirements Transmission Process of QFD

Lisha Geng [1,2] and Lixiao Geng [3]

[1] *School of Business Administration, Hebei University of Economics and Business, Shijiazhuang, China*
[2] *Department of Management Engineering, Shijiazhuang Vocational College for Scientific and Technical Engineering, Shijiazhuang, China*
[3] *College of Economics and Management, Hebei University of Technology, Tianjin, China*

Correspondence should be addressed to Lisha Geng; genglisha09@sina.com

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Quality Function Deployment (QFD) is a quality management tool that transmits customer requirements into product design or innovation process to improve products' customer satisfaction. For the first time, this paper points out the distortions of customer requirements existing in the transmission process of QFD that are caused by the methods for calculating the importance degree of output information. The distortions lead to the designed or innovated product meeting less important customer requirements, without meeting more important customer requirements, so products' customer satisfactions are decreased. In order to avoid the distortions, a new method for calculating the importance degree of output information is proposed and an example is illustrated to demonstrate the effectiveness and superiority of the new method.

1. Introduction

QFD (Quality Function Deployment) is an effective product design method which is put forward in Japan in 1960s. By a series of matrices, customer requirements are converted into product design requirements, and customer requirements are integrated into the product development design process to improve product's quality and customer satisfaction [1].

QFD is a structured method, which connects customer requirements with engineering specifications, parts specifications, and production processes to form operational planning for production [2]. It has three functions: (1) finding problems for product's design driven by VOC (Voice of Customer, also called customer requirement); (2) transferring customer requirements logically into product design process; (3) integrating the knowledge of multifunction and interactive design team into the design process of the product [3]. Being able to transmit customer requirements into product design process, QFD prevents enterprises from designing products blindly and helps enterprises organize product design process more smoothly and effectively to meet customer requirements [4].

The method for calculating the importance degree of QFD output information determines the reliability of customer requirement transmission process. In the first phase of QFD, customer requirements are converted to product technical characteristics, outputting the importance degrees of the technical characteristics. The method for calculating the importance degrees of the technical characteristics in subsequent phases is consistent with the first phase, so the method for calculating the importance degrees in the first phase represents the method for calculating the importance degree of the QFD output information. The importance degrees of technical characteristics in the first phase of QFD are determined by the importance degree of customer requirements and the relationship between customer requirements and technical characteristics.

Using the traditional method for calculating the importance degree of QFD output information, it inevitably appears that, in the first phase of QFD, the importance degree of the technical characteristic strongly related to more important customer requirement is lower, but it plays more important role for improving product's customer satisfaction; thus the distortion in the customer requirement transmission process appears.

In 2015, Franceschini proposed OPM (Ordinal Prioritization Method) to calculate the importance degrees of technical characteristics. This method gives priority to the technical characteristics strongly related to all customer requirements and supposes that their importance degrees are absolutely higher than the technical characteristics that are moderately related to the customer requirements [6].

Although OPM avoids the distortion of customer requirements caused by the traditional method, it overemphasizes the importance degrees of the technical characteristics strongly related to customer requirements and neglects the different effects of customer requirements with different importance degrees on the importance degrees of the technical characteristics. When the difference of customer requirement importance degrees is big, the importance degree of the technical characteristic that is moderately related to more important customer requirement is even higher than the importance degree of the technical characteristic strongly related to less important customer requirement. Therefore, OPM also leads to another kind of distortion in customer requirement transmission process.

For the first time, this paper pointed out that the distortions in the transmitting process of QFD are caused by the methods for calculating the importance degree of output information. Existing researches have not put forward effective ways to solve the distortions. Therefore, this paper puts forward a new method, which avoids the distortions of the output information in the customer requirements transmission process and ensures the effect of the implementation of QFD.

This study is organized into five sections. Section 2 briefly introduces the development and the main content of QFD. Section 3 analyzes the distortions of the output information in customer requirement transmission process of QFD. Section 4 puts forward a new method to deal with the distortions. Section 5 concludes the original contribution.

2. Quality Function Deployment

2.1. The Development of QFD

2.1.1. 1960s-80s: The Formation Stage. In the late 1960s, Japan broke the product imitation and duplication development mode after World War II and gradually performed product innovation mode. At that time, enterprises were eager to create a theory or method that could control the quality of products at the early stage of product development, which prompted the formation of QFD. In 1972, Professor Akao Yoji published the method of quality deployment in the publication, which was used before the production process, and deployed the quality of the product to preproduction process. However, this method was not accurate in terms of product quality. This problem was solved by the quality table made by the Kobe heavy industry shipyard, which promoted the formation of Quality Function Deployment (QFD). In 1975, the Institute of Japanese Quality Management established the computer research institute (renamed to the QFD Institute in 1978), led by Professor Akao Yoji, which promoted the development of QFD in Japan.

Table 1: Main advantages and defects of QFD.

Advantages	Defects
Promoting departments' cooperation	The subjectivity of the information cannot be overcome
Reducing development cycle and cost	Consuming a lot of time by entering data
Improving product' quality	Unpredictable risk, cost, and other factors
Transmitting data logically	Data are distorted in the transmission process
Improving customer satisfaction	Specific solution has not been pointed out

2.1.2. 1980s-90s: The Development Stage. After 1980s, QFD began to be used by Japanese enterprises for product design, quality management, decision making, and team building [15, 16], involving manufacturing, transportation, electronics, architecture, education, services, and other industries [17, 18]. Scholars began to publish articles on the benefits brought by QFD; for example, QFD helped enterprises to design customer friendly products, shorten product development cycles, and improve product quality and reliability [19–23]. For example, the application of QFD in Toyota Corporation reduced the production cost by 60% and shortened the development cycle by 33% [24]. In 1983, Professor Akao Yoji published an article on QFD in Journal of Quality Control founded by the American Association of Quality Control, which began the spread of QFD in the United States. In 1987, Professor Akao Yoji gave a speech on QFD in Italy, which began the spread of QFD in Europe. After 1990s, QFD was introduced into China by Xiong Wei who was taught by Akao Yoji when he studied in Japan.

2.1.3. 1990s-Present: The Improving Stage. In 1990s scholars did a lot of researches on the application of QFD and published some review articles after that. Chan and Wu have reviewed 650 articles related to QFD [25]. Gremyr and Raharjo have reviewed 45 articles about QFD [20], which have promoted the spread and development of QFD in the whole world. With the continuous dissemination of QFD and the in-depth study of scholars, the defects of the application of QFD have been put forward by scholars [19, 26]. The main advantages and defects of QFD are shown in Table 1. In order to solve problems in an effective way, scholars integrate QFD with other theories and methods, as shown in Table 2.

2.2. The Main Content of QFD. The core of QFD is the HoQ (House of Quality), which is also the first phase of QFD. The House of Quality is mainly composed of the relationship matrix between customer requirements and technical

Table 2: Integration research of QFD.

Representatives	Integrated object	Research contents
Almannai [7], Chen [8]	QFD and FEMA	FEMA handles the risks ignored in QFD
Ma and He [9], Ji [10]	QFD and DOE	DOE optimizes parameters for QFD
Xiong [5], Caligiana [11]	QFD and TRIZ	TRIZ handles the conflicts in QFD
Mendoza [12]	QFD and DFMA	DFMA optimizes QFD design scheme
Nie [13]	QFD and SWOT	SWOT provides the input source for QFD

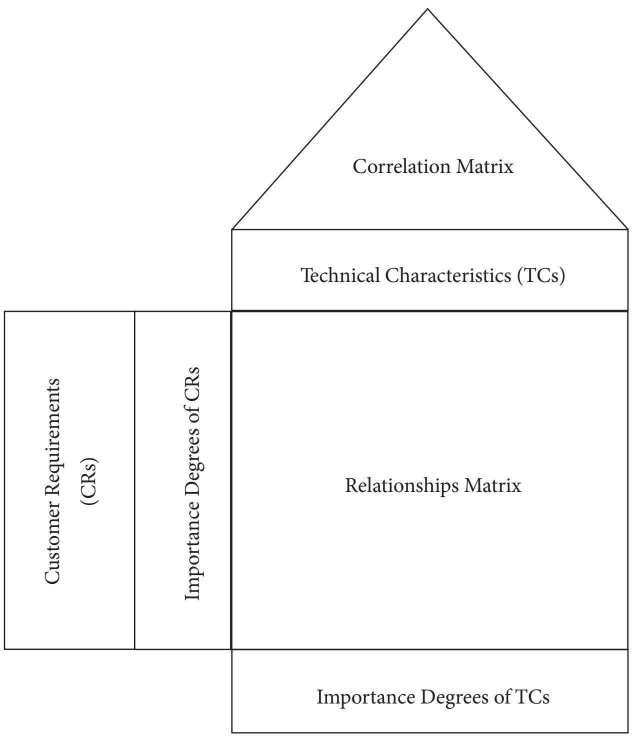

Figure 1: House of Quality [3].

characteristics, and the correlation matrix of technical characteristics. It looks like a house, as shown in Figure 1. According to the actual situation and purpose, the House of Quality can be adjusted appropriately.

By the House of Quality, customer requirements and their importance degrees, the relationships between customer requirements and technical characteristics, and the correlations of technical characteristics are input to calculate the importance degrees of technical characteristics by quantitative methods as the output information in the first phase of QFD [27].

The House of Quality mainly consists of the left wall, the roof, the ceiling, the room, and the basement.

