Application of the Improved QFD Method Case Study: Kitchen Utensils Rack Design

Dini Endah Setyo Rahaju and Dian Retno Sari Dewi

***Abstract*—**This paper presents an application of the improved QFD method for determining the specifications of kitchen utensils rack. By using the improved method, the subjective nature in original QFD was reduced; particularly in defining the relationship between customer requirement and engineering characteristics. The regression analysis that was used for obtaining the relationship functions between customer requirement and engineering characteristics also accommodated the inaccurateness of the competitive assessment results. The improved method which is represented in the form of a mathematical model had become a formal guidance to allocate the resource for improving the specifications of kitchen utensils rack. The specifications obtained had led to the achievement of the highest feasible customer satisfaction.

***Keywords*—**Customer satisfaction, kitchen utensils rack design, QFD, specifications.

I. Introduction

QUALITY FUNCTION DEPLOYMENT (QFD) is a broadly used methodology to bring quality into product design. It is a customer-focused product methodology that was originally invented by Shigeru Mizuno and Yoji Akao in the 1966. The systematic QFD process uses a matrix to represent each design phase. The first matrix, known as House of Quality (HOQ, see Fig. 1), is used to translate the customer requirements into product engineering characteristics. The design specifications are then determined, based on the information contained in the HOQ.

The QFD method suffers from its subjective nature that comes from one's judgments that may lead to create bias in the output. One of the sources of the inaccurateness is the quantification of competitive assessment results. Respondents simply assign numerical ratings with minimal rigor [2]. Another source of lack of objectiveness in QFD is the valuation of the relationship between customer requirements and engineering characteristics. The results of team design's assessment are expressed in 1-3-9, or another scale ratings. Using such ratings may create future drawbacks in QFD, as it may vary its actual result [1].

Wasserman, 1993, brought forward another weakness of conventional QFD, regarding of the absence of formal method to determine the design specifications. In the conventional QFD, target value of engineering characteristic is established by team consensus, and merely focuses on customer satisfaction, without taking cost or budget limitation into consideration [3].

Askin and Dawson, 1998, has developed a formal model to deal with the shortcomings of the conventional QFD. The proposed model is an improvement of knapsack model that was developed by Wasserman, 1993. Regression analysis was employed to model the relationships between customer requirements and engineering characteristics.

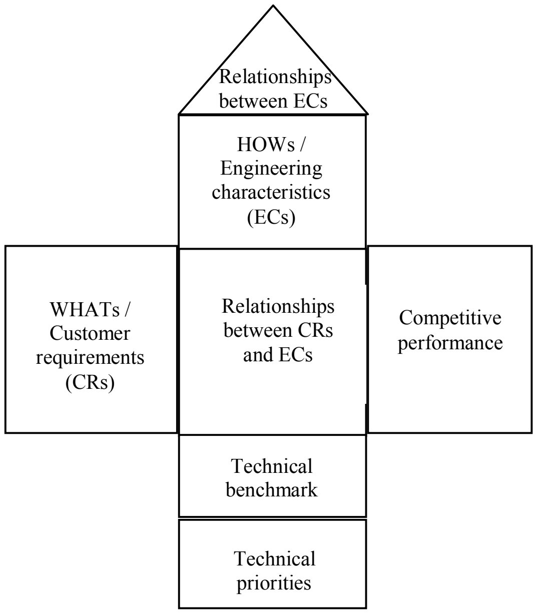

Fig. 1 House of Quality

This paper presents the successful application of the improved method for kitchen utensils rack design.

II. The Formal Model

The formal model that was used to establish the design specifications is briefly explained in this section. It was proposed by Askin and Dawson in 1998. The complete mathematical model is presented in part A, while its underlying assumptions are listed in part B.

A. Mathematical Model

The objective of the formal model is to maximize total customer satisfaction, and is formulated as:

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$$\text{Maximize} \sum_j \lambda_j V_j, \quad (1)$$

where λ_j is the normalized relative importance weight of customer requirement j (so that $\sum_j \lambda_j = 1$), V_j is the value of customer requirement j; and subject to:

$$\gamma_j \leq V_j \leq 1 \ (\gamma_j \geq 0) \forall j, \quad (2)$$

$$V_j = \left(\sum_i \beta_{ij} x_i^{cc} - V_j^{min}\right) : \left(V_j^{max} - V_j^{min}\right) \forall j, \quad (3)$$

$$L_i \leq x_i \leq U_i \ \forall i, \quad (4)$$

$$x_i^{cc} = \frac{\{x_i - ((U_i + L_i)/2)\}}{(U_i - L_i)/2} \forall i, \quad (5)$$

$$Z_i = x_i - x_i^0 \quad \forall i, \quad (6)$$

$$\sum_i c_{p_i} Z_i \leq C_p, \quad (7)$$

$$\sum_i c_{D_i} Z_i \leq C_D, \quad (8)$$

$$\sum_i t_i Z_i \leq T. \quad (9)$$

Equation (2) allows the minimum value γ_j occurs for customer requirement j. The value of customer requirement is normalized by using (3); the normalized value of customer requirement j is denoted by V_j, where $V_j = 0$ if all related engineering characteristics are set on their least favorable value, and $V_j = 1$ if all related engineering characteristics are set on their most favorable value.

In this paper, the relationship between each customer requirement j and the engineering characteristics is defined objectively using regression function. The regression function to express the value of customer requirement j is represented by $\sum_i \beta_{ij} x_i^{cc}$, where β_{ij} denotes the regression coefficient and the coded value of engineering characteristic i is denoted by x_i^{cc}. The regression coefficient β_{ij} stands for relationship value between customer requirement j and engineering characteristic i .

Equation (4) states that the feasible values of engineering characteristic i , i.e. x_i, lie between its lower and upper bound, i.e. L_i and U_i. The optimization technique will search the best x_i that maximizes total customer satisfaction, subject to all the constraints that are stated in the model.

The formula to standardize x_i is shown in (5). As the result, the value of the coded engineering characteristic i , that is denoted by x_i^{cc}, lies between -1 and 1. The engineering characteristic value that is used as an input for the regression analysis should be coded by using (5). In the regression analysis, the associated engineering characteristics will act as predictor variables. V_j^{min} is the value of regression function when all the x_i^{cc} are in the worst level, and V_j^{max} occurs when all the x_i^{cc} are in the best level.

Equation (6) denotes the improvement level of engineering characteristic i, that is relative to the default value x_i^0, for the case the larger, the better. For the case the smaller, the better, it becomes $Z_i = |x_i - x_i^0|$.

The company's resources constraints are expressed in (7)-(9). Those equations present the production budget (C_p), the research and development budget (C_D), and the duration of development time (T) limitations. The amount of resource that is consumed per unit of engineering characteristic i improvement are denoted as c_{p_i}, c_{D_i} and t_i.

B. Assumptions

The application of the basic mathematical model requires the following specific conditions to be satisfied:

1) The engineering characteristics are uncorrelated; consequently the roof part of the HOQ is unnecessary to be described.
2) Each engineering characteristic only has one direction of improvement, for examples: the larger, the better or the smaller, the better.
3) There is a linear functional relationship between each customer requirement and engineering characteristics.
4) The presence of preferential independence among customer requirements.

III. Application of the Improved Methodology

It takes 5 steps to employ the complete improve methodology, as presented in part A-E.

A. Problem Statement

When using the basic mathematical model in the improved methodology, we first have to assure that the product to be developed matches the conditions that are required; i.e. meeting all the assumptions. Particularly, in complying with the necessity that the engineering characteristics should be uncorrelated, product with relatively simple design is considered appropriate. The correlations among engineering characteristics are hard to be avoided in complicated design. In this paper, the simple kitchen utensils rack was chosen to be developed (see Fig. 2).

Fig. 2 Kitchen utensils rack

B. Gathering Customer Requirements

Customer requirements list is needed as the main input of QFD. Those needs are known as voice of customer (VOC). 30 lead users were interviewed to collect the raw needs. The VOC was interpreted and arranged into a list of final customer requirements that are placed in WHATs part of the HOQ. In the case of many customer requirements have been collected, Kawakita Jiro method and tree diagram may be used to reduce the quantity and arrange them [4]. We may also see [5] to get the detailed procedure to interpret raw needs and arranging the results. Here, the final customer requirements of kitchen utensils rack that were identified are 'tray capacity', 'easy to put and reach out the utensils', and 'easy to clean'.

The importance ratings of the customer requirements were collected. A survey using samples of 300 respondents was conducted. The respondents simply assigned a numerical rating varies from 1 to 6 to express how important the requirement to them. So, as the result of the survey that had been conducted, it was about 300 importance ratings were collected.

