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An Integrated QFD Models with Variety Management

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Abstract: Improving Design for Variety (DFV) can satisfy more customer requirements, but increase the complexity of product design and manufacturing. QFD, also known as House of Quality (HOQ), is a method that transforms Customer Requirements (CRs) into Engineering Characteristics (ECs), and then transforms ECs into Components Design (CDs). DFV include the variety in products and in components, and the product variety needs to be realized in component variety. With QFD, it is possible to transfer the requirement of CR to the requirement of CD including variety requirement. How QFD responds to DFV management so that it can plan ECs considering the impact of design changes on CDs was examined. This paper proposed a QFD optimization model that can quantify the interrelationships among ECs and support DFV management. A case study on an automobile development verified the effectiveness and feasibility of the proposed model.

Keywords: QFD, Design for variety, Optimization.

1. Introduction

Quality Function Deployment (QFD) was proposed by Japanese quality management scholars Yoji Akao and Shigeru Mizuno in the early 1970s, and has been widely applied in the world wide (Yoji Akao 2012). QFD can transform Customer Requirements (CRs) into Engineering Characteristics (ECs) in product design, and further transform ECs into Component Design (CDs). In order to satisfy more customers, many firms will provide more kinds of products which may increase product variety. A higher product variety usually brings more CRs, which will generate more ECs and more CDs. In order to make decisions on product variety in QFD, several impact factors need to be considered, i.e., the interrelationships among ECs, the benchmark in CRs, ECs and CDs, etc. Usually, these factors are examined qualitatively, but few quantitatively. One reason is the interrelationships among ECs are difficult to be quantitatively examined. This study is to found a quantitative model on the transform process in QFD. It can support the quantitative analysis of the interrelationships among ECs and support variety management. It is also known as design for variety (DFV).

2. Literature Review

1) QFD operation process. The tool of QFD looks like a house and is also called as House of Quality (HOQ). A sample including two stages is shown in Figure 1. In the first stage, the requirements on CRs are transformed to the requirement on ECs with one HOQ. The CRs and their weights are located in the left wall; the ECs and the interrelationships between each pair of ECs are located in the top roof; the relationship matrix between CR and EC is located in the center; the competitive information is located in the right wall. In the second stage, the requirements on ECs were transformed to the requirements on CDs with another HOQ.

There are six steps for building the first HOQ, i.e., 1) identify CRs, 2) identify ECs, 3) relate CRs to ECs, 4) conduct an evaluation of competing products or services, 5) evaluate ECs and develop targets, 6) determine which ECs to deploy in the remainder of the production and delivery processes (Evans and Lindsay, 2011). In the 5th step, the priorities of CRs can be transformed to the weights of ECs through a multiplication operation with the relationship matrix between CRs and ECs. The priorities of ECs are the targets of ECs to be deployed in the remainder processes. It can be decided according to the weights of ECs, the competitive evaluations, and the interrelationships analysis among ECs. The sequence of the above six steps was understood as the forward process in QFD. The second transform process on transforming ECs to CDs is similar as the first stage.

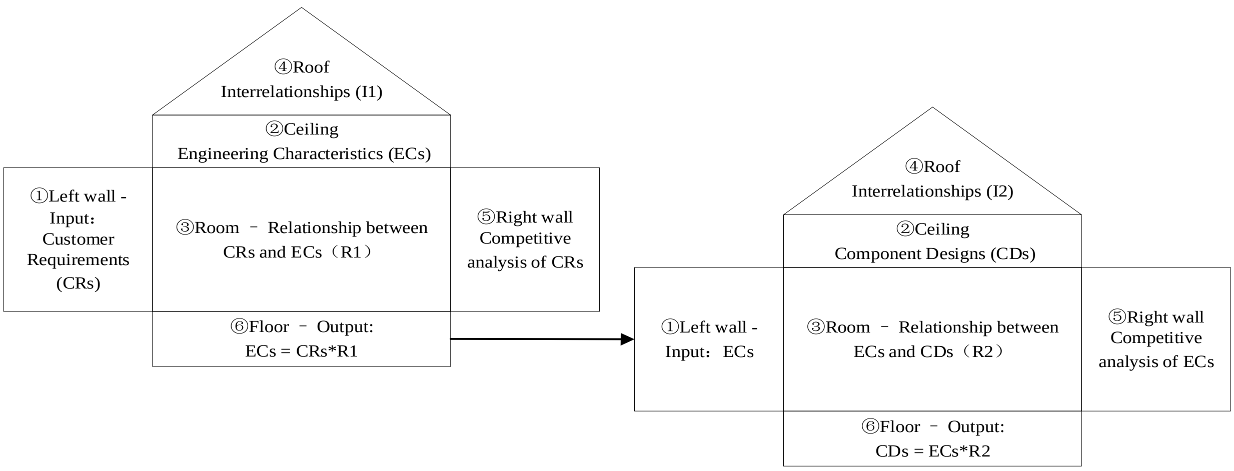

Figure 1. The house of quality sample

2) DFV decisions in QFD. Kekre S. and Srinivasan K. (1990) proposed that compared with a relatively single product line, product variety can better meet the individual requirements of customers, thereby improving customer loyalty and enabling enterprises to gain market share advantages. While product variety can satisfy CRs, it also increases the complexity of product design. Design for Variety (DFV) is to consider the impact of component and product variety in design, so as to balance the gained benefit and increased cost. The product variety is also supported by component variety. Coupling Index (CI) is used to measure the impact of the design changes in one component on the other components. Because the components are tangible, the changes can be measured through the summary of the change degree in different dimensions, i.e., component size changes, product architecture changes, parameter changes, etc. As a general design rule, if one component has a higher CI value, it would better make fewer changes on the component. For the improvement design of one existing product, there are original value of CDs. For the new product design, the original value of CDs can be defined from the cost down view.

When the CDs changes, the design change is embodied in the second stage of QFD. When implementing the DFV management, the ECs are affected by the CDs changes brought by the product design. On the other hand, the ECs are also affected by CRs. QFD completes the transformation of CRs into ECs and ECs into CDs in the first two stages. This process usually does not consider the changes brought about by DFV to the planning of ECs. Therefore, in order to better support the DFV management in QFD, the CI between CDs can be added to the first stage of QFD and the interrelationship between each of ECs can be quantified. A QFD optimization model is to be established to support the planning of ECs under the DFV management.

3) Interrelationships among ECs. One problem in QFD is that the interrelationships among ECs has not been well considered. There are usually two ways to deal with the interrelationships among ECs. Some studies choose to only analyze the interrelationships from the qualitative view when using QFD method, and artificially adjust the QFD output results subjectively. Some studies founded quantitative models on the interrelationships. These models are applicable to the cases with a small number of ECs. For instance, Dawson, D. and Askin, R. G. (1999) used Design of Experiment (DOE) to determine the interrelationship among ECs, and established a corresponding mathematical model with the objective to maximize customer satisfaction. The quantity of ECs in the case was three. Karsak, E. E. et al. (2003) used Analytic Network Process (ANP) to set cost budget, scalability level and manufacturability level goals to derive the importance of ECs. The case design included seven ECs. The quantitative methods become much more complex as the quantity of ECs increasing.

Two problems on QFD methods were targeted: 1) the traditional QFD methods cannot support DFV management; 2) the interrelationships among ECs in QFD are not well quantitatively studied. In order to improve QFD with supporting DFV, this paper proposes a QFD optimization model with quantifying the interrelationships among ECs.

3. QFD Optimization Model

In the traditional QFD, the relationship matrix between CRs and ECs does not consider the interrelationships among ECs when scoring. In fact, when product design changes, ECs interact with each other. It is necessary to quantify and score the interrelationship between each pair of ECs to obtain the interrelationship matrix. At the same time, the second stage of QFD does not consider the design changes caused by DFV on CDs. This paper adopted CI to measure the impact of the design changes on CDs to support DFV. The QFD optimization model is established as follows. The decision variables are the target value of EC. The optimization objective is to maximize the customer satisfaction degree realized by CRs. The notations of model are as follow: n: The quantity of CRs. m: The quantity of ECs. p: The quantity of CDs.

$$\max F(x)=\sum_{i=1}^{n} x_i \tag{1}$$

$$s.t.\begin{cases} x_i=\sum_{j=1}^{m} r_{ji}a_j+\sum_{k<j}\sum_{j=2}^{m} r_{ji}t_{jk}a_j & i=1,2,...,n & (1-1) \\ c_q=\sum_{j=1}^{m} g_{jq}a_j & q=1,2,...,p & (1-2) \\ \frac{1}{\left|c_q-c_q^0\right|}\le \frac{\sum_{k\ne q}^{p} CI_{qk}}{\sum_{k=1}^{p}\sum_{q=1}^{p} CI_{qk}} & q=1,2,...,p & (1-3) \\ L_i\le x_i\le U_i & i=1,2,...,n & (1-4) \end{cases}$$

x_i – The satisfaction degree of the CRi, i=1,2,…,n.

a_j – The target value of the ECj, j=1,2,…,m.

x_i – The satisfaction degree of the CRi, i=1,2,…,n.

a_j – The target value of the ECj, j=1,2,…,m.

c_q – The target value for DFV with the CDq, q=1,2,…,p.

c_q^0 – The original value of the CDq, q=1,2,…,p.

$R=\left(r_{ji}\right)_{m\times n}$ – The relationship matrix between ECs and CRs, r_{ji} indicates the correlation between the ECj and the CRi in the first stage of QFD.

$G=\left(g_{jq}\right)_{m\times p}$ – The relationship matrix between ECs and CDs, g_{jq} indicates the correlation between the ECj and the CDq in the second stage of QFD.

$T=\left(t_{kj}\right)_{m\times m}$ – The interrelationship matrix between each of ECj.

$CI=(CI_{qk})_{p\times p}$ –The coupling index between each of CDq.

L_i, U_i – The lower and upper limits of x_i.

In constraint (1-1), the optimal model was founded on the relationships between the target values of ECs and the satisfaction degree of CRs. The model considered the interrelationships between each pair of the ECs. Constraint (1-1) represents that the transformation of ECs into CRs in the first stage of QFD.

Constraint (1-2) represents that the transformation of requirements of ECs into the requirements of CDs in the second stage of QFD.

Constraint (1-3) represents that the changes between the targeted value for DFV with CDs and original value of CDs are inversely proportional to CI between CDs. It can support the rule on CI design that if one component has a higher CI value, it would better make fewer changes on the component.

Constraint (1-4) represents that the satisfaction degree of CRi will not exceed the upper limit, nor will it be lower than the lower limit of the target value of CRi. The values of the coefficients U and L in the model are estimated according to the actual situations of enterprises.

4. Numerical Experiments of QFD Optimization Models

Numerical experiments include the 6 steps. Step 1: According to market research, there are 7 CRs for one automotive product. By competitive product analysis, the targeted CR importance can be defined as shown in Table 1. Step 2: According to the design team analysis, there are 10 ECs. Step 3: The correlation between each CR and each EC and the correlation between each EC and each CD were defined base on technical analysis. Step 4: The interrelationship between each pair of ECs were defined based on technical analysis. Step 5: Experts scored the CI between each pair of CDs. Step 6. LINGO software is used to solve the QFD optimization model to obtain the targets of ECs. The comparison results between the targeted ECs with interrelationships and without interrelationships are shown in Table 2.

Table 1. The targets of CRs

Customer Requirements	CR1	CR2	CR3	CR4	CR5	CR6	CR7
Targets	25.43	15.50	10.89	11.49	27.75	6.44	2.50

Table 2. The targets of ECs

Engineering Characteristics	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9	EC10
With Interrelationship	16.38	16.72	10.16	31.36	3.61	8.89	10.55	0.00	2.35	0.00
Without interrelationship	15.51	27.13	15.50	8.58	6.46	8.17	4.92	3.95	2.72	7.07
Deviation	0.87	10.41	5.34	22.78	2.85	0.72	5.63	3.95	0.37	7.07

The numerical experiment results show that under the limitation of DFV there are deviation in ECs planning between with and without interrelationships among ECs. When the CDs changes, it has a great impact on the planning of EC4, EC2, and EC10. The planning of EC1, EC6, and EC9 are insensitive to changes in CDs.

5. Conclusion and Future Studies

With more types of products proposed, DFV becomes important in product design. This paper proposed a QFD optimization model by introducing CI constraints to consider the quantitative interrelationship between ECs, and the numeral experiments verified the feasibility of the QFD optimization model. The model can improve the resource allocation with QFD. Several suggestions can be proposed based on the results.

1) The DFV management can respond quickly to the CRs and improve the customer satisfaction. Product variety can increase higher changes in CDs, so as to impact the design of ECs. The proposed model in this paper improved the QFD method by introducing CI to realize the QFD support DFV management. When CDs change, ECs can be re-planned within the allowable variation of CI constraints.

2) The interrelationships between each pair of ECs can affect the accuracy of QFD output, and need to be considered in QFD more accurately. This paper verifies the necessity of the optimization model to join the interrelationships between each pair of ECs through experiment design and give the solutions. It supports the integration between QFD and DFV management.

There are some limitations in this study which would be examined in the future research. When the design of CDs changes, the change solutions on EC8 and EC10 are 0 due to the constraint of CI. This limitation may be too strict. Other limitation may be considered, i.e., Spearman rank correlation coefficient. The proposed model focuses on the cost down design with QFD and DFV, but may not be suitable for the innovative product designs without limitations on the original value on component design.

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