(1) The left wall is made up of customer requirements and their importance degrees, which are the input information of the House of Quality.

(2) The roof is made up of the correlation matrix of technical characteristics. The correlation matrix is used to express the conflicting relationship (indicated by "+") or the supportive relationship (indicated by "-") between technical characteristics.

(3) The ceiling is made up of technical characteristics that meet customer requirements. The process of generating technical characteristics transforms customer requirements from the market perspective to product design perspective.

(4) The room is the main part of the House of Quality, which is made up of the relationship matrix between customer requirements and technical characteristics, expressing how customer requirements and technical characteristics are related.

(5) The basement is made up of the importance degrees of technical characteristics, which constitute the output information of the House of Quality. Taking into consideration the information provided by each part of the House of Quality, the importance degrees of the technical characteristics are calculated.

In 1980s, American Supplier Institute (ASI) proposed the four phases of QFD, including product planning matrix or the House of Quality, part configuration matrix, process design matrix, and production control matrix, as shown in Figure 2 [5]. In the first phase, the House of Quality for product planning that is widely used is the research object that scholars mainly focus on. The four phases of QFD transmit customer requirements to the downstream of the product design process, but lead to QFD being too large and complex. By adjusting the content and structure of QFD, product can be designed in a more convenient way. For example, scholars build the House of Quality with customer requirements and technical characteristics and adjust the second phase as the matrix between technical characteristics and product functions for converting customer requirements to product functions, so the conceptual design of product is realized [28]. Because the design conflicts of products have been already identified in the first phase, correlation matrices are omitted in subsequent phases [29]. The four phases of QFD are as follows:

The First Phase. Product planning matrix or the House of Quality, defining the relationship between customer requirements and technical characteristics.

The Second Phase. Part configuration matrix, defining the relationship between technical characteristics and part characteristics.

The Third Phase. Process design matrix, defining the relationship between part characteristics and process characteristics.

The Fourth Phase. Production control matrix, defining the relationship between process characteristics and production requirements.

Table 3: House of Quality for airplane task, adapted from [14].

CR	W_i	TC_1	TC_2	TC_3	TC_4	TC_5	TC_6	TC_7
CR_1	5	9		7	7	7	5	
CR_2	4	5		9		7		
CR_3	3	5		5	3	3		
CR_4	5	5	7			5	9	
CR_5	5	5	3	5	3	3		9
CR_6	4		5	3	3	3		3
CR_7	3	5	5					
CR_8	3		3	3	3	3		3
CR_9	3					9		
W_j		145	94	132	80	160	70	66
P_j		2	4	3	5	1	6	7

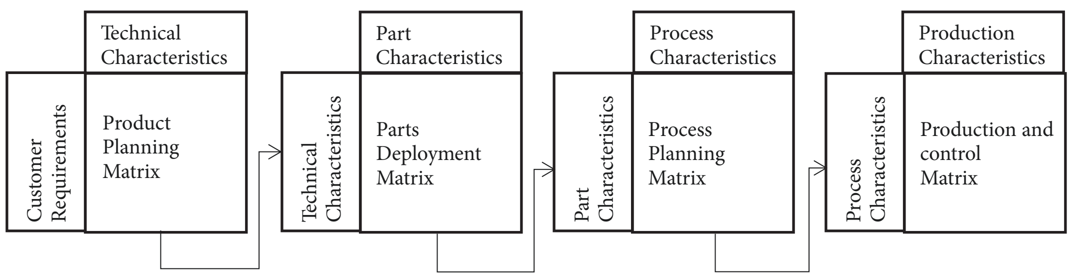

Figure 2: The four phases of QFD [5].

3. Analyzing the Distortions in Customer Requirement Transmission Process of QFD

Information distortion refers to information deviating from the reality or a certain standard [30].

Customer requirements provide useful information for product developers. Meeting customer requirements is the basic goal for product design or innovation. Generally, customers have various requirements for a single product. To improve customer's satisfaction, meeting the most important customer requirements firstly is the primary task of product design. Customer requirements are deployed into corresponding design problems of products based on the output information of QFD.

Driven by customer requirements, the importance degree of output information in each stage of QFD is calculated by certain methods. While being calculated by existing methods, the output information strongly related to the most important customer requirement may not be the most important. Solving the most important problem reflected by the most important output information will not meet the most important customer requirements.

Because of the defects of the methods for calculating the importance degree of QFD output information, the driving effect of the higher customer requirements is decreased, causing the distortion of the customer requirement in the transmission process.

By analyzing traditional method and OPM, it is explained in the following parts that the importance degree of QFD output information deviates from the actual importance degrees of customer requirements, so the designed product meets less important customer requirements, without meeting more important customer requirements, and the customer satisfaction of the designed product is decreased.

