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Research Note

Quality Function Deployment, Value Engineering and Target Costing, an Integrated Framework in Design Cost Management: A Mathematical Programming Approach

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In this paper, the need to incorporate three famous design cost management methods, called: Quality Function Deployment (QFD), Value Engineering (VE) and Target Costing (TC) into a single model has been addressed. Each method performs very well in cost management procedures as design activities. These methods have been incorporated into a mathematical programming model, in order to achieve the maximum benefit of each method. The model, essentially, optimizes customer satisfaction subject to target cost. The tool is a mixed integer zero-one nonlinear programming. The unified model has been proposed to prevent a non-optimal solution when methods interact with each other. The practitioner should be confident that the quality solution would be achieved in contrast to when the methods are applied sequentially. A simple automobile design example was formulated and solved to show the performance of the model.

INTRODUCTION

Considering cost in the design process is an important issue. Many features of a product and ways in which to produce it are determined in the design phase. This encourages careful consideration in all stages of the design activities. Much research has been conducted in this subject through different approaches. Many authors studied cost through Quality Function Deployment (QFD) planning [1-3], where others studied this process using the Value Engineering (VE) methodology for design activities [4,5]. Target Costing (TC) is another approach to design cost management [4,6]. All three methods try to manage cost in the design phase and, therefore, achieve competitive produce. The complementary effect of these methods has been recognized by many researchers. In particular, Cooper and Slagmulder [4], in their book, comprehensively discussed the interaction between the target costing method and value engineering. They elaborately present the Survival Zone for a product that consists of three characters:

1. Price,
2. Functionality,
3. Quality.

They discussed how these three factors interact with each other and provide the Zone for the operations of the firm. This Survival Zone is presented in Figure 1. The interaction of price and functionality was, also, discussed by them. Here, an attempt has been made to incorporate the third method (QFD) in this set. It is believed that a mathematical model is the proper tool for this incorporation and its feasible region precisely demonstrates the Survival Zone, which was described in [4].

In the following sections, first, there is a brief explanation of these three methods. Then, a mathematical programming will be introduced to incorporate all three methods in one model, therefore, achieving an optimized result. A numerical example from the automobile industry will accompany the model.

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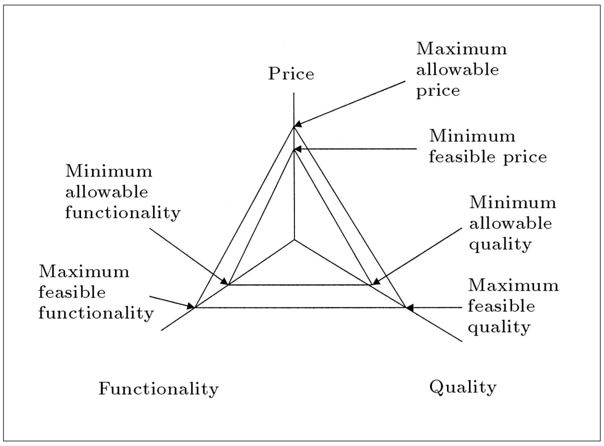

Figure 1. The survival zone for a product source [4].

QUALITY FUNCTION DEPLOYMENT (QFD)

QFD is an overall concept that provides a means of translating customer requirements into the appropriate Technical Attribute (TA) for each stage of product development and production. Considering cost into the House Of Quality (HOQ) has been studied by some researchers [7-9]. It provides a tool for cost management in the design phase. Approaching cost to QFD, using mathematical modeling, has also been the subject of different articles [1-3]. All articles reported successful experiments when considering cost in the QFD planning.

QFD was originally proposed through collecting and analyzing the opinions of the customer to develop products with higher quality in order to meet or surpass customer needs. Thus, the primary functions of QFD are product development, quality management and customer need analysis. Later, QFD's function was expanded to wider fields, such as design, planning, decision-making, engineering, management, teamwork, time and cost.

The major benefits of using QFD are:

* QFD helps companies to make the key trade-offs between what the customer demands and what the company can afford to produce;
* QFD improves effective communication between company divisions and enhances teamwork;
* Quality is built in upstream;
* QFD increases customer satisfaction by making sure that customer demands are brought into the product development process;
* Important production control points are not overlooked;
* QFD brings together all the data required for the development of a good product and the development team sees very quickly, where additional information is needed during the process. