Application of Combination Weighting Based On G1-MSE in QFD

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Abstract. QFD, as the main means of current demonstration, is widely used in product development and system demonstration. This paper first briefly introduces the basic analysis process of QFD, and then analyzes the research status of the mapping relationship between "customer demand and product characteristics". Aiming at the problem of qualitative index weighting, this paper compares the advantages and disadvantages of the subjective weighting method of AHP and G1 weighting method. Based on the analysis of the common objective weighting methods, this paper applies the principle of least mean square error to carry out objective weighting, and uses the idea of deviation and minimum to carry out combination weighting, and puts forward the combination weighting method based on G1-MSE. An example is given to verify that this method can reasonably solve the importance evaluation problem of qualitative indicators in QFD.

Keywords: QFD, G1 Weighting Method, MSE, The Sum Of Deviation Is Minimum, Combination Of Empowerment

Quality Function Deployment (QFD), first proposed by Yoji Akao, a Japanese quality expert, in 1966, is a kind of product design and development driven by customer demand, with a solid theoretical foundation and extensive application [1]. The basic idea is that in the process of product development, all related activities are task-driven according to the needs, preferences and expectations of customers, so as to maximize the product development to meet the needs of customers. The key is the establishment of the House of Quality (HOQ), a graphical method for determining the relationship between customer needs and the performance of the corresponding product or service. The establishment of HOQ mainly includes customer demand, product characteristics, the importance of customer demand, the relationship between demand and product characteristics, the relationship between characteristics and target value. Among them, the relationship between requirements and product characteristics is the main concern of current product development and system demonstration.

1. Basic Analysis Process of QFD
The basic principle of QFD is in the form of the house of quality, the quantitative analysis of the relationship between customer requirements and engineering measures, after data analysis to find the
greatest engineering measures to meet the demand of customer contribution, to guide the design personnel to seize the principal contradiction, to carry out the stability optimization design, develop products to meet customer demand [2].

Constructing a scientific and reasonable hierarchical relationship is the basis of demand analysis. Through the construction of a "demand-characteristics" multi-level structure, the demand scheme is divided into detailed categories to find out the product capability required to fulfill customer demand, and the hierarchical relationship among different levels is defined to construct the frame diagram as shown in Figure 1.

![Figure 1. Hierarchical relationship between customer demand and product features (capabilities)](image)

Zhou Jian and Lei Chang used the theory of Quality Function Deployment (QFD), combined with grey correlation analysis and GM(1,N) gray model, to generate the "small sample" and "poor information" scored by experts, and extract the information of demand importance and technical feature importance, which can quickly guide the functional design and technical resource allocation of the information system [3]. Ju Pinghua and Chen Zi used Probability Language Multiplication Analytic Hierarchy Process (PL-MAHP) to determine the initial weight of customer demands. According to the correlation between customer demands, fuzzy cognitive map (FCM) was used to carry out reasoning analysis on customer demands and obtain the final weight.

In order to effectively deal with the ambiguity and uncertainty in the expert evaluation information of QFD team[6], Nicolas Haber and Mario Fargnoli enhanced the quality function deployment of product service system (QFDFORPSS) method through Kano model, and used the fuzzy analytic hierarchy process to properly evaluate these parameters and their inherent uncertainties, and verified them in the case of hemodialysis equipment manufacturer cooperation in the field of medical equipment[7]. However, at present, most of the literatures mainly focus on the importance analysis of quantitative indicators, while the results of subjective weighting are still the main basis for qualitative indicators. There are few studies on objective weighting and combination weighting. In this paper, G1 weighting method is used as subjective weighting method, MSE principle is used as objective weighting method, combined with the idea of deviation and minimization, and combined weighting method is used to scientifically analyze the importance of qualitative indicators.

2. Subjective and Objective Combination Weighting Based On G1-MSE

2.1. Subjective Weighting Based on G1 Weighting Method

AHP, as the most commonly used subjective weighting method in QFD, can introduce the experience and subjective judgment of experts and decision makers into the evaluation process, construct the judgment matrix and conduct consistency test, and finally get the weight [8]. However, this method has a high requirement for expert scoring and a large amount of computation. On this basis, G1 weighting method is proposed to improve AHP [9].

Suppose you have M subtasks (T₁, T₂...Tₘ), N product capabilities (C₁, C₂...Cₙ). First, experts in related fields of group K were selected for evaluation. In the evaluation, the most important capability Cₓ₁ is selected from the N product capabilities, and then the most important indicator Cₓ₂ is selected from the remaining N-1 capabilities, and the ranking of product capability importance is obtained by such an analysis. Then the experts compare the two adjacent abilities according to their importance...
order, and give the importance ratio of $C_{xi-1}$ to $C_{xi}$ ($i = 2, 3, 4...N$), and its assignment value is shown in Table 1.

Table 1. $r_{ki}$ assignment table

| $r_{ki}$ | Instructions                                      |
|---------|---------------------------------------------------|
| 1.0     | The index $C_{xi-1}$ is equally important as $C_{xi}$ |
| 1.2     | The index $C_{xi-1}$ is slightly more important than $C_{xi}$ |
| 1.4     | The index $C_{xi-1}$ is significantly more important than $C_{xi}$ |
| 1.6     | The index $C_{xi-1}$ is strongly more important than $C_{xi}$ |
| 1.8     | The index $C_{xi-1}$ is extremely important than $C_{xi}$ |

Positions 1.1, 1.3, 1.5 and 1.7 are in between when $k$ is the expert evaluation completed, “$k$” importance ranking and importance ratio $r_{ki}$ are obtained for each task, and the subjective weight calculation “$\omega$” is:

$$\omega_k = \left(1 + \sum_{i=2}^{n} \prod_{j=2}^{n} r_{ij}\right)^{-3}$$

$$\omega'_{ki} = r_{ki} \omega_k, \quad i = n, n-1...3, 2$$

The weighted average of the subjective weight of “$k$” experts on the importance of indicators is carried out, and the subjective weight of each capability indicator in Task $T_m$ is obtained as follows:

$$\omega_{ki} = \sum_{j=1}^{k} \beta_j \omega'_{kj}$$

$\beta_k$, The evaluation weight of the KTH expert, when the evaluation weight of all experts is the same,

$$\beta_k = \frac{1}{k}$$

2.2. Objective Weighting Based on MSE

Objective weighting is to use the relationship between the original data to determine the weight of the target through certain mathematical methods. It does not depend on the subjective judgment of people and has good mathematical support. Currently, the main objective weighting methods include principal component analysis, rough set, entropy weight method, coefficient of variation method, etc. [10-13]. Principal component analysis (PCA) is to use the correlation between indicators to integrate, delete but not change the original information, so as to achieve the purpose of dimensionality reduction. However, in QFD, the correlation between indicators is difficult to merge, and most cases can be considered separately. Rough set uses the principle of attribute reduction to reorganize data by analyzing the actual situation of indicators and whether tasks are completed. However, in actual product development, in order to better complete the sub-task of requirements, the various capabilities of the product are always complete, which restricts the use of rough set. Of entropy method and the variation coefficient method is to use the data to reflect the discrete degree index of importance, that data, the greater the degree of discrete and the higher the index weight, but in practice often heavy index due to will be taken seriously, result in discrete degree often is very small, and the qualitative index cannot give accurate quantitative data. Therefore, the above methods are not applicable to the objective weight analysis of qualitative indicators.

In order to solve the above problems, the 0-3 scale method and the mean square error (MSE) were used as the basic methods of objective weighting [14].

Among them, marking ability is the ability that is necessary to complete the core task and has a decisive influence on the effective performance of the task. Once without the support of this ability, the corresponding activities cannot be completed. Key competencies: the ability necessary to complete the main task and having a significant influence on the completion of the task; General ability: it is necessary to complete non-main tasks, and has certain influence on the completion of tasks, but does
not affect the realization of tasks; Irrelevant competencies: competencies are not related to tasks. The 0-3 scale method divides the product capability into four levels, which are represented by 0, 1, 2 and 3 respectively, according to the actual situation of the contribution of each capability in the completion of the demand task. Among them, marking ability is the ability that is necessary to complete the core task and has a decisive influence on the effective performance of the task. Once without the support of this ability, the corresponding activities cannot be completed. Key competencies: the ability necessary to complete the main task and having a significant influence on the completion of the task; General ability: it is necessary to complete non-main tasks, and has certain influence on the completion of tasks, but does not affect the realization of tasks; Irrelevant competencies: competencies are not related to tasks.

Reflect the amount of mean square error is the calculation method of t and estimator error between theta, because when demand task by personnel, time, climate and so on many internal and external factors, thus causes the scaling method of evaluation, theta produces change, by using the principle of mean square error, find out the real value of t and the condition of minimum deviation, t can better reflect the actual situation at this time.

Assuming that the specific conditions of k demand tasks are collected, the solving formula is as follows:

\[
\min \text{MSE}(t^m) = \frac{1}{k} \sum_{i=1}^{k} (t^m - \theta^m)^2 \tag{4}
\]

\[
t^m = 0,1,2,3, \quad \theta^m = 0,1,2,3
\]

\[
\theta^m
\]

represents the estimated value of the NTH capability of the m task in the k case; \(t^m\) represents the true value of the NTH ability of the MTH task.

2.3. Combinatorial Empowerment

The combined weight of product capability can be obtained by integrating subjective weight and objective weight. As a subjective weighting method, the results obtained by G1 are greatly affected by subjective factors. Although the optimal solution of the capability scale is obtained by MSE minimization, there are still errors. Although there are some errors in both of the two weighting methods, the results obtained are close to the real situation. Therefore, we can use the idea of deviation and minimum to carry out the combination of subjective and objective weights and construct the optimization model:

\[
\min \sum_{i=1}^{n} [\mu_G (\omega_i - \omega_i^m)^2 + \mu_d (\omega_i - \omega_i^d)^2] \tag{5}
\]

\[
st. \sum_{i=1}^{n} \omega_i = 1, \omega_i > 0, \mu_G + \mu_d = 1
\]

\[
\mu_G \text{ and } \mu_d \text{ represents subjective and objective preference factors}, \omega_i \text{ represents the combined weight of each capability.}
\]

3. Case Analysis

Now, in order to complete product development, QFD should be used to analyze the importance of product capability. Through preliminary analysis, it has been obtained that customer needs can be divided into six sub-tasks: T1, T2,...T6, product development includes 5 capabilities C1, C2,...C5, the task importance has been obtained through expert evaluation and analytic hierarchy process

\[
\alpha = (0.0406, 0.1899, 0.4094, 0.0571, 0.1130, 0.1899)
\]
Now, five expert groups of specialized fields are composed to make subjective evaluation by means of G1 weighting, and to conduct objective scale on 12 groups of related product development cases. Under this condition, the importance of product capability is analyzed.

3.1. G1 Weighting Method to Analyze Subjective Weights
G1 weighting method is used to calculate the subjective weight.

1) Take the analysis of 6 abilities in Task T1 as an example. Construct the expert evaluation table, as shown in Table 2.

| Ranking | The panel 1 | The panel 2 | The panel 3 | The panel 4 | The panel 5 |
|---------|-------------|-------------|-------------|-------------|-------------|
| C2>C3>C4>C1 >C5 | C2>C3=C1>C4 >C5 | C2>C3>C4>C5 >C1 | C2>C3>C4>C5 >C1 | C2>C3>C4>C5 >C1 |
| rk | r2=1.4,r3=1.4, r4=1.2,r5=1.6 | r2=1.4,r3=1.4, r4=1.2,r5=1.6 | r2=1.4,r3=1.4, r4=1.2,r5=1.6 | r2=1.4,r3=1.4, r4=1.2,r5=1.6 |

2) For the data given by expert group 1, formula (1) can be used to obtain:

\[ \omega_{C_1}^G = 0.0912 \]

Equation (2) is used to obtain;

\[ \omega_{C_3}^C = r_2 \cdot \omega_{C_1}^G = 0.1458; \quad \omega_{C_2}^C = r_4 \cdot \omega_{C_1}^G = 0.1750; \quad \omega_{C_4}^C = r_5 \cdot \omega_{C_1}^G = 0.2450; \quad \omega_{C_2}^C = r_3 \cdot \omega_{C_1}^G = 0.3430 \]

3) By analogy, the subjective weights of the 5 groups of experts on the 6 abilities in Task T1 were obtained. Since the expert groups had the same professional level when selecting the experts, the evaluation weights were the same. Equation (3) was used to obtain the final subjective weights of the six abilities in Task T1, as shown in Table 3.

| The panel 1 | The panel 2 | The panel 3 | The panel 4 | The panel 5 | The comprehensive weights |
|-------------|-------------|-------------|-------------|-------------|--------------------------|
| C1          | 0.2450      | 0.2193      | 0.2103      | 0.2500      | 0.2381                   | 0.23254                  |
| C2          | 0.3430      | 0.3070      | 0.3031      | 0.3000      | 0.3333                   | 0.31728                  |
| C3          | 0.1458      | 0.1565      | 0.1503      | 0.1488      | 0.1417                   | 0.14862                  |
| C4          | 0.0912      | 0.0979      | 0.0835      | 0.0930      | 0.0886                   | 0.09084                  |
| C5          | 0.1750      | 0.2193      | 0.2526      | 0.2082      | 0.1983                   | 0.21068                  |

4) According to this method, the subjective weight of product capability in other tasks can be obtained, and the result is input into HOQ to obtain product capability. And weight distribution, as shown in Table 4.

| Ability importance | T1   | T2   | T3   | T4   | T5   | T6   | Task importance |
|--------------------|------|------|------|------|------|------|-----------------|
| C1                 | 0.23254 | 0.31728 | 0.14862 | 0.09084 | 0.21068 | 0.0406 |
| C2                 | 0.25584 | 0.25722 | 0.17654 | 0.16048 | 0.14192 | 0.1899 |
| C3                 | 0.29690 | 0.21914 | 0.15500 | 0.13736 | 0.19160 | 0.4094 |
| C4                 | 0.15910 | 0.22278 | 0.15640 | 0.16782 | 0.29390 | 0.0571 |
| C5                 | 0.23130 | 0.31540 | 0.16690 | 0.14804 | 0.13856 | 0.1130 |
| Ability importance | 0.2616 | 0.2344 | 0.1854 | 0.1525 | 0.1661 |               |
3.2. MSE Analysis of Objective Weights

The 0-3 scale method and MSE were used for objective weighting analysis. Taking the analysis of the six capabilities in Task T1 as an example, a capability scale table is constructed, as shown in Table 5.

Table 5. Product capability scale table in Task T1

| The serial number | C1 | C2 | C3 | C4 | C5 |
|-------------------|----|----|----|----|----|
| 1                 | 1  | 3  | 1  | 0  | 2  |
| 2                 | 0  | 3  | 2  | 1  | 2  |
| 3                 | 2  | 1  | 3  | 0  | 0  |
| 4                 | 0  | 3  | 2  | 1  | 1  |
| 5                 | 1  | 3  | 2  | 1  | 1  |
| 6                 | 2  | 3  | 2  | 1  | 1  |
| 7                 | 2  | 2  | 0  | 0  | 2  |
| 8                 | 2  | 3  | 0  | 1  | 1  |
| 9                 | 1  | 3  | 2  | 0  | 1  |
| 10                | 1  | 2  | 0  | 0  | 0  |
| 11                | 2  | 3  | 1  | 0  | 2  |
| 12                | 1  | 2  | 2  | 0  | 2  |

2) By the same method, the objective scale of product capabilities in other tasks can be obtained according to this method, and the results are input into HOQ to give the task importance degree combined with the task, and the importance ranking and weight distribution of product capabilities can be obtained, as shown in Table 7.

Table 7. Objective Importance of Product Capability

| Ability support | Ability importance | Importance ranking |
|-----------------|--------------------|--------------------|
| 2.5014          | 2.1534             | C1>C2>C3>C5>C4     |
| 1.4927          | 1.1492             |                    |
| 1.5235          | 1.1534             |                    |
| 0.2836          | 0.2441             |                    |
| 0.1693          | 0.1303             |                    |
| 0.1727          | 0.1899             |                    |

3.3. Combination Weighting and Conclusion Analysis Based On Deviation and Minimum
On the basis of the subjective and objective weights, the combination weights are given based on the idea of deviation and minimum. Equation (5) is used to obtain the combination weight. In order to facilitate the conclusion, a comparison table of subjective, objective and combined weights of product capability importance is constructed, as shown in Table 8. And get the G1-MSE combination weighting comparison line chart through Matlab, as shown in Figure 2.

### Table 8. Comparison of Importance of Product Capability

|   | G1   | MSE  | Combination of empowerment |
|---|------|------|---------------------------|
| C1 | 0.2616 | 0.2836 | 0.2726 |
| C2 | 0.2344 | 0.2441 | 0.23925 |
| C3 | 0.1854 | 0.1693 | 0.17735 |
| C4 | 0.1525 | 0.1303 | 0.1414 |
| C5 | 0.1661 | 0.1727 | 0.1694 |

### Figure 2. Weighted line diagram of G1-MSE combination

Through the comparison table of capability importance and the line chart of weight comparison, the following conclusions can be drawn:

On the whole, the subjective and objective results have a high degree of fit, and the results obtained by the two are relatively close to the real situation. From the perspective of a specific importance weight and sorting ability, ability in the C3 and C5 in the subjective and objective empower sorting result is different, can be seen from the line chart on compared to other areas in the subjective and objective weight deviation of C1 ~ C5 this area is larger, smaller deviation in C5 place, this is because the weight is conducted on the basis of analyzing the scale method, the volatile line chart changes lead to objectively, while at the same time with the method of MSE, the results more close to the actual value, but the error still exists, leading to the emergence of this situation; The weight obtained by combination weighting in the form of deviation and minimum is close to the subjective and objective weight, and can better represent the real situation.

Through the analysis, we can get the importance degree ranking and weight of the latest product capability connected with the real situation.

**Sorting:** C1 > C2 > C3 > C5 > C4,

**Weight:** \( \omega = (0.27260, 0.23925, 0.17735, 0.14140, 0.16940) \)

### 4. Conclusion

Aiming at the analysis method of mapping relation of qualitative indicators in QFD, this paper proposes a combined weighting method based on G1 weighting and minimum MSE weighting. G1 weighting method is used to carry out expert evaluation and weight calculation, and the subjective weight is obtained. Using the 0-3 scale method, the qualitative indexes are quantified objectively. On this basis, the minimum MSE method is used to find the ability scale which is closest to the real value, and then the
objective weight is obtained. Through the analysis of the subjective and objective weight results, to judge whether the conclusions of the two are close to the real situation; In full consideration of the subjective weighting of artificial and uncertain factors, the objective weighting error, based on the idea of deviation and minimization combination weighting, to get the best result. Combined with the example analysis, this method has the application value to solve the problem of qualitative index analysis in QFD.

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