3.1. Calculating the Importance Degree of QFD Output Information by the Traditional Method. The House of Quality in the first phase is the most important content of QFD, and the construction process and calculation method in the following phases of QFD are consistent with the first phase, so taking the technical characteristics output in the first phase as an example, the methods for calculating the importance of QFD output information are discussed. Taking the House of Quality for aircraft task in existing literature as an example (as shown in Table 3), the distortion caused by traditional method for calculating the importance degree of QFD output information is analyzed [14]. In order to better understand the calculating process, Table 3 only involves the figures needed to be calculated, and the specific contents of both customer requirements and technical characteristics are omitted.

In Table 3, CR and W_i represent customer requirements and their importance degrees, respectively. TC, W_j, and P_j represent technical characteristics, the importance degrees of technical characteristics, and their ranking results, respectively.

The importance degrees of the technical characteristics output in the first phase of QFD are calculated by formula

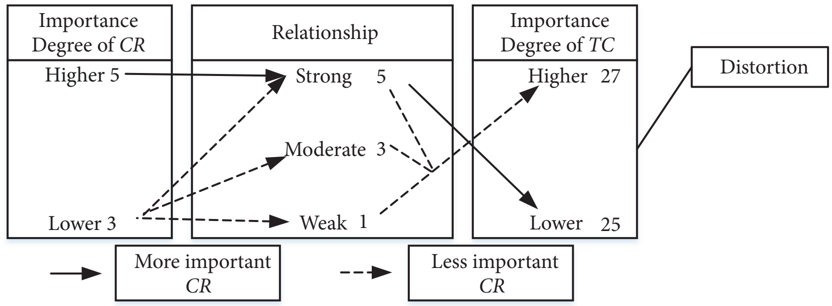

FIGURE 3: The first kind of distortion.

(1). In formula (1), r_{ij} represents the relationship between customer requirement i and technical characteristic j.

$$W_j = \sum_{i=1}^{m} W_i r_{ij}, \quad i = 1, 2, \ldots, m; \; j = 1, 2, \ldots, n. \tag{1}$$

3.2. The Distortion Caused by the Traditional Method. In order to improve product's customer satisfaction, meeting more important customer requirements is the most important object of product design or innovation. Therefore, it is necessary to effectively control the transmission process of customer requirements, ensuring that the technical characteristics strongly related to more important customer requirements are more important, so they can be improved first.

In Table 3, the important degrees of technical characteristics W_j are calculated by the traditional method. However, there are two problems with the calculation results.

Problem 1. In Table 3, TC_7 is strongly related (the relationship is 9) to the most important customer requirement CR_5 (the importance degree is 5). Improving TC_7 can fully satisfy CR_5, while the importance degree of TC_7 is the lowest (66). It means that although TC_7 can satisfy the most important customer requirement, its importance degree is the lowest. In the condition of limited resources, enterprises choose key technical characteristics based on their importance degrees to determine the improving direction for product. Therefore, with the lowest importance degree, TC_7 will not be regarded as the main object for improving, and the target product will not fully satisfy the most important customer requirement CR_5.

Problem 2. In Table 3, CR_1 is one of the most important customer requirements and TC_1 is strongly related (the relationship is 9) to it, so improving TC_1 firstly will meet CR_1 in an effective way. According to the value of W_j, which represents the importance degrees of technical characteristics, TC_1 is less important than TC_5. However, TC_5 is not strongly related to any of the most important customer requirements. It means that TC_1 is strongly related to the most important customer requirement, but its importance is relatively lower, while TC_5 is not strongly related to the most important customer requirement, but its importance is relatively higher.

TABLE 4: A relationship matrix of customer requirements and technical characteristics.

CR	W_i	TC_1	TC_2	TC_3
CR_1	0.8		9	
CR_2	0.1	9		9
CR_3	0.3	9		9
CR_4	0.4	9		9
CR_5	0.1	3		1
W_j		7.5	7.2	7.3
P_j		1	3	2

Thus, improving TC_5 firstly will not adequately meet the most important customer requirement.

The traditional method inevitablely leads to the result in Table 4. TC_2 is strongly related to the most important customer requirement (CR_1), but its importance degree is the lowest, while other technical characteristics with higher importance degrees are not related to the most important customer requirement at all. Therefore, the importance degrees of the technical characteristics that are not related to the most important customer requirement are relatively higher, but the importance degree of the technical characteristic (TC_2) that is strongly related to the most important customer requirement is the lowest.

Therefore, the first kind of distortion in customer requirement transmission process of QFD is shown in Figure 3. One technical characteristic is strongly related to more important customer requirements, but its importance degree is relatively lower (25), while another technical characteristic is variously related to less important customer requirement, but its importance is relatively higher (27). Therefore, more important customer requirements cannot be met by selecting the key technical characteristic according to its importance degree.