For each customer requirement, a weighted average of those numerical ratings was taken. A normalization method was then applied, so that the value of the sum of the normalized weighted averages is equal to 100% (see [4]). That normalized value is also known as the normalized relative importance weight of customer requirement. Fig. 3 shows the customer requirements' normalized relative importance weights for the kitchen utensils rack. Later, those normalized weights would be used to develop the objective function of the mathematical model (10).

C. Identification of the Relationship between Customer Requirement and Engineering Characteristics

The functional relationship between customer requirement and engineering characteristics was then established using regression analysis. Before the regression analysis can be done, the engineering characteristics that are associated to the customer requirements should be defined.

Here, three engineering characteristics related to the customer requirements were identified, i.e. 'wire quantity' (rods/15centimeters), 'tray length' (centimeter), and 'space between trays' (centimeter). Considering some technical aspects, the 'tray width' is considered as fixed sized, i.e. 33 centimeters. Next, the information of the technical competitive benchmark and the related competitive performance ratings were collected.

Using the same questionnaire that was used for obtaining the importance ratings of customer requirements, the competitive performance ratings also can be collected. See [6], to get the details of the method of doing such the survey. The competitive performance ratings data represent the competing products' performances that are perceived by customers, regarding its ability in fulfilling customer requirements. The numerical ratings that range from 1 to 6 were used to reflect the perceived performances. Those ratings would be used as response variable data in the regression analysis. By involving the competitive performance ratings in the regression analysis, the variance of those ratings that arise as the result of imprecise quantification, was accommodated.

The weighted average of the competitive performance ratings were computed for each customer requirement. Those ratings were placed in the right side of the HOQ.

Technical competitive benchmark data may be used as one of the information sources to define the allowable range of specifications. Those generally display the engineering characteristics values that are able to be achieved using the available technology. Using the best and the worst values of the engineering characteristics that were found in the market as the specifications boundaries assure that the developed product is able to compete with the others. It is necessary to be noted that the competitor products are in the same class with ours.

Three of the product's competitors which its technical values also represent the technical allowable ranges of kitchen utensils rack were chosen. Hence, to be able to compete with those products, the technical values of engineering characteristics should lie on the range from 4 to 7rods/cm for wire quantity, 42 to 57cm for the length of the rack, and 25 to 33cm for the space between trays (see Fig. 4). The standardization method was then applied by using (5); accordingly the lower bound of the allowable technical range will take value of -1, and the upper bound will take value of 1. The allowable technical ranges and the standardized specifications for the kitchen utensils rack are presented in (17)-(22).

In regression analysis, the standardized technical values were used as predictor variables data, and the related performance rating was used as response variable data. See [7] to find the details of using the design of experiment method to obtain the better input data to be used in the regression analysis. Here the analysis was done by using the software of Minitab 14 and the results are shown below.

Customer requirement		Importance ratings					
		1	2	3	4	5	6
Tray capacity	%Answers from all respondents	0.00%	0.00%	2.10%	39.00%	50.70%	8.30%
	Weighted average $=\sum(\text{rating}\times\text{percentage answers})$			(1x0.00%)+(2x0.00%)+(3x2.10%)+(4x39.00%)+(5x50.70%)+(6x8.30%) = 4.65			
	Normalized weight $=\dfrac{\text{weighted average}}{\sum\text{weighted average}}$			$\dfrac{4.65}{10.96}=0.424$			
Customer requirement		Importance ratings					
		1	2	3	4	5	6
Easy to put and reach out the utensils	%Answers from all respondents	3.40%	18.60%	50.00%	25.20%	2.80%	0.00%
	Weighted average			3.05			
	Normalized weight			0.278			
Customer requirement		Importance ratings					
		1	2	3	4	5	6
Easy to clean	%Answers from all respondents	1.70%	13.40%	48.60%	30.00%	5.50%	0.70%
	Weighted average			3.26			
	Normalized weight			0.297			
	$\sum$ weighted average			4.65+3.05+3.26 = 10.96			

Fig. 3 Normalized relative importance weights of customer requirement

Regression Analysis: 'Tray capacity' versus 'Tray length'

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The regression equation is
Tray capacity = 3.35 + 0.918 Tray length

Predictor      Coef    SE Coef       T       P
Constant     3.34806   0.02317  144.47   0.000
Tray length  0.91848   0.02693   34.10   0.000

S = 0.672124   R-Sq = 57.3%   R-Sq(adj) = 57.2%
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Regression Analysis: 'Easy to put and reach out the utensils' versus 'Tray length'; 'Space between trays'

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The regression equation is
Easy to put and reach out the utensils = 3.31 +
0.328 Tray length + 0.340 Space between trays

Predictor            Coef   SE Coef       T      P
Constant          3.30698   0.02241  147.60  0.000
Tray length       0.32797   0.08723    3.76  0.000
Space between     0.34036   0.08238    4.13  0.000
trays

S = 0.629057   R-Sq = 45.7%   R-Sq(adj) = 45.6%
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Regression Analysis: 'Easy to clean' versus 'Wire quantity'

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The regression equation is
Easy to clean = 3,55 - 1.15 Wire quantity
Predictor      Coef      SE Coef       T      P
Constant       3.54975    0.02195   161.71  0.000
Wire quantity -1.15238    0.02617   -44.04  0.000

S = 0.641760   R-Sq = 69.1%   R-Sq(adj) = 69.0%
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The regression results were then used in setting up (14)-(16).

The original HOQ for the kitchen utensils rack is presented in Fig. 4. In the original HOQ, the relationships between customer requirement and engineering characteristics were identified subjectively by team's consensus. Particularly for the 'tray capacity' requirement, the original HOQ shows that it is very strongly related to 'tray length' (represented by 9 relationship rating) and weakly related to 'space between trays' (represented by 1 relationship rating). However when we did the regression analysis by using 'space between trays' as one of the predictors, the result shows a little contradiction with the actual fact. The regression function that was obtained showed that 'space between trays' has a negative relationship with 'tray capacity', while by using the common sense we may believe that the more we create the 'space between trays', the bigger the capacity of the tray will be. Hence, in the regression analysis, the 'space between trays' then was excluded. The elimination of 'space between trays' only reduces the R-Sq by about 2%.

In the other regression functions, the same engineering characteristics with the original HOQ were identified having relationship with the associated customer requirement. Accordingly, we may see that the relationship functions which were developed using regression analysis are considered in line with the relationships that are shown in the original HOQ.

D. Model Formulation

The information regarding the amount of resource consumed per unit improvement of engineering characteristic and total resource available have to be collected before the complete mathematical model is developed.

Total available budget for the kitchen utensils rack development was IDR 209.12. It was spent to pay the production cost to improve the engineering characteristics that in the beginning of the design process were settled on the worst level.

The idle production cost that was regained when we reduce a wire rod in every 15 cm rack length was IDR 920.88; the amount of IDR 114.66 was needed to make the rack a cm longer; and the amount of IDR 190.72 was needed to make the space between trays a cm wider. Equation (26) was defined based on that information, while (23)-(25) shows the engineering characteristics' improvement level.

Equations (11)-(13) show that we did not define the specific lower bound for the customer requirement value. Commonly, the specific lower bound is determined based on the competitive benchmark information. In our case, the competitive environment had already been involved when the range of engineering characteristics values was settled on.

The complete mathematical model that was used for deriving the kitchen utensils rack's specifications is presented below.

Maximize $0.424\,V_1 + 0.278\,V_2 + 0.298\,V_3,$ (10)

Subject to

$$0 \le V_1 \le 1, \quad (11)$$
$$0 \le V_2 \le 1, \quad (12)$$
$$0 \le V_3 \le 1, \quad (13)$$

Customer Requirements	Relative Importance	Engineering Characteristics: Wire quantity	Tray length	Space between trays	Competitive Performance Ratings: A	B	C
Tray capacity	0.424		9	1	4.59	3.35	2.55
Easy to put and reach out the utensils	0.278		9	9	3.97	3.69	2.65
Easy to clean	0.298	9			3.14	4.71	2.41
		rods/15cms	cm	cm			
Technical Benchmark	A	4	57	33			
	B	6	53	32			
	C	7	42	25			

Fig. 4 Original HOQ

$$V_1 = \frac{\left((3.35+0.918x_2^{cc})-2.432\right)}{(4.268-2.432)}, \quad (14)$$
$$V_2 = \frac{\left((3.31+0.328x_2^{cc}+0.34x_3^{cc})-2.642\right)}{(3.978-2.642)}, \quad (15)$$
$$V_3 = \frac{\left((3.55-1.15x_1^{cc})-2.4\right)}{(4.7-2.4)}, \quad (16)$$
$$4 \le x_1 \le 7, \quad (17)$$
$$42 \le x_2 \le 57, \quad (18)$$
$$25 \le x_3 \le 33, \quad (19)$$
$$x_1^{cc} = \frac{\{x_1-((7+4)/2)\}}{(7-4)/2}, \quad (20)$$
$$x_2^{cc} = \frac{\{x_2-((57+42)/2)\}}{(57-42)/2}, \quad (21)$$
$$x_3^{cc} = \frac{\{x_3-((33+25)/2)\}}{(33-25)/2}, \quad (22)$$
$$Z_1 = |x_1 - 7|, \quad (23)$$
$$Z_2 = x_2 - 42, \quad (24)$$
$$Z_3 = x_3 - 25, \quad (25)$$
$$-(920.88)Z_1 + 114.66Z_2 + 190.72Z_3 \le 209.12. \quad (26)$$

