Proceedings of the International Conference on Applied Mechanical Engineering Research (IC-AMER2019)
NIT Warangal, India – May 02-05, 2019
Paper No. XXX (The number assigned when the papaer is accepted)

Evaluation of Design Concept in Product Development Using QFD - Based Optimization

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Abstract

Product design concept evaluation is a team based decision making effort during product development process for evaluating the product design concepts generated. In order to sustain a product in the present competitive market scenario, design team has to identify the design solution which should reflect the customer needs to ensure customer satisfaction. In this paper an attempt has been made to develop a methodology using Quality Function Deployment (QFD) for obtaining optimum design solution to meet the customer needs. The QFD-based optimization methodology reflects the customer priorities in making a trade-off between the product design requirements. The methodology is developed by using the first phase of QFD called House of Quality (HOQ). The construction of HOQ is initiated with the identification of customer needs. Kano technique is employed in this work for understanding and categorization of customer needs. The inter-relationship matrix of HOQ is prepared by using swing method. To obtain the individual satisfaction level of each customer need, utility functions are established. The methodology provides the overall customer satisfaction indices (OCSI) for the product design solutions. The optimum design solution is identified on the basis of OCSI values. An illustrative example is presented in this paper to demonstrate the proposed methodology.

***Keywords*:** Design concept evaluation, Quality Function Deployment, House of Quality, Utility analysis

1. Introduction

In the present competitive market environment, manufacturing companies are looking towards customer centric product development strategy for producing their products. Though there are different stages in product development process, product conceptualization is the key stage which comprises concept generation and concept selection [1].The product concept generation starts with the identification of customers' needs, establishing target specifications and results into a set of product design concepts. Once the concept generation has been completed, evaluation is essentially required for the selection of best design solution. The judging activity during selection from a range of competing design solutions is referred to as design concept evaluation. The evaluation of design concepts influences on all subsequent phases of product development with regards to cost, quality and performance of the end-product [2]. The poor selection of a design concept may not be compensated at later design stages and incurs a highly redesign expenses. Therefore, it is necessary to adopt an appropriate evaluation and decision tools for supporting the efficiency in selecting optimum design concepts at conceptual design stage. There are many design concept selection methods reported in the literature for assisting product designers to take right decision on design concept selection. Okudan and Tauhid [2] made literature survey on design concept selection methods published between 1980 and 2008. They clearly pointed out that there is a need to develop a fast and simple methodology that gives importance to customer requirements. Song et al., [3] carried a study which aims at improving the effectiveness of concept evaluation in the early phases of new product development using both rough AHP and rough TOPSIS. Vinodh et al., [4] presented a study in which the concept selection in fit environment by using fuzzy VIKOR. Zhu et al., [5] addressed the issue of handling vagueness in design concept evaluation by integrating rough number based AHP and VIKOR. In order to satisfy the rapidly changing customer demands, the manufacturing firms are under increasing pressure to establish customer-focused product development. In this context, it is necessary for appropriate evaluation and selection of optimum design concept to meet the expectations of the customers. To address the evaluation of product design concepts under customer-focused product development, QFD-based optimization methodology has been proposed in this paper. It is developed by using QFD, Kano model analysis (KMA), Swing weighting method (SWM), Utility analysis. These techniques are discussed briefly in the following sections.

1.1 Quality Function Deployment (QFD)

QFD is a well-known customer - driven product development technique [6].The principle tool of QFD is the HOQ chart which appears like a normal house and provides the inter-relationship between customers' conception and designers' conception. In fact QFD process initiated with capturing the voice of customer (VOC) and it can be used to measure customer satisfaction. In this work Kano model analysis is employed for capturing the VOC.

1.2 Kano Model Analysis (KMA)

The KMA is intended to categorize the attributes of a product or service, based on how well they are able to satisfy the needs of the customers [7]. According to Kano model CNs can be classified into the following five categories such as Attractive (*A*), Must-be (*M*), One-dimensional (*O*), Indifferent (*I*) and Reverse (*R*) [8].The implementation of KMA starts with the identification of CNs by conducting interviews with the customers. Then Kano questionnaire has to be developed and it examines each customer need with a pair of questions in functional and dysfunctional forms. There are five possible answers for each pair of questions: like, must-be, one-dimensional, neutral, live with and dislike. On the basis of customer responses to both the questions, each CN is classified as one of the five Kano categories for that customer by checking the Kano evaluation table [9].Berger et al., [9] proposed customer satisfaction index (CS), which is calculated by dividing the sum of frequencies of attractive and one-dimensional attributes with the sum of the frequencies of attractive, one-dimensional, must be and indifferent attributes. The value of CS lies between 0 and 1. The value of CS close to 1 indicates greater satisfaction while the value close to 0 indicates lower satisfaction.