According to the above analysis, the first kind of distortion of the output information in customer requirement transmission process of QFD caused by the traditional method is as follows: some technical characteristics are related to some less important customer requirements, while their importance degrees are relatively higher; other technical characteristics are strongly related to more or the most important customer requirements, while their importance degrees

Table 5: The relationship between customer requirements and technical characteristics.

	TC_1	TC_2	TC_3	TC_4	TC_5
CR_1	○	●	△		
CR_2		●		●	
CR_3		△	●	△	
CR_4			○	○	○

Note. Relationship: ● strong; ○ moderate; △ weak [6].

Table 6: The decision process for the importance degrees of technical characteristics based on OPM.

Relationship	CR_1	CR_2	CR_3,CR_4
Strong	1: TC_2	2: TC_2,TC_4	3: TC_3
Moderate	4: TC_1	5: 无	5: TC_4,TC_3,TC_5
Weak	6: TC_3	7: 无	8: TC_2,TC_4
/	9: TC_4,TC_5	10: TC_1,TC_3,TC_5	11: TC_1,TC_2,TC_5

are relatively lower. Therefore, designing products based on the information output by QFD with traditional method cannot fully meet more important customer requirements and reduces the driving effect of customer requirements, and customers' satisfaction for the designed product is decreased. This is the first kind of distortion in the customer requirement transmission process.

3.3. Calculating the Importance Degree of QFD Output Information by OPM. In order to improving the calculation method of QFD, Franceschini proposed OPM (Ordinal Prioritization Method) that was the variant of Yager's method to calculate the importance degrees of the output information of QFD in 2015 [6, 31]. By OPM, the calculation process of the importance degrees of technical characteristics in the first phase of QFD is taken as the importance degrees decision making process for a series of solutions. Customer requirements are considered as decision makers and technical characteristics as solutions.

Suppose that the House of Quality is composed of four customer requirements and five technical characteristics. The ranking of the importance degrees of customer requirements is $CR_2 > CR_1 > CR_3 \approx CR_4$. The relationships between customer requirements and technical characteristics are shown in Table 5, in which *CR* represents customer requirement and *TC* represents technical characteristic. Prioritizing the importance degrees of technical characteristics by OPM, the decision process is shown in Table 6. It is based on the principle that the importance degree of the technical characteristic that is strongly related to the most importance customer requirement is the highest, ranked as the first. What ranked as the second is the technical characteristic that is strongly related to the second important customer requirements, prioritizing the importance degrees of technical characteristics according to the order they appear in. Thus, the ranking of the importance degrees of the technical characteristics in Table 5 is $TC_2 > TC_4 > TC_3 > TC_1 > TC_5$.

3.4. The Distortion Caused by OPM. According to OPM, the importance degree of the technical characteristic that strongly related to the most important customer requirement is the highest, which can avoid the distortion caused by the traditional method, but there are three deficiencies:

First, OPM only identifies the ranking order of the importance degrees of technical characteristics, but cannot quantitatively calculate the value of the importance degree for each technical characteristic, so the transmission process is not very accurate.

Second, on the occasion that multiple technical characteristics are strongly related to the most customer requirements, it is impossible to further distinguish the importance degrees of these multiple technical characteristics by OPM.

Third, when the differences of the importance degrees for customer requirements are big, the results calculated by OPM are not reliable.

OPM ensures that the technical characteristics strongly related to customer requirements are more important than the technical characteristics moderately related to customer requirements. It emphasizes the importance degrees of technical characteristics strongly related to customer requirements, and it can solve the distortion caused by the traditional method. However, when the differences of the importance degrees among customer requirements are big, OPM provides wrong results and also causes the distortion.

Two customer requirements are taken as an example to analyze the distortion of the output information caused by OPM, as shown in Figure 4. According to OPM, the technical characteristics strongly related to customer requirements are more important than the technical characteristics moderately related to customer requirements. However, after giving specific values to the importance degrees of customer requirements and the relationships between customer requirements and technical characteristics, it is found in Figure 4 that the importance degree of the technical characteristic that is moderately related to (the relationship is 3) more important customer requirement (the important degree is 5) is 15, while the importance degree of the technical characteristic that is strongly related to (the relationship is 5) less important customer requirement (the importance degree is 2) is 10. Thus, the technical characteristic strongly related to customer requirement is less important than the technical characteristic moderately related to customer requirement. This result is opposite to the result obtained by OPM. The reason is that OPM does not take into account the fact that customer requirements with different importance degrees have different impacts on the importance degrees of technical characteristics, which decreases the importance degrees of the technical characteristics that are moderately related to more important customer requirements, resulting in the distortion of the output information in the process of customer requirements transmission.