E. Setting Optimal Specifications

Many optimization software packages can be used to find the optimal solutions of a mathematical model. Here Lingo 9.0 software was used and the optimal solutions are shown below.

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Objective value: 0.9745989

Variable          Value              Reduced Cost
    V1          1.000000                 0.000000
    V2         0.9086290                 0.000000
    V3          1.000000                 0.000000
    X1          4.000000                 0.000000
    X2          57.00000                 0.000000
    X3          31.56386                 0.000000
  X1CC         -1.000000                0.000000
  X2CC          1.000000                0.000000
  X3CC         0.6409658                0.000000
    Z1         -3.000000                 0.000000
    C1         -2762.640                 0.000000
    Z2          15.00000                 0.000000
    C2          1719.900                 0.000000
    Z3          6.563863                 0.000000
    C3          1251.860                 0.000000
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According to the optimal solutions that were obtained, the kitchen utensils rack with its optimal specifications (in millimeter) is illustrated in Fig. 5.

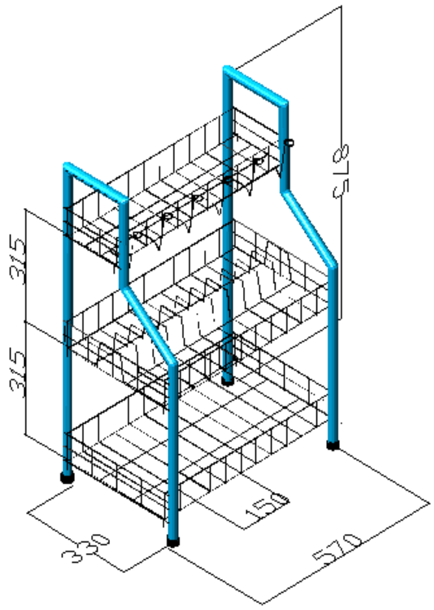

Fig. 5 The optimal specifications

IV. Discussions

Using the improved QFD method in determining the kitchen utensils rack's specifications, the subjective rating that represents the strength of relationship between customer requirement and engineering characteristic successfully was substituted with the coefficient of regression function that is considered as the more objective representation. Competitive ratings data had been used as response variables in regression analysis, by this way the subjective nature in QFD that comes from respondent's judgment of product's performance had been accommodated.

In order to achieve the greatest customer satisfaction by determining kitchen utensils rack's specifications; the available resource will be allocated first to the engineering characteristic which has the biggest contribution to the customer satisfaction, for each unit resource that has been spent. Therefore, engineering characteristic with the lowest resource needed per standardized unit improvement and is able to create biggest increase in customer satisfaction will be the first to be upgraded to the best possible level.

For the kitchen utensils rack, the 'wire quantity' was to be the first to be improved to its best level, because it needed no cost to upgrade it. Moreover, the upgrading would reduce the production cost. The improvement in 'wire quantity' that was made brings 0.298 units increase in customer satisfaction. The improvement also created IDR 2762.64 addition to the improvement budget.

The next engineering characteristic to be improved was 'tray length'; it needed IDR 1719.9 to improve it to its best level. That improvement created 0.561 units increase in customer satisfaction. Hence, IDR 3068.494 was needed to create 1 unit increase in customer satisfaction. In 'space between trays', more resource was needed to create 1 unit increase in customer satisfaction (IDR 10782.98 per unit customer satisfaction gained). Therefore, 'tray length' has bigger priority to be improved.

IDR 2971.76 budget was left after the wire quantity had been upgraded. It was more than enough to be used to improve the 'tray length' to its best level. The 'space between trays' then, got the rest of budget that would be used to upgrade its level. The IDR 1251.86 remaining budget was enough to improve 6.564 units of space between trays and created 0.116 units of customer satisfaction.

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