1.3 Swing Weighting Method (SWM)

It is one of the most appropriate methods for weight estimation. This method derives the weights by asking the decision maker to compare a change from the least preferred to the most preferred value on one attribute to a similar change in another attribute. The SWM is relatively simple, transparent and easy to use.

1.4 Utility Analysis (UA)

Utility analysis is used to help a decision maker in making real valued function that encodes the decision maker's preference for all possible outcomes [10].The risk in product design can be represented using utility function, which explains a decision maker's attitude towards risk resulting from any risky decisions. In this view, utility function transfers objective value of the design into customer satisfaction level. Though there are different forms of utility functions, but exponential form of utility function is widely considered [11].

2. Proposed Methodology

The step by step methodology of the proposed QFD-based optimization is discussed below.

***Step 1*:** Capturing the VOC and the prioritization of customer needs using KMA

The KMA serves the purpose of capturing the VOC and helps to categorize the customer needs (CNs). The priority structure of CNs gives scope on understanding about the intensity of desires about the product which is required for the design team while establishing design requirements (DRs). The KMA provides the customer satisfaction indices for the customer needs. The normalized values of satisfaction indices give the weightages (w_i) for the CNs. The KMA has to be carried as discussed in the earlier section.

***Step 2*:** Establishment of design requirements

After determining the priority structure of CNs, the appropriate DRs are established by the design team in view of achieving customer satisfaction.

***Step 3*:** Prepare Inter-relationship matrix of HOQ using SWM

The relationship coefficients between the CNs and DRs are obtained by using swing method [12].

***Step 4*:** Generation of conceptual design solutions

The product design concept is an approximate description of the product. It is the concise description of how the product will satisfy the CNs. During the concept generation stage of product development, the design team has to develop different alternative concepts (design solutions) with their expertise in the field of designing the particular product. Usually the design solutions are having different values for the DRs of the product. The competitors design strategy is also to be considered with a view to achieve market position.

***Step 5*:** Establish a set of utility functions

To establish utility functions, the following procedure is employed.

(a) Choose the utility function on the basis of nature

If the nature of utility function is decreasing, then the exponential utility function is

$$U(x) = a\left(1 - e^{cx+b}\right)$$

If the nature of utility function is increasing, then the exponential utility function is

$$U(x) = a\left(1 - e^{-cx+b}\right)$$

In the above equations, c is the risk aversion coefficient (RAC) and a, b are constants. The risk aversion coefficient (c) indicates the degree of risk aversion. The reciprocal of RAC is known as risk tolerance (ρ) [13].

(b) Estimate the risk tolerance (ρ):

The risk tolerance is assessed by determining the best and worst values in the data and using the certainty equivalent (CE). A value of CE has to be chosen by the decision maker. The risk tolerance is estimated by using the following equation.

$\rho = R$ (High value – Low value)

In the above equation, the value of R is directly read from the tables corresponding to $Z_{0.5}$ and the value of $Z_{0.5}$ is calculated on the basis of nature of utility function [14]. After obtaining the value of R find the value of ρ and then determine the value of c.

(c) Setup utility functions:

The utility function is established by evaluating the constants a and b by substituting the value of c. Similarly set up all the utility functions.

***Step 6*:** Compute the overall customer satisfaction indices (OCSI) for all the product design solutions

On the basis of HOQ chart and the values of utility functions, the OCSI is expressed as follows.

$$OCSI = \sum w_i (Y_i) \qquad (1)$$

Where w_i = Weightage of the i^{th} CN and Y_i = Individual satisfaction level of the i^{th} CN.

The value of Y_i is determined by using the following expression

$$Y_i = \sum r_{ij} \left[U_{ij} \left(x_j \right) \right] \tag{2}$$

Where r_{ij} = Relationship coefficient between the i^{th} CN and j^{th} DR. This value is obtained from inter-relationship matrix of HOQ.

U_{ij} (x_j) = Utility function representing the relationship between i^{th} CN and j^{th} DR.

***Step 7*:** Identify the optimum product design concept.

Compare the OCSI values of all the design solutions and select the design solution with higher OCSI value and then proceed for further stages of product design.

3. Illustrative Example

To demonstrate the proposed methodology domestic ceiling fan is considered an example product. Personnel interviews were conducted with the customers to capture the voice of customers. After several comprehensive discussions, six major customer needs are identified and those are: more human comfort (MC), less noise (LN), less power consumption (LPC), small size (SS), less cost (LC) and service reliability (SR). In order to carry out KMA, Kano questionnaire has been developed in both functional and dysfunctional form and administered to eighty customers with different demographic characteristics. On the basis of responses of the customers, the needs are categorized and customer satisfaction indices for all the needs are computed. The normalized values of these indices give the weightages (*w*) for the CNs. The weightages of CNs presented in Table 1. The DRs for the domestic ceiling fan are obtained by conducting brainstorming sessions with the design experts. The outcome of the discussions explored six DRs and they are: air delivery (AD), number of blades (NB), span length (SL), motor speed (MS), power rating (PR) and warranty (WR).The inter-relationship matrix of HOQ is developed by using Swing method as discussed in step 3 of the proposed methodology. The Table 2 shows the inter-relationship matrix of HOQ. The design concepts are generated through discussions made with the focus groups. The outcome of the discussions generated seven design solutions (DS) which are shown in Table 3.The utility functions for DRs in view of satisfying CNs are established as discussed in step 5 of the proposed methodology. While establishing utility function for air delivery in view of satisfying more comfort, the values obtained for $z_{0.5}$ is 0.28 and the corresponding value of R is 0.49.The values of risk tolerance (c), a, b are computed and they are 40.67, 1.1532 and 4.597 respectively. Then the utility function is $U_{11}(x) = 1.1532\left(1 - e^{-0.0245x + 4.597}\right)$. Similarly other utility functions are also generated.

The individual satisfaction levels of each CN are determined as follows.

$$Y_1 = r_{11}\left[U_{11}(220)\right] + r_{12}\left[U_{12}(3)\right] + r_{13}\left[U_{13}(50)\right] + r_{14}\left[U_{14}(350)\right] + r_{15}\left[U_{15}(38)\right] = 0.514$$

$$Y_2 = r_{21}\left[U_{21}(220)\right] + r_{22}\left[U_{22}(3)\right] + r_{23}\left[U_{23}(50)\right] + r_{24}\left[U_{24}(350)\right] + r_{25}\left[U_{25}(38)\right] = 0.372$$

$$Y_3 = r_{31}\left[U_{31}(220)\right] + r_{34}\left[U_{34}(350)\right] + r_{35}\left[U_{35}(38)\right] = 0.453$$

$$Y_4 = r_{41}\left[U_{41}(220)\right] + r_{42}\left[U_{42}(3)\right] + r_{43}\left[U_{43}(50)\right] + r_{44}\left[U_{44}(350)\right] + r_{45}\left[U_{45}(38)\right] = 0.535$$

$$Y_5 = r_{51}\left[U_{51}(220)\right] + r_{52}\left[U_{52}(3)\right] + r_{53}\left[U_{53}(50)\right] + r_{54}\left[U_{54}(350)\right] + r_{55}\left[U_{55}(38)\right] + r_{56}\left[U_{56}(1)\right] = 0.548$$

$$Y_6 = r_{66}\left[U_{66}(1)\right] = 0$$

The computation of OCSI for the DS-1 is discussed below.

OCSI = (0.215×0.514) + (0.18×0.372) + (0.172×0.453) + (0.126×0.535) + (0.161×0.548) + (0.143×0) = 0.411

The OCSI for all the design concepts are computed in the same way and the OCSI values obtained for the DS-2, DS-3, DS-4, DS-5, DS-6 and DS-7 are 0.4108, 0.4606, 0.4562, 0.3335, 0.3745 and 0.4453 respectively. On comparing the values of OCSI for all the design solutions, the DS-3 possess highest value and hence it is the optimal design solution in view of reflecting customer needs in to the design of the product.

Table 1. Kano categorization of CNs and weightages

CNs	Kano categorization						CSI	Weightage (w)
	A	O	M	I	R	Category		
MC	40	20	12	8	0	A	0.750	0.215
LN	30	20	15	15	0	A	0.625	0.180
LPC	0	18	0	2	0	A	0.600	0.172
SS	5	30	35	10	0	O	0.438	0.126
LC	15	30	20	15	0	O	0.562	0.161
SR	15	25	30	10	0	M	0.500	0.143

Table 2. Inter-relationship matrix of HOQ

CNs	DRs					
	AD	NB	SL	MS	PR	WR
MC	0.267	0.133	0.067	0.267	0.267	0.000
LN	0.250	0.167	0.167	0.333	0.083	0.000
LPC	0.110	0.000	0.000	0.440	0.440	0.000
SS	0.285	0.285	0.071	0.214	0.142	0.000
LC	0.125	0.125	0.125	0.250	0.250	0.125
SR	0.000	0.000	0.000	0.000	0.000	1.000

Table 3. Design solutions for domestic ceiling fan

DS	AD (m^3/min)	NB	SL(inch)	MS (rpm)	PR (W)	WR (yr.)
DS-1	220	3	50	350	38	1
DS-2	230	3	48	385	35	1
DS-3	270	4	56	350	38	2
DS-4	235	3	47	340	74	2
DS-5	205	4	49	310	70	1
DS-6	210	5	52	290	50	1
DS-7	187	4	42	255	75	1

4. Conclusions

The proposed QFD-based optimization paves the way for developing products which provide more customer satisfaction as it reflects the customers' preferences in the product and reduces the gap between customers' conception and designers' conception. This methodology can be applied to any product development where customers' preferences need to be primarily considered.

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