An Integrated QFD and Kano's Model to Determine the Optimal Target Specifications

by Dewi Dian Retno Sari

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Dian Retno Sari Dewi
Industrial Engineering Department
Widya Mandala Surabaya Catholic University
Surabaya, Indonesia
dianretnosd@yahoo.com

Dini Endah Setyo Rahaju
Industrial Engineering Department
Widya Mandala Surabaya Catholic University
Surabaya, Indonesia

Abstract*— *The excellence of Quality Function Deployment (QFD) methodology for translating customer needs into target specifications had been broadly known. However, a number of researches had revealed some methodological flaws. Those stated that QFD did not have a formal methodology to optimally allocate the resource available for product development. QFD also employed subjective technique in assessing the relationship between customer need and engineering characteristics. In addition, QFD implicitly assumed that the fulfillments of customer needs linearly related to customer satisfaction. However, Kano's model notified that the fulfillment of a customer need might have a nonlinear effect to the customer satisfaction. With regard to those issues, this paper presented an optimization model to allocate product development resource. The relationship between engineering characteristics and customer need was assessed using regression technique. Kano's model was integrated in the model to represent the relationship between customer needs and customer satisfaction. The proposed model was then applied to determine the target specifications of wooden single bed frame. The result showed that by using the target specifications obtained, a great customer satisfaction was created.

Keywords*— *customer satisfaction; Kano's model; optimization; product development; Quality Function Deployment

I. INTRODUCTION

Quality Function Deployment (QFD) is a methodology that has been commonly used to develop product which conforms to customer needs. QFD's structured tool, i.e. House of Quality (HOQ) consists of matrices that have been systematically arranged to help the development team translates customer needs to the corresponding engineering target specifications [1]. Despite of its benefit in maximizing customer satisfaction through better product design, several researches notified that the conventional QFD suffered from some methodological flaws [2,3,4]. According to those researches, the conventional QFD did not provide sufficient formal methodology to the decision makers. HOQ contained lots of information necessary for the decision making process, yet it did not equip the development team with a formal way to optimally allocate the product development resource to maximize customer satisfaction. Furthermore, in the conventional QFD, the decisions were made based on many subjective assessments. One of these subjective judgments was used in the evaluation of the relationship strength between customer need and engineering characteristics. Dealing with those issues, this paper presents a mathematical model to maximize customer satisfaction by optimally allocating product development resource. The relationship between customer need and engineering characteristics was established by using regression technique.

Moreover, in the conventional QFD, the fulfillment of customer need was considered related linearly to customer satisfaction. The customer satisfaction would increase proportionally to its customer need's importance weight as the customer need met. On the other hand, Kano's model classifies the customer needs into several categories, according to its impact on customer satisfaction [5,6]. One of those categories, namely satisfier, contains customer needs which have linear impact on customer satisfaction when it is met. Though, there also exist customer needs which are classified into attractive category and basic category. Attractive category contains customer needs which have non linear impact on customer satisfaction when met. And the customer needs which have no or insignificant impact on customer satisfaction, even when those are fully met, are included in basic category. In this paper, Kano's model is integrated into the proposed mathematical model to make better representation of the relationship of the customer need fulfillment and customer satisfaction improvement [7,9]. An application of the optimization model for setting the target specifications of wooden single bed frame is also presented.

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II. THE PROPOSED OPTIMIZATION MODEL

The proposed mathematical model is presented below.

$$\text{Max } S_P = \left(\sum_j s_j^1\right) \Big/ S_{P\max} \qquad (1)$$

The objective function, as written in equation (1) is developed to maximize total customer satisfaction score, which value lies between 0 and 1.

Subject to

$$S_{P\max} = \sum_j s_j^{\max} \qquad (2)$$

Total maximum potential contribution of all customer needs ($S_{P\max}$) is considered as the sum of the maximum of all customer need's contributions to customer satisfaction. The maximum of contribution of customer need j is notated as $s_j^{\max}$ and represents a maximum satisfaction score that can be reached by customer need j. For the customer needs that are considered as attractive needs, $s_j^{\max}$ usually gets a relative high score.

$$S_P > S_S \qquad (3)$$

In the case of the development team is interested in creating a better product than competitor's, it is necessary to add equation (3). In this way, the product developed will deliver a higher total customer satisfaction score than the competitor's product.

$$x_i^{ncc} = \frac{\{x_i^n - ((U_i + L_i)/2)\}}{(U_i - L_i)/2} \; \forall j \; n = 0,1 \qquad (4)$$

