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COST ENGINEERING WITH QFD: A MATHEMATICAL MODEL

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Abstract: *Cost engineering helps the firms in decision-making with respect to product development. It is primarily concerned with cost estimation and cost control. Decisions made during the design phase have a significant influence on development and life cycle costs. The effective cost management during the design phase of a product is essential to develop a product with minimum cost and desired quality of the customer. In this paper a mathematical model is established by incorporating cost engineering techniques such as Target Costing (TC) and Value Engineering (VE) with Quality Function Deployment (QFD) to develop a product. An illustrative example is also presented.*

Keywords*: Cost engineering, Quality Function Deployment, Value Engineering, Target costing*

1. INTRODUCTION

In the current market scenario, the manufacturing firms have to develop a product that is affordable to the customer and at the same time the product has to satisfy the customer in respect of quality. Therefore, product design must be optimized with regard to cost, design requirements and value considerations of the customer. The application of cost management technique such as target costing (TC) during product design is appropriate to estimate the cost of a product. [1]. Value Engineering (VE) is a cost control approach that thoroughly examines the relationship between the function of a product and its cost. It can be used during the design stage of a product. Quality Function Deployment (QFD) is a customer-driven product development technique. It is a four phase structured methodology to translate the customer needs in to design requirements, and subsequently into parts characteristics, process plans, and production requirements associated with its manufacture [2]. The second phase of QFD is the best choice for applying VE approach [3]. QFD methodology consists of four sets of matrices. Product planning matrix is the first matrix, which is known as House of Quality (HOQ) and it maps prioritized list of customer needs to an appropriate design requirements. The HOQ gives the priority ratings of the design requirements. The second matrix of QFD is the assembly/parts deployment matrix which maps the prioritized design requirements obtained from HOQ to critical parts characteristics. The other matrices are process planning matrix and production planning matrix [4].

Value engineering (VE) is a methodology used to analyze the function of the goods and services and to obtain the required functions of the user at the lowest total cost without reducing the necessary quality of performance [5].

VE approach can also be termed as functional cost analysis in which weightages for the functions of each part can be compared with the relative costs of the corresponding parts and can be expressed as the ratio of function to cost, called value ratio [6]. On the basis of value ratio, the levels of the parts characteristics can be established. It is performed before the production stage.

Target costing (TC) is an essential tool for cost management in a competitive environment. It is a market driven strategy that involves pricing a firms' product based on the levels that give it the best competitive advantage [7]. The target costing process begins by establishing a selling price based on market research for the new product. From this target selling price, the desired (target) profit is subtracted to determine the target cost [8].

The price and profit are the independent variables. Prices are decided by what customers are willing to pay, and profit is determined by what financial markets expect as a return from that particular industry. The dependent variable is cost, which implies that a firm has to manage its cost to meet the external constraints compelled by the product and financial markets in which it operates [9].

Target cost is simply the allowable cost of a product that yields the required rate of return.

2. COST ENGINEERING WITH QFD

According to the American Association of Cost Engineers, cost engineering is defined as the area of engineering practice where engineering judgment and experiences are utilized in the application of scientific principles and techniques to the problem of cost estimation, cost control and profitability [10]. Cost estimation is the process of predicting the true cost of producing a product. Cost management is the technique of managing the product development process in order to achieve the cost estimate. As cost estimation is an integrated element of the target costing frame work, TC helps to estimate and mange the cost of the product during product development. Since the fundamental principle of Value Engineering is minimizing the cost of a product without compromising the quality, VE supports the TC methodology for cost control.

In view of enhancing quality, value and customer satisfaction QFD has been adopted in various industries. In the present difficult economic times, it is necessary to integrate cost deployment in to QFD [11]. Cost deployment in QFD leads to achieve the target cost of the product while keeping a balance with quality [12]. Tsai and Chang [13] proposed a method of quick cost estimation based on function characteristics and the QFD technique. Target cost management will not be successful without the support of VE [14]. This technique helps to develop a right product and VE shows the best way of performing it. Bode and Fung [15] integrates design costs into the QFD frame work, which assists the designers to optimize product development resources towards customer satisfaction.

