

## A Novel Method on Customer Requirements Preferences Based on Common Set of Weight

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**Abstract:** Quality function deployment (QFD) has been widely used as a multi-functional design tool to translate lingual voice of customer requirements (CRs) to a product's technical attributes in the design, development of products, process planning and production planning strategies. Even though QFD efforts have been extensively used, assessing information from participant experts is still difficult task in QFD planning. The proposed voting methodology uses common set of weight (CSW) method as a well known technique in data envelopment analysis (DEA) to aggregate each of the requirements expressed by customers and comparisons among the product produced by own company with competitive products. Using such flexible method can reduce cognitive burden of designers and engineers on the presence of lack of enough data and different points of voters' view. Based on the dominance concepts of DEA with incomplete information, we developed a systematic two phase method for prioritizing customers' requirements with a numerical example.

**Key words:** Quality Function Deployment (QFD), House of Quality (HOQ), Data Envelopment Analysis (DEA), Common Set of Weight (CSW), Customer Preference

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### INTRODUCTION

Quality Function Deployment which nowadays has been used successfully originally proposed by Akao in 1972 in Mitsubishi. It is a set of methods that involve creating a few tables called House of Quality (HOQ) to help the product development team systematically relate the customer requirements (CRs) that represent the overall customer concerns to the engineering characteristics (ECs), which represent the technical performance specifications of a developing product. The HOQ matrix constitutes an assemblage of the results of the benchmarking and cause & effect matrices methods together with additional information. Therefore, information is included both on what makes customers happy and on measurable quantities relevant to engineering and profit maximization. QFD also help decision-makers better understand how their system differs from competitor systems, both in the eyes of their customers and in objective features to support what might be called moderately formal decision-making.

Cohen (1995) believed that QFD is a method to encourage product development members to communicate more effectively with each other to formulate business problems and possible solutions. Experiments states that QFD has reduced design time by 40% and design costs by 60% (Revell & Cox, 1997). These improvements are caused by the increased communication among functional groups early in the product development process and by assuring that the voice of the customer is built into the development process (Hauser & Clausing, 1988; Urban & Hauser, 1993).

Fig. 1 shows sequences of a typical traditional four step QFD consist of product planning, product design, process planning and process control phases, which CRs arranged as customer desires in rows and ECs in columns of the first HOQ matrix. In each separate phase expert groups tries to sequentially find out the ways of conforming customer needs. As shown in the figure at each stage, the ECs, may called "Hows" are carried to the next phase as CRs or "Whats".

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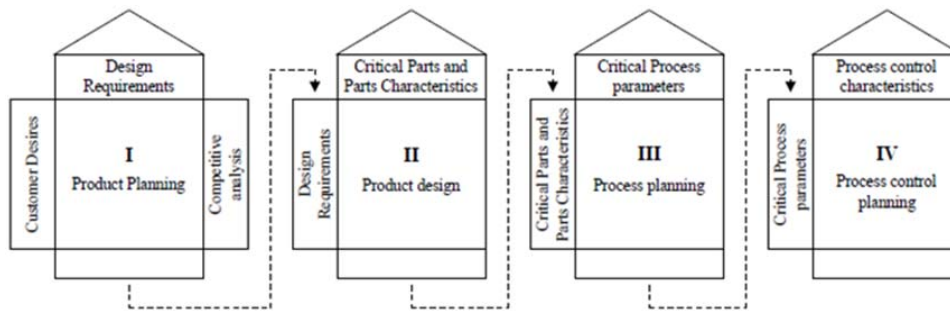


Fig. 1: The four phases traditional QFD (Cohen, 1995).

From the point of view of procedure, QFD uses a series of HOQ matrices. The philosophy governing how QFD is to be applied is placed on both what needs to be done and how it is to be done.

Franceschini [2002] believed that the principal stages necessary for the construction of the first HOQ matrix includes: 1) Identifying customer requirements (CRs) and their perceptions, 2) Identifying product and engineering design requirements (ECs), 3) Drawing up a relationship matrix, 4) Planning and deploying expected quality (by listing CRs in order of importance and benchmarking competitive products), 5) Comparing ECs through a technical importance ranking, 6) Analyzing the correlations existing between the various characteristics (correlation matrix) and 7) Prioritizing ECs.

Figure 2 illustrates the functional bonds linking operative phases and appropriate HOQ zones. Carnevalli and Miguel, 2008 presented a review, analysis, classification and codification of the literature on QFD produced between 2002 and 2006. They concluded that the majority of the published articles were case studies. In most of the cases, the work goals were about adapting QFD for a specific application. There are also several studies of intended improvements to the method that introduce quantitative tools and techniques. Among them fuzzy logic, Analytic Hierarchy Process (AHP), Analytic Network Process (ANP) and Artificial Neural Nets (ANN) applied more frequently in prioritizing of CRs and ECs. In most cases, the use of these techniques aims at reducing the subjectivity of the analysis performed on the quality matrix, that is, to improve operations that use QFD.

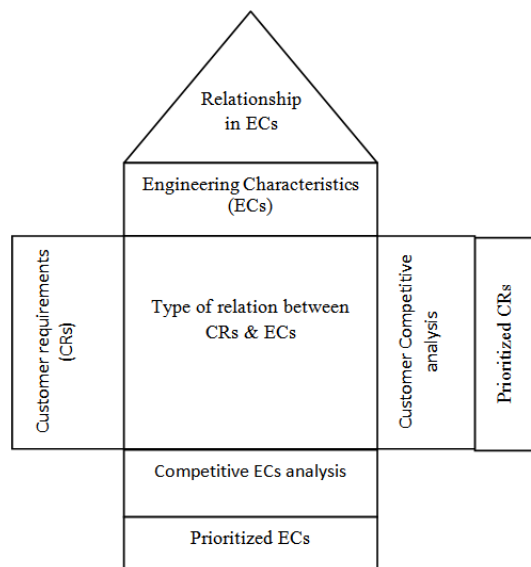


Fig. 2: Main components of the house of quality (HOQ).

AHP method, with or without fuzzy logic helped to define the degree of importance of the demanded quality (Armacost *et al.*, 1994, Wang *et al.*, 1998, Myint, 2003, Bhattacharya *et al.* 2005, Lin & Wang, 2008) and to help in the correlations between the data in the matrixes (Partovi, 2001, 2006). On the presence of vagueness or impreciseness of data, the fuzzy concept was also applied to such cases (see Kwong and Bai,

2002, Tang 2008). Chen and Fung, 2006 proposed using fuzzy weighted average method in the fuzzy expected value operator in order to rank technical attributes in fuzzy QFD. Analytic network process (ANP) also used for ranking characteristic in QFD process (see Karsak *et al*, 2003; Partovi, 2006; Ridder *et al*,2008).

The neural network (NN) technique was also used in the QFD for considering the uncertainty of the available human experts. Myint 2003, Lai, Ho, and Chang, 1998 applied in the decision-making process combining voting and linear programming techniques to aggregate individual preference into group consensus. Ho, Lai, and Chang,1999 also proposed an integrated group decision-making method to aggregate team members' opinions and minimize inconsistency over group and individual preferences for determining the importance weights of CRs.

Kwong and Bai, 2002, 2003 employed group decision-making method and AHP incorporated with fuzzy set theory to determine the importance weights of CRs. Chin-Hung Liu, 2009 proposed a group decision-making method with fuzzy set theory and genetic algorithms in quality function deployment. In the recent paper data envelopment analysis used for prioritizing in QFD process. Ramanathan *et al.*, 2009 proposed QFD–DEA methodology to obtain the relative importance of ECs when several factors have to be considered simultaneously. Also Kamvysi *et al.*, 2010 used combination of QFD with AHP-ANP and Data Envelopment Analysis (DEA) with AHP and ANP called DEAHP-DEANP methodologies to prioritize selection criteria in a service context. Han *et al.* suggested a linear partial ordering approach for assessing the knowledge from participants and prioritizing ECs. Kim *et al.* developed two robustness indices and proposed the notion of robust prioritization that ensures the ECs prioritization to be robust against the uncertainty.

Commonly, the QFD process involves various inputs in the form of linguistic data, e.g., human perception, judgment, evolution on importance of CRs or strengths of relationship between CRs and ECs are highly subjective and vague (Kim, Moskowitz, Dhingra, & Evans, 2000; Chan & Wu, 2002; Bai & Kwong, 2003; Fung, Chen, & Tang, 2006).

Due to existence of ambiguities in the real voting cases, we focused on the way of prioritizing CRs based on gathered information of different customer both in primary and secondary phase. The proposed novel methodology uses the customers' votes and applying common set of weight (CSW) in DEA to evaluate the "Whats" to derive priorities of CRs. DEA is a widely used tool in efficiency analysis and measurement. It is a linear programming based technique for measuring the relative efficiency of a set of competing decision-making units (DMUs) where the presence of multiple inputs and outputs makes the comparisons difficult. The relative efficiency of the 'multiple inputs and outputs' in DMU are typically defined as a ratio (weighted sum of the DMU's outputs divided by weighted sum of the DMU's inputs). So, if the higher performance in the relative efficiency can be obtained, the input data of ratio must have lower values and the output data of ratio must have higher values. Or, when the input data are constrained to fixed values and the output data have higher values, the relative efficiency also has a higher performance.

Imposing bounds on factor weights, limits the flexibility of DEA in assigning individual sets of weights to each of the participating DMUs. In the extreme case, when no flexibility is allowed, a Common Set of Weights is applied for the assessment of all DMUs. Such a common set can serve as a yardstick to which the results of the ordinary ("flexible") DEA outcomes are compared. When numbers of DMUs are less than sum inputs and outputs, basic DEA model cannot identify the efficient unit, hence CSW is a. There are several method for identify CSW( see Jahanshahloo *et al.*, 1997; Hosseinzadeh *et al.*, 2000; Saati *et al.*, 2005; Kuosmanen *et al.*, 2006; Saati, 2008) . In this paper we used the last proposed two step method to apply CSW in DEA. Step one is Bounds determination. To determine the upper bounds on output weights, the model 1 is considered in step 1.

$$\text{Max } u_r \tag{1}$$

$$\text{S. t } \sum_{i=1}^m v_i x_{ij} \leq 1; \forall j$$

$$\sum_{r=1}^s u_r y_{rj} - \sum_{i=1}^m v_i x_{ij} \leq 0; j = 1, 2, \dots, n$$

$$u_r, v_i \geq 0 \forall r, i; i = 1, \dots, m; r = 1, \dots, s$$

In second step a CSW model 2 is applied.

Max  $\emptyset$  (2)

$$S.t \quad \sum_{r=1}^s u_r y_{rj} - \sum_{i=1}^m v_i x_{ij} \leq 0; \forall j$$

$$U_r^l + \emptyset(U_r^u - U_r^l) \leq u_r \leq U_r^l + \emptyset(U_r^u - U_r^l); \forall r$$

$$V_i^l - \emptyset(V_i^u - V_i^l) \leq v_i \leq V_i^l - \emptyset(V_i^u - V_i^l); \forall i$$

Through the following model, the efficiency of each DMU can be evaluated as follows:

$$e_j = \frac{\sum_{r=1}^s \hat{u}_r y_{rj}}{\sum_{i=1}^m \hat{v}_i x_{ij}}; \forall j \quad (3)$$

where,  $\hat{u}_r$  ( $r = 1, \dots, s$ ) and  $\hat{v}_i$  ( $i = 1, \dots, m$ ) are optimal values of (2).

The rest of paper is organized as follows: Section 2 provides the suggested method followed by a short background on common set of weight technique. To follow the proposed concept systematically, a numerical example is given in Section 3. Section 4 closes with conclusion.

**2. The Proposed Methodology:**

In real cases many quality engineers prefer to follow customer perceptions in lingual terms. A common way may make use of the subsequent states such as:

Very high (VH), High (H), Moderate (M), Low (L) and Very Low (VL)

Usually, in this manner experts vote on CRs' importance via the mentioned lingual terms in two sequential phases. Hence we could count number of votes on each lingual term to applying DEA method to find final customer perception. As said before, this process should be applied in two sequential phases called hereinafter as primary and secondary phase.

Primary stage engaged of voters points of view on each CR. Through applying CSW as a well-known technique in DEA the primary weights of the  $i^{th}$  customer requirements, say  $W_{CR_i}^P$  is calculable. Secondary phase finalized the primary mentioned weights by affecting the customers' comparisons among own characteristics with those of other competitor's products (benchmarking process). Such final weights vector hereinafter is showed by  $W_{CR_i}^S$  for each customer requirements. The proposed procedure of calculating  $K$  customer requirement weights in two sequential phases is given below:

**Phase 1:** Calculating primary weights of the each customer requirement,  $W_{CR_i}^P$ .

1. Consider every CRs or "Whats" are DMU and select  $N$  voters to declare their point of view on CRs perceptions in lingual terms
2. Count number of votes,  $n_{ij}$  of the  $i^{th}$  DMU and the  $j^{th}$  lingual term, where  $i = 1, 2, \dots, K$  and  $j = 1, 2, \dots, m$  hence  $m = 5$  for the mentioned five levels of lingual terms.
3. Apply CSW technique to calculate efficiency of the  $i^{th}$  DMU,  $E_{DMU_i}$  and score of the  $j^{th}$  lingual terms,  $S_j$ , where each DMU have  $N$  output and one dummy input.
4. Apply SAW technique for calculating the primary weights of the  $i^{th}$  customer requirement is

$$W_{CR_i}^p = \sum_{j=1}^m S_j n_{ij}$$

**Phase 2:** Calculating Secondary weights of the each customer requirement,  $W_{CR_i}^s$ :

5. Follow  $N$  voters' perceptions on the  $K$  customer requirements. To deal correctly with each of CRs expressed by customers to have comparison among the product produced by own company,  $C_1$ , and some competitive products, say  $L$ , belonging to the same market segment,  $C_l$ ;  $l = 1, 2, \dots, L$ .
6. Consider every competitors are DMU and count number of votes,  $n_{ij}$  of the  $l^{th}$  DMU and the  $j^{th}$  lingual term, where  $i = 1, 2, \dots, L$  and  $j = 1, 2, \dots, m$  hence  $m=5$  for the mentioned five levels of lingual terms.
7. Apply CSW technique to calculate efficiency of the  $i^{th}$  DMU on  $i^{th}$  customer requirements,  $E_{DMU_{il}}$  and calculate the secondary score of the  $j^{th}$  lingual terms,  $SS_j$ , where each DMU have  $N$  output and one dummy input.
8. Apply SAW technique for calculating the secondary weights of the  $i^{th}$  customer requirement is

$$W_{CR_i}^p = \sum_{j=1}^m SS_j n_{ij}$$

9. Prioritize customer requirements based on their secondary weights.

**4. Illustrate Example:**

In this section a numerical example based on the proposed method showed step by step. For this issues assume  $W_1, W_2, W_3, W_4, W_5$  show five customer requirements identified as major "Whats" and we ask over 10 voters for evaluation of the importance of them. Also suppose there are three companies for customer competitive evaluation which shows them with phrase ( $C_1, C_2, C_3, C_4$ ). On them  $C_1$  is relevant to own company and  $C_2, C_3, C_4$  for competitive.

Table 1 delivers the primary voters' perceptions on the each CR based on the mentioned lingual term abbreviations.

**Table 1:** The ten experts' perceptions on the relative importance of the 5 "Whats".

Whats	Voters' number									
	1	2	3	4	5	6	7	8	9	10
$W^1$	L	H	M	VH	M	H	M	VH	H	H
$W^2$	H	L	H	H	VH	M	H	M	H	VH
$W^3$	VL	M	L	M	H	M	H	VH	M	M
$W^4$	M	H	M	H	M	VH	M	VL	H	L
$W^5$	M	H	VL	M	M	L	M	H	L	L

After counting of total votes of each linguistic variable table 2 could gain. Consider each "Whats" act as a DMU, and voters are their outputs. Then the present problem consists of five DMU with ten outputs and one dummy input achieved value one. After running CSW model, efficiencies of each DMU and scores of the defined lingual terms may get as shown in tables 3 and 4.

**Table 2:** Number of votes of each linguistic term on each "Whats".

DMUs	Very low	Low	Moderate	High	Very high
$W^1$	-	1	3	4	2
$W^2$	-	1	2	5	2
$W^3$	1	1	5	2	1
$W^4$	1	1	4	3	1
$W^5$	1	3	4	2	-

**Table 3:** Calculated efficiency of decision making units based on the CSW model.

DMUs	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	W <sub>4</sub>	W <sub>5</sub>
Efficiency	0.845	0.845	1	1	0.99

**Table 4:** Calculated scores of the given linguistic terms based on the CSW model.

linguistic variable	VL	L	M	H	VH
Score	0.236	0.079	0.047	0.047	0.118

By using simple additive weighting method (SAW) weights of each DMUs are acquirable as:

$$\begin{aligned}
 W_1 &= 0(0.236) + 1(0.079) + 3(0.047) + 4(0.047) + 2(0.118) = 0.644 \\
 W_2 &= 0(0.236) + 1(0.079) + 2(0.047) + 5(0.047) + 2(0.118) = 0.644 \\
 W_3 &= 1(0.236) + 1(0.079) + 5(0.047) + 2(0.047) + 1(0.118) = 0.762 \\
 W_4 &= 1(0.236) + 1(0.079) + 4(0.047) + 3(0.047) + 1(0.118) = 0.762 \\
 W_5 &= 1(0.236) + 3(0.079) + 4(0.047) + 2(0.047) + 0(0.118) = 0.755
 \end{aligned}$$

In order to normalizing the DMUs weights we divided them to the largest score, hence it is  $W_3=0.762$ . Therefore the prior weights of CRs based on the voters' points of view will be

$$(W_{CR_1}^P, W_{CR_2}^P, W_{CR_3}^P, W_{CR_4}^P, W_{CR_5}^P) = (0.845, 0.845, 1, 1, 0.99)$$

In order to finalize customer perceptions, comparison among the product produced by own company with competitive products belonging to the same market segment are necessary. So a questionnaire is sent to a group of 10 customers to inquire on the level of importance of each CRs. In it individual customers are requested to evaluate the degree of satisfaction obtained within own company from the use of the product, as well as the degree of satisfaction obtained from the product marketed by their strongest competitors.

Table 5 conveys level of pleasure of each voter on each "Whats" through comparison between own company showed by competitor # 1 and three other competitors codified as 2, 3 and 4.

Table 6 offers total votes on each linguistic term. Consider hence  $C_1, C_2, C_3, C_4$  act as decision making units and the ten voters' linguistic variables perform as their output and assume one dummy input with value 1. After carrying out CSW model, efficiencies of each DMU and scores of the defined lingual terms may get as shown in tables 7 and 8.

**Table 5:** Degree of satisfaction obtained from the ten voters perceptions on the 5 "Whats".

Voter #	1				2				3				4				5			
Competitor #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
W <sub>1</sub>	M	H	M	L	VH	VH	H	M	H	M	H	M	M	H	M	L	M	H	M	M
W <sub>2</sub>	L	M	M	L	H	M	H	M	L	M	M	M	M	VH	H	M	L	M	L	M
W <sub>3</sub>	H	VH	M	M	M	H	M	M	VH	H	M	H	H	H	L	M	H	L	M	M
W <sub>4</sub>	L	M	H	M	M	VH	H	M	H	H	L	M	M	M	H	M	L	L	M	L
W <sub>5</sub>	M	H	M	L	M	H	M	L	M	L	M	M	L	H	VH	M	M	M	L	L
Voter #	6				7				8				9				10			
Competitor #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
W <sub>1</sub>	L	H	VH	M	VL	M	M	L	M	H	M	M	VH	H	M	H	L	M	H	M
W <sub>2</sub>	M	M	L	M	L	H	M	M	M	M	H	L	H	H	M	M	VL	M	L	L
W <sub>3</sub>	M	H	M	L	M	VH	L	L	H	VH	H	M	VL	L	H	M	M	H	M	L
W <sub>4</sub>	L	M	M	M	M	M	VL	L	H	H	M	H	VH	M	VH	M	H	M	H	M
W <sub>5</sub>	M	H	M	M	H	L	L	M	M	M	L	VL	M	M	L	M	M	M	H	M

**Table 6:** Number of votes of each linguistic term on each "Whats".

	W1					W2					W3					W4					W5				
	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH
C <sub>1</sub>	1	2	4	1	2	1	4	3	2	-	1	-	4	4	1	-	3	3	3	1	-	1	8	1	-
C <sub>2</sub>	-	-	3	6	1	-	7	2	1	-	2	-	5	3	-	1	6	2	1	-	2	4	4	-	-
C <sub>3</sub>	-	-	6	3	1	-	3	4	3	-	-	2	6	2	-	1	1	3	4	1	-	4	4	1	1
C <sub>4</sub>	-	3	6	1	-	-	3	7	-	-	-	3	6	1	-	-	2	7	1	-	1	3	6	-	-

**Table 7:** Efficiency of DMUs for each "Whats" and competitors.

DMUs	W <sub>1</sub>	W <sub>2</sub>	W <sub>3</sub>	W <sub>4</sub>	W <sub>5</sub>
C <sub>1</sub>	1	1	1	0.845	0.545
C <sub>2</sub>	0.571	0.862	1	0.715	0.727
C <sub>3</sub>	0.571	0.75	0.786	1	1
C <sub>4</sub>	0.691	0.565	0.857	0.509	0.909

**Table 8:** Efficiency of the competitors.

DMUs	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>
Efficiency	1	0.883	0.936	0.804

By using SAW technique, the final weights of each CRs or "Whats" are acquirable as:

$$(W_{CR_1}^S, W_{CR_2}^S, W_{CR_3}^S, W_{CR_4}^S, W_{CR_5}^S) = (0.549, 0.616, 0.827, 0.705, 0.706)$$

The final weights vector shows priorities proceed as  $CR_3 > CR_5 > CR_4 > CR_2 > CR_1$

**5. Conclusion:**

Deriving rankings of CRs and ECs is a crucial step towards successful QFD when different experts have different points of view. Ranking on the importance of each customer requirement is essential in every QFD process and is on the deep focus of the present effort. In this paper, we proposed a novel method for prioritizing customer requirement in two sequential phase. The proposed methodology used voting process to assess perception information in QFD process, DEA model with common weights to determine the values of the linguistic terms, and efficiency of DMUs. The main benefits of the proposed method are:

1. Customer requirements' preferences calculated quantitatively on two sequential dependent phase called primary and secondary.
2. The proposed method utilizes general lingual terms and voting process and is able to aggregate different votes acceptably and precisely.
3. Due to the model structure, there are possibility to apply simultaneous other goals respect to restrictions.

The numerical example has been investigated to illustrate the applications of the proposed novel methodology.

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