It is supposed that the importance degrees of the customer requirements in Table 6 are 5, 2, 1, and 1 respectively. 0, 1, 3, and 5 indicate unrelated, weakly related, moderately related, and strongly related, respectively, customer requirements and technical characteristics [5]. Calculating

Table 7: The contribution degrees of technical characteristics.

Relationship	CR_1:5	CR_2:2	CR_3=CR_4:1
Strong=5	C_{12}=25	C_{22}=C_{24}=10	C_{33}=5
Moderate=3	C_{11}=15	/	C_{34}=C_{33}=C_{45}=3
Weak=1	C_{13}=5	/	C_{32}=C_{34}=1
Unrelated=0	C_{14}=C_{15}=0	C_{21}=TC_{23}=TC_{25}=0	C_{31}=C_{41}=C_{42}=C_{35}=0

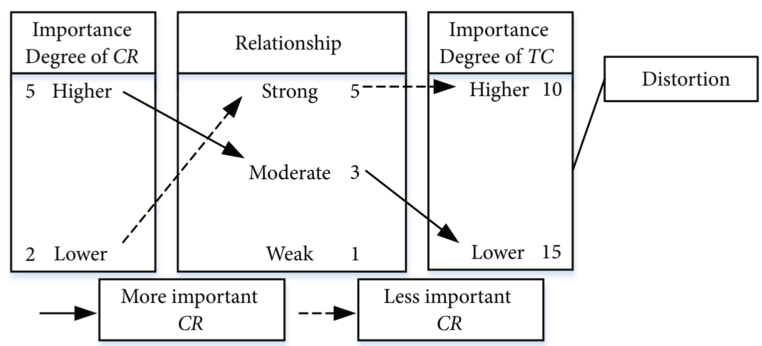

Figure 4: The second kind of distortion.

the contribution degrees of the technical characteristics and the results are shown in Table 7.

Contribution degree is a new concept proposed in this paper, which refers to how important the output information is for improving input information in every stage of QFD. There are two reasons for introducing the concept of contribution degree:

First, the concept of the contribution degree will avoid the distortion caused by OPM. According to OPM, the output information strongly related to the input information is more important than the output information not strongly related to the input information. This is a qualitative process. OPM neglects the differences among the importance degrees of the input information. Actually when the differences are big, even the output information moderately related to more important input information will be more important than the output information strongly related to less important input information. The value of contribution degree is calculated quantitatively by the importance degrees of both the input information and the output information, so it solves the distortion caused by OPM.

Second, contribution degree reflects the value of importance degree of each piece of output information to each piece of input information. The highest contribution degree finally determines how important the output information is to product design for the first ranking. The traditional method only calculates the importance degree of the output information totally, without considering the highest contribution degree, and the distortion occurs, so proposing the concept of the contribution degree can avoid the distortion caused by the traditional method.

Taking the contribution degrees of technical characteristics in the first phase of QFD as an example, the calculation process of the contribution degree is explained. It is assumed that there are m customer requirements and n technical characteristics in the House of Quality, the contribution degree of technical characteristic j to customer requirement i is calculated by the importance degree of customer requirement i, and the relationship between technical characteristic j and customer requirement i is shown as follows:

$$C_{ij} = W_i r_{ij} \quad i = 1, 2, \ldots, m; \ j = 1, 2, \ldots, n. \tag{2}$$

In formula (2), C_{ij} represents the contribution degree of technical characteristic j to customer requirement i, W_i represents the importance degree of customer requirement, and r_{ij} represents the relationship between customer requirement i and technical characteristic j.

In Table 7, C_{11} represents the contribution degree of TC_1 to CR_1, which is 15. C_{22} and C_{24} represent the contribution degrees of TC_2 and TC_4 to CR_2; both of them are 10. The higher the contribution degree, the more important its corresponding technical characteristic. Obviously, TC_1 is more important than TC_2 and TC_4, which is opposite to the results calculated by OPM.

4. Dealing with the Distortions in Customer Requirements Transmission Process of QFD

4.1. A New Method for Calculating the Importance Degree of QFD Output Information. By analyzing the traditional method and OPM, it is found that both of the two methods will result in the distortions in the customer requirements transmission process of QFD. Consequently, a new method for calculating the importance degree of QFD output information is proposed, which solves the following problems:

(1) In order to avoid the first kind of distortion in the process of customer requirement transmission, the concept of

contribution degree is introduced. The highest contribution degree of the output information is taken as the first standard to measure the importance degree of output information, which avoids the phenomenon that the highest contribution degree of the output information is high, while the importance degree is low. This makes up the deficiency of the traditional method for calculating the importance degrees of QFD output information.

(2) To avoid the second kind of distortion caused by OPM, the differences of the customer requirements' importance degrees are considered. Besides, the prominent role of the most important customer requirement played in product design is considered. Accordingly, the highest customer requirement importance degree is taken as the standard to standardize the importance degrees of all customer requirements.

(3) When the highest contribution degrees of multiple pieces of output information are the same, the contribution degree of the output information to all input information is taken into account, and the total contribution degree is calculated as the second standard to measure the importance degree of the output information.

The total contribution degree is calculated for further distinguishing the importance degree of the output information when the highest contribution degrees of multiple pieces of the output information are the same. For example, several technical characteristics are strongly related to the most important customer requirements, so the highest contribution degrees of the technical characteristics are the same. To distinguish which technical characteristic is more important, the total contribution degree is used to calculate the contribution degree of the technical characteristic to all the customer requirements.

Taking the calculation process of the importance degrees of technical characteristics in the first phase of QFD as an example, it is explained for the specific steps of the new method proposed in this paper.

Step 1. Suppose that W_{max} is the highest importance degree of the customer requirement. In order to reflect the differences of the importance degrees of the customer requirements, formula (3) is used to standardize the importance degrees of all the customer requirements. $\overline{W}_i$ is the standardized importance degrees of customer requirements.

$$\overline{W}_i = \frac{W_i}{W_{\max}}, \quad i = 1, 2, \ldots, m. \tag{3}$$

Step 2. Calculate the contribution degree C_{ij} of each technical characteristic to each customer requirement using formula (4). r_{ij} represents the relationship between technical characteristic j and customer requirement i.

$$C_{ij} = \overline{W}_i * r_{ij}, \quad i = 1, 2, \ldots, m; \ j = 1, 2, \ldots, n. \tag{4}$$

Step 3. Calculate the highest contribution degree C_j^{max} and the total contribution degree C_j^{sum} for all the technical characteristics using formula (5) and formula (6), respectively.

$$C_j^{\max} = \max\left\{C_{ij}\right\} \tag{5}$$

$$C_j^{sum} = \sum_{i=1}^{m} C_{ij}. \tag{6}$$

Step 4. Divide the technical characteristics into different grades according to the highest contribution degree C_j^{max}. Technical characteristics with the same C_j^{max} are divided into the group with the same grade. All technical characteristics can be divided into k grades. They are $V_1, V_2, \ldots, V_k$, and V_1 is the highest grade.

$$V_1 = \max\left(C_{\max}^j\right) \tag{7}$$

Suppose that technical characteristic j belongs to grade r, $1 \le r \le k$. There are l technical characteristics in grade r. The sum of the total contribution degrees of the technical characteristics in grade r is S_r.

$$S_r = \sum_{t=1}^{l} C_{tj}^{sum}, \quad t = 1, 2, \ldots, l; \ j = 1, 2, \ldots, n. \tag{8}$$

Step 5. Calculate the importance degrees of the technical characteristics W_j.

If there is only one technical characteristic in grade V_1, the importance degree of the technical characteristic W_j in grade V_1 is calculated by formula (9).

$$W_j = V_1 + \left(V_1 - V_2\right). \tag{9}$$

If there are l technical characteristics in grade V_1, $l \ge 2$, the importance degrees of the technical characteristics W_j in grade V_1 are calculated by formula (10).

$$W_j = \left[V_1 + \left(V_1 - V_2\right)\right] + \left(V_1 - V_2\right) * \frac{C_j^{sum}}{S_r}. \tag{10}$$

Calculate the importance degrees of the technical characteristics in grade V_r with formula (11), $r \ge 2$.

$$W_j = V_r + \left(V_{r-1} - V_r\right) * \frac{C_j^{sum}}{S_r} \tag{11}$$

The importance degrees of all the technical characteristics are calculated by the above five steps.

4.2. Case Study. Calculate the importance degrees of the technical characteristics in Table 3 using the new method proposed in Section 4.1.

Step 1. According to formula (3), all the customer requirements are standardized by 5, that is, the highest importance degree of customer requirement, and get the standardized results $\overline{W}_i$.

Table 8: The calculation results for the relationship matrix of airplane.

CR	W_i	$\overline{W}_i$	TC_1	TC_2	TC_3	TC_4	TC_5	TC_6	TC_7
CR_1	5	1	9		7	7	7	5	
CR_2	4	0.8	4		7.2		5.6		
CR_3	3	0.6	3		3	1.8	1.8		
CR_4	5	1	5	7			5		
CR_5	5	1	5	3	5	3	3		9
CR_6	4	0.8		4	2.4	2.4	2.4	7.2	2.4
CR_7	3	0.6	3	3					
CR_8	3	0.6		1.8	1.8	1.8	1.8		1.8
CR_9	3	0.6					5.4		
C_j^{sum}			29	18.8	26.4	16	32	12.2	13.2
C_j^{max}			9	7	7.2	7	7	7.2	9

Step 2. Calculate the contribution degree of each technical characteristic C_{ij} with formula (4).

Step 3. Calculate the highest and the total contribution degree of technical characteristic C_j^{max} and C_j^{sum}, respectively, with formula (5) and (6). The results of Steps 1 to 3 are shown in Table 8.

Step 4. All the technical characteristics are divided into three grades according to the highest contribution degree: V_1, V_2, and V_3. V_1 is the highest grade.

$$V_1 = 9 = \{TC_1, TC_7\}$$
$$V_2 = 7.2 = \{TC_3, TC_6\} \qquad (12)$$
$$V_3 = 7 = \{TC_2, TC_4, TC_5\}$$

Calculate the sum of the total contribution degree of the technical characteristics in every grade S_r with formula (8), $r = 1, 2, 3$.

$$S_1 = 29 + 13.2 = 42.2$$
$$S_2 = 12.2 + 26.4 = 38.6 \qquad (13)$$
$$S_3 = 18.8 + 16 + 32 = 66.8$$

Step 5. Calculate the importance degree of each technical characteristic W_j.

Choose appropriate formula to calculate the importance degrees of technical characteristics for every grade. Since there are two technical characteristics in V_1, formula (10) is used to calculate the importance degrees of TC_1 and TC_7.

$$W_1 = [9 + (9 - 7.2)] + (9 - 7.2) * \frac{29}{42.2} = 12.04$$
$$W_7 = [9 + (9 - 7.2)] + (9 - 7.2) * \frac{13.2}{42.2} = 11.36 \qquad (14)$$

Formula (11) is used to calculate the importance degrees of technical characteristics in other grades, and the importance degrees of all technical characteristics are obtained, as shown in Table 9. The results show that the importance degrees of TC_1 and TC_7 are the first and second, respectively, and both TC_1 and TC_7 are strongly related to the most important customer requirements. Improving TC_1 will gain a higher customer satisfaction than improving TC_5, which is the most important technical characteristic get by traditional method, since TC_5 is not strongly related to the most important customer requirements. The new method effectively preserves the driving effect of the most and more important customer requirements.

Table 9: The importance degrees of technical characteristics for airplane.

TC	TC_1	TC_2	TC_3	TC_4	TC_5	TC_6	TC_7
W_j	12.04	7.04	8.43	7.05	7.09	7.77	11.36

$$W_6 = 7.2 + (9 - 7.2) * \frac{12.2}{38.6} = 7.77$$
$$W_3 = 7.2 + (9 - 7.2) * \frac{26.4}{38.6} = 8.43$$
$$W_2 = 7 + (7.2 - 7) * \frac{18.8}{66.8} = 7.06 \qquad (15)$$
$$W_4 = 7 + (7.2 - 7) * \frac{16}{66.8} = 7.05$$
$$W_5 = 7 + (7.2 - 7) * \frac{32}{66.8} = 7.09$$

5. Conclusion

Taking the calculating method of the importance degrees of technical characteristics in the first phase of QFD as an example, it is pointed out that distortions exist in customer requirement transmission process due to the defects of QFD output information importance degree calculation methods. The distortions result in the designed or innovated product meeting less important customer requirements, but not meeting more important customer requirements, which causes the mismatch between the designed product and customer requirements, thus reducing product's customer satisfaction.

By analyzing the traditional method and OPM, it is pointed out that two kinds of distortion are caused.

The first kind of distortion: some technical characteristics variously related to less important customer requirements, but not strongly related to more important customer requirements, have higher importance degrees, while some technical characteristics strongly related to more important customer requirements and seldom related to less important customer requirements have lower importance degree. Thus, the designed product based on the output information of QFD cannot meet more important customer requirements.

The second kind of distortion: because of ignoring the differences of the importance degrees of customer requirements and overemphasizing the importance degrees of the technical characteristics that are strongly related to customer requirements, the importance degrees calculated are distorted. When the differences of the importance degrees are big, the technical characteristics that are moderately related to more importance customer requirements are more important than the technical characteristics that are strongly related to less important customer requirements. This phenomenon also reduces the driving effect of more important customer requirements, which results in the designed product being unable to meet more important customer requirements.

In order to avoid the distortions in customer requirement transmission process, a new method for calculating the importance degree of QFD output information is proposed. In order to consider the differences of the importance degree of QFD input information, the importance degree of the input information is standardized by the highest importance degree. Besides, the concept of contribution degree of output information in QFD is proposed. The ranking results of the importance degree of the QFD output information are obtained by twice ranking according to the total and the highest contribution degree of the output information. At last, the superiority of the method is verified by a specific example.

Data Availability

This paper points out the distortions of existing methods, so the data are adapted from existing literature.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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