In this paper an attempt has been made to establish a mathematical model which integrates second phase of QFD, VE and Target costing. VE is incorporated in the second phase of QFD for obtaining the various levels of parts characteristics. Correlations among the parts characteristics and inter-relationship between the design requirements and the parts characteristics of parts deployment matrix are considered in the establishment of mathematical model. The weightages of the design requirements obtained by considering the customer needs priority in HOQ are carried in the second QFD matrix to deploy customer preferences.

3. FORMULATION OF MATHEMATICAL MODEL

In the model, the parts deployment matrix is considered and VE approach is adopted to establish different design alternatives. TC methodology is employed to set the cost of the product.

Notations:

$i =$ Design requirement, $i = 1, 2, \ldots m$

$j =$ Part characteristic, $j = 1, 2, \ldots n$

$m =$ Number of design requirements

$n =$ Number of parts

$L_{jl} =$ Number of level of parts

$l = 1, 2, 3$ for $j = 1, 2, \ldots n$

$w_i =$ Priority rating for i^{th} design requirement

$r_{ijl} =$ Inter - relationship values of parts deployment matrix

$R_{ijk} =$ values in roof of parts deployment matrix

$C_{jl} =$ Cost of part j in level l

$Y_i =$ Summation effects of parts characteristics for i^{th} design requirement

$TC_j =$ Target cost of the j^{th} part

$x_{jl} =$ Decision variable:

$x_{jl} =$ 1, part characteristic is appropriate at level l

$x_{jl} =$ 0, otherwise.

Objectives:

Maximize customer satisfaction (Z_1)

$$\text{Max.}\, Z_1 = \sum_{i=1}^{m} w_i Y_i \tag{1}$$

Minimize total cost (Z_2)

$$\text{Min } Z_2 = \sum_{i=1}^{n} TC_i \tag{2}$$

Constraints:

$$\sum_{l=1}^{l_j} C_{jl}\; x_{jl} \le T_j \tag{3}$$

$$\sum_{l=1}^{l_j} x_{jl} = 1 \tag{4}$$

$$Y_i = \sum_{j=1}^{j=n} \sum_{l=1}^{l_j} r_{ijl} \left(x_{jl} \right) + \sum_{j=1}^{n-1} \sum_{k=j+1}^{n} \sum_{l=1}^{l_j} \sum_{u=1}^{l_k} R_{ijk} \left(x_{jl} \right) \left(x_{ku} \right) \tag{5}$$

$$x_{jl} \in \{ 0,1 \} \tag{6}$$

4. ILLUSTRATIVE EXAMPLE

To demonstrate the proposed model, domestic refrigerator is considered as an example product. The first phase of QFD is the product planning in which

House of Quality (HOQ) is established. Customer expectations in a domestic refrigerator are obtained through personal interviews with the customers, market surveys. The six basic customer needs are identified through factor analysis [16]. The seven design requirements are obtained through design experts. The customer needs and design requirements are shown in table1.

Table 1: List of customer needs and design requirements

Customer needs	Design requirements
Service reliability (SR)	Enhancing compressor performance (ECOMP)
Preservation (PRE)	Enhancing condenser performance (ECONP)
Refrigeration effect (RE)	Enhancing evaporator performance (EEP)
Storage volume (SV)	Use good thermal insulation material (UGTIM)
Price (PR)	Quick response to trouble shooting (QRTS)
Energy consumption (EC)	Effective refrigerator controls (ERC)
	Optimum design of refrigerator compartments (ODRC)

The outcome of the HOQ is the priority structure of the design requirements and it is the input to the Parts deployment matrix. Venkata Subbaiah et al. [17] determined the priority ratings of design requirements for a domestic refrigerator using conjoint analysis and QFD-ANP methodology, which are shown in table 2.

Table 2: Priority ratings of design requirements

Design requirements	Priority ratings (w_i)
ECOMP	10.61
ECONP	19.22
FFP	20.40
UGTIM	14.54
QRTS	6.43
ERC	9.27
ODRC	15.81

The parts characteristics and their levels are identified to meet the design requirements by the design team using VE technique. Costs of principal parts of the domestic refrigerator corresponding to different levels are shown in table 3. The parts deployment matrix is established by conducting brain storming sessions with technical experts of the design team. The scale 1-3-9 is used to assign relationship values in the matrix. The inter relationship values (r_{ijl}) represent the relationship between each design requirement (i) and part characteristic (j) at each level (l). The intensity of the correlation between the parts characteristics j and k for the i^{th} design requirement is represented by R_{ijk}. Figure 1 shows the parts deployment matrix.