The engineering characteristic values should be coded using equation (4) to eliminate the effect of different scaling of different engineering characteristics.

$$p_j^n = \beta_0 + \sum_i \beta_{ij} x_i^{ncc} \; \forall j \; n = 0,1 \qquad (5)$$

In the conventional QFD, relationship strength of customer need j and the engineering characteristics are denoted by using subjective ratings, such as 1, 3, 9. To reduce the subjectivity of the relationship evaluations, the regression technique is applied. The regression function obtained is as in equation (5). β_{ij} represents the relationship strength between engineering characteristics i and customer need j.

$$s_j^1 = s_j^0 \left(\frac{p_j^1}{p_j^0}\right)^{k_j} \; \forall j$$

$$1 \le p_j^n \le 5, 0 < s_j^n \le 100 \; n = 0,1 \qquad (6)$$

Equation (6) is based on [8] and then was adjusted similar to [9]. For practical reasons, the development team may use 2 for Kano's attractive parameter, 1 for Kano's satisfier parameter, and 0.5 for Kano's basic parameter.

$$\gamma_j \le p_j^1 \le 5 \left(\gamma_j = r_{js}\right) \forall j \qquad (7)$$

γ_j is defined to ensure that the product developed has better performance than competitor's product in meeting customer need j.

$$L_i \le x_i^n \le U_i \; \forall i \; n = 0,1 \qquad (8)$$

For engineering chacteristic i, its values lie between upper bound U_i and lower bound L_i.

$$Z_i = \left|x_i^1 - x_i^0\right| \; \forall i \qquad (9)$$

The improvement made for engineering characteristics i is presented by using equation (9) while the resource that may limit the specifications improvements are showed by equation (10), (11) and (12).

$$\sum_i \left(c_{D_i} Z_i + c_{p_i} Z_i\right) \le B \qquad (10)$$

$$\sum_i t_i Z_i \le T \text{ (if the activities of improvements were carried in series manner) or} \qquad (11)$$

$$\max_i t_i Z_i \le T \text{ (if the activities of improvements were carried in parallel manner)} \qquad (12)$$

where:

S_P =total customer satisfaction

$S_{P\max}$ =total maximum potential contribution of customer needs

S_S = competitor's total customer satisfaction score

s_j^0 =initial satisfaction score contributed by customer need j, per 100 units

s_j^1 =satisfaction score gained by meeting the customer need j, per 100 units

$s_j^{\max}$ = maximum contribution of customer need j to customer satisfaction

k_j = Kano's parameter of customer need j

x_i^0 = initial natural value of engineering characteristic i

x_i^{0cc} = initial value of engineering characteristic i, centered and coded

x_i^1 = natural value of target of engineering characteristic i

x_i^{1cc} = centered and coded value of target of engineering characteristic i

L_i = lower bound of engineering characteristic i values

U_i = upper bound of engineering characteristic i values

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β_{ij} = regression parameter

β_0 =regression constant

p_j^0 = initial product performance in meeting customer need j

p_j^1 = current product performance in meeting customer need j

γ_j = the lowest performance allowed in meeting customer need j

r_{js} = competitor performance in meeting customer need j

Z_i = the improvement of engineering characteristic i

c_{p_i} = production cost needed to make a unit improvement of engineering characteristic i

c_{D_i} = R&D cost needed to make a unit improvement of engineering characteristic i

B = the available budget for product development

t_i = time needed to make a unit improvement of engineering characteristic i

T = the available time for product development

III. AN ILLUSTRATIVE EXAMPLE

An application of the proposed model is presented in this section. The target specifications of the wooden single bed frame were determined using the optimization model.

Four customer needs were identified during observations and lead user interviews. Those customer needs were: facilitates user's daily activity (CN_1), occupies minimum space (CN_2), sturdy (CN_3), large storage space (CN_4). CN_1 meant that the product should support user's additional activities on bed, such as reading, typing on laptop, and writing. CN_2 meant that the frame needed minimum space when used, CN_3 meant that the frame was not easily broken, while CN_4 meant that customers needed a bed frame that had an additional function as storage space. By using Kano's questionnaire, those customer needs were classified into several categories. CN_1 was classified into attractive category, CN_2 was a satisfier, CN_3 was a basic, and CN_4 was an attractive.

Next, six related engineering characteristics were identified, i.e. head thickness (EC_1), distance between top of the head and top of the mattress (EC_2), distance between top of the mattress and floor (EC_3), leg cross sectional area (EC_4), slat board width (EC_5), distance between slat boards (EC_6). Figure 1 shows a bed and a bed frame images with the engineering characteristics.

The HOQ of the wooden bed frame is presented by Figure 2. The roof part of the HOQ was not defined, because the proposed model assumes that all engineering characteristics are independent. In this way, the linear regression function can be used to represent the relationship between customer need and engineering characteristics. The relative importance weights of customer needs are the normalized values of the averages of customer needs importance weights data. The importance weights data were collected using a survey. See [10], to get the details of how to do such survey. Three designs of competitor's products were selected as benchmarks, i.e. product B, product C, product D, while product A is the base product to be developed. The benchmarking result showed the product performance in meeting certain customer need; the performance was measured by customers as respondents in a survey using the 1 to 5 rating scales. The average performance of each product in meeting certain customer need is presented in the right columns of HOQ matrix.

Figure 1. Engineering characteristics

		Engineering Characteristics						Benchmark			
Customer Needs	Relative Importance Weight	EC_1	EC_2	EC_3	EC_4	EC_5	EC_6	Product A	Product B	Product C	Product D
CN_1	0.214	9	9	3				2.05	3.98	2.98	3.07
CN_2	0.291	9						4.03	3.00	3.03	2.92
CN_3	0.290				9	9	3	3.00	3.95	3.01	4.01
CN_4	0.204	9	9	9				2.08	3.04	3.72	3.86

Figure 2. House of Quality

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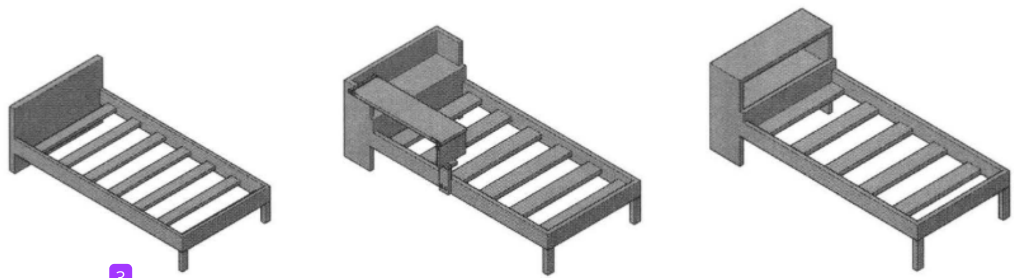

Product A

Product B

Product C and D

Figure 3. Concept designs

TABLE 1. Product specifications

Engineering Characteristics	Product A	Product B	Product C	Product D
EC_1 (cm)	6	30	25	35
EC_2 (cm)	20	27	22	30
EC_3 (cm)	46	53	53	55
EC_4 (cm^2)	24	35	24	35
EC_5 (cm)	10	15	15	15
EC_6 (cm)	20	20	25	25

Figure 3 shows the 3D of the concept designs of product A, B, C and D, while Table 1 contains the specifications details. The feasible range of engineering characteristics were defined as follows: 6 to 37.4 cm for EC_1, 20 to 36.6 cm for EC_2, 46 to 55 cm for EC_3, 24 to 35 cm² for EC_4, 10 to 15 cm for EC_5, and 20 to 25 cm for EC_6. Those ranges might show the technically accepted and/or technically feasible specifications.

The relationship between customer need and engineering characteristics was assessed using regression technique. The engineering characteristics were the independent variables and the product performances were the dependent ones. The regression results are as follows:

$$CN_1 = 1.93 + 9.36\,EC_1 - 3.33\,EC_2 - 6.16\,EC_3$$

$$CN_2 = 3.34 - 0.627\,EC_1$$

$$CN_3 = 3.50 + 0.479\,EC_4 - 0.0034\,EC_5 + 0.0274\,EC_6$$

$$CN_4 = 3.05 - 3.89\,EC_1 + 0.943\,EC_2 + 3.92\,EC_3$$

Using $\alpha = 5\%$, the significant predictors were those which P value < 0.05.

The minimum product performance in meeting certain customer need was defined to assure that the prk,oduct would be able to perform its basic functions and also to ensure that the performance was not below market expectation. Considering technical and market requirements, it was determined that the minimum product performance in meeting CN_1 was 3.04, and in meeting CN_2 was 3.03; while the minimum performance value in meeting CN_3 and CN_4, in consecutive manner, were 3.01 and 3.04.

In this case example, the resource constraint was the available budget for product improvement, i.e. IDR 200,000. The incremental improvement costs for engineering characteristics were IDR 4250 per cm for EC_1, IDR 2716 per cm for EC_2, IDR 2980 per cm for EC_3, IDR 377 per cm² for EC_4, IDR 1130 per cm for EC_5, and IDR 283 per cm for EC_6. The other resources, such as development time, were considered unbounded.

The initial satisfaction score, denoted by s_j^0 per 100 units, that was contributed by certain product performance level in meeting customer need j, denoted by p_j^0 and quantified in 1 to 5 rating scales, was obtain using focus group discussions. For customer need indexes (j) 1 to 4, the corresponding s_j^0 for certain p_j^0, in consecutive manner, were as follows: $s_1^0 = 25$ for $p_1^0 = 2.50$, $s_2^0 = 65$ for $p_2^0 = 4.03$, $s_3^0 = 40$ for $p_3^0 = 3.00$,and $s_4^0 = 25$ for $p_4^0 = 2.08$.

In this case example, the maximum satisfaction score that was able to be reached by the basic need was 60 per 100 units and 100 per 100 units for the other customer need categories.

According to the input data, the complete mathematical model was described as follows.

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$$\text{Max } S_P = \left(s_1^1 + s_2^1 + s_3^1 + s_4^1\right) / S_{P\max} \quad (13)$$

Subject to

$$S_{P\max} = 100+100+100+60 \quad (14)$$

$$x_1^{ncc} = \frac{\{x_1{}'' - ((37.4+6)/2)\}}{(37.4-6)/2}; \quad x_2^{ncc} = \frac{\{x_2{}'' - (36.6+20/2)\}}{(36.6-20)/2};$$

$$x_3^{ncc} = \frac{\{x_3{}'' - (55+46/2)\}}{(55-46)/2}; \; x_4^{ncc} = \frac{\{x_4{}'' - (35+24/2)\}}{(35-24)/2};$$

$$x_5^{ncc} = \frac{\{x_5{}'' - (15+10)/2)\}}{(15-10)/2}; \; x_6^{ncc} = \frac{\{x_6{}'' - (25+20)/2)\}}{(25-20)/2} \quad (15)$$

$$p_1^n = 1.93 + 9.36 x_1{}^{ncc} - 3.33 x_2{}^{ncc} - 6.16 x_3{}^{ncc};$$

$$p_2^n = 3.34 - 0.627 x_1{}^{ncc};$$

$$p_3^n = 3.5 + 0.479 x_4{}^{ncc} - 0.0034 x_5{}^{ncc} + 0.0274 x_6{}^{ncc};$$

$$p_4^n = 3.05 - 3.89 x_1{}^{ncc} + 0.943 x_2{}^{ncc} + 3.92 x_3{}^{ncc} \quad (16)$$

$$s_1^1 = 25\left(\frac{p_1^1}{2.05}\right)^2; \; s_2^1 = 65\left(\frac{p_2^1}{4.03}\right)^1;$$

$$s_3^1 = 40\left(\frac{p_3^1}{3.00}\right)^{0.5}; \; s_4^1 = 25\left(\frac{p_4^1}{2.08}\right)^2 \quad (17)$$

$$3.04 \le p_1^1 \le 5; \; 3.03 \le p_2^1 \le 5;$$

$$3.01 \le p_3^1 \le 5; \; 3.04 \le p_4^1 \le 5 \quad (18)$$

$$6 \le x_1^n \le 37.4; \; 20 \le x_2^n \le 36.6; \; 46 \le x_3^n \le 55;$$

$$24 \le x_4^n \le 35; \; 10 \le x_5^n \le 15; \; 20 \le x_6^n \le 25 \quad (19)$$

$$4520\,(x_1{}'' - 6) + 2716\,(x_2{}'' - 20) + 2980\,(x_3{}'' - 46) + 2 \times 377\,(x_4{}'' - 24) + 7 \times 1130\,(x_5{}'' - 10) + 283\,(x_6{}'' - 20) \le 200000 \quad (20)$$

The result of this model are the score of engineering characteristics. The result showed that model was able to perform under constrain restriction. The engineering characteristic for EC6 is the smaller the better, meanwhile the others are the larger the better. We have run the sensitivity analysis and the result is satisfied for all engineering characteristics. For the larger the better engineering characteristic, the output will increase, and will decrease for the smaller the better criteria.

IV. CONCLUSION

Setting target specifications by using the proposed mathematical model, the available development resource was spent effectively to increase total customer satisfaction. By integrating the Kano's model into the optimization model, the relationship between certain customer need fulfillment and perceived customer satisfaction was better represented.

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