Principal parts characteristics	Costs of the parts at the different levels					
	Level I	Cost (Rs)	Level II	Cost (Rs)	Level III	Cost (Rs)
PC1:Hermetic Compressor (HC)	1/3 hp	2,800	1/6 hp	2,350	1/8 hp	2,000
PC2: Wire and Tube Condenser (WTC)	$11''\times10''\times2$ row	700	$10''\times10''\times2$ row	500	$9''\times9''\times2$ row	450
PC3: Roll-Bond Evaporator (RBE)	3/8 '' dia., 55' length	1,500	3/8 '' dia., 45' length	1,200	5/16 '' dia., 40' length	1,000
PC4: Capillary Tube (CT)	0.036 in.dia., 14.6 ft length	66	0.036 in. dia., 13.6 ft length	62	0.036 in. dia., 10.6 ft length	48
PC5: Overload Protector with PTC Relay (OLPPTCR)	Open type	250	Box type	180	------	------
PC6: Leak Proof Refrigerator Cabinet (LRC)	PUF insulation make	900	Glass wool insulation make	600	------	------
PC7: Automatic Defrost Mechanism (ADM)	Electronic sensors type	2,000	Manual type	1,000	------	------
PC8: Thermostat Control (TC)	Electronic sensors type	500	Mechanical type	325	------	------
PC9: Multi Purpose Compartment (MPC)	Large size	900	Medium size	700	Small size	600

Table 3: Costs of various parts of the refrigerator corresponding to different levels

Table 4 shows the results when optimizing the objectives individually as case (i) and case (ii). In the case (i), the customer satisfaction index and the total cost of the refrigerator obtained are 23431.26 and Rs.9, 616 respectively. The customer satisfaction index and cost are reduced to 11314.56 and Rs.6, 203 respectively in case (ii). In view of attaining highest level of customer satisfaction, the refrigerator is manufactured by assembling all the parts under level I. But to provide the refrigerator at a minimum cost to the customer, the parts of the refrigerator such as hermetic compressor, condenser, evaporator, capillary tube, multi-purpose compartment are selected in level III and over load protector, refrigerator cabinet , defrost mechanism and thermostat control have to be selected in level-II.

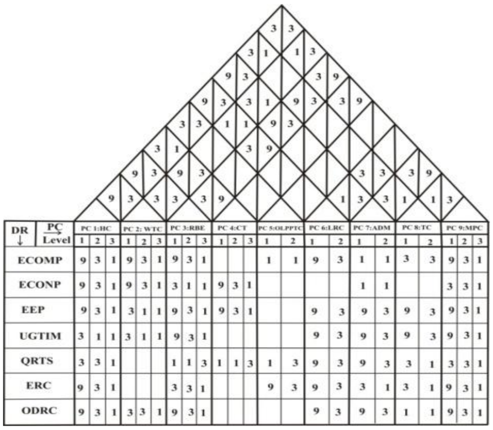

Figure1: Parts Deployment Matrix

Table 4: values of objectives and decision variables

Objectives	Case (i)	Case (ii)
	Maximize customer satisfaction	Minimize total cost
Customer satisfaction index	23431.26	11314.56
Total cost	Rs.9,616	Rs. 6,203
Decision variables	$x_{11}, x_{21}, x_{31}, x_{41}, x_{51}, x_{61}, x_{71}, x_{81}, x_{91}$	$x_{13}, x_{23}, x_{33}, x_{43}, x_{52}, x_{62}, x_{72}, x_{82}, x_{93}$

5. CONCLUSIONS

The model presented in this paper improves product development and intends to balance customer satisfaction, cost and functionality of the product. As parts deployment matrix of QFD is considered in the model, it is possible to change the parts characteristics in accordance with the customer views. The TC along with VE is appropriate to control and manage the cost of the product during the design stage. In order to trade-off both customer satisfaction and cost, the model can be extended to carry out multi-objective optimization. The further research may be carried out by solving the model under fuzzy environment to resolve the inherent uncertainty associated with the cost estimation of various parts of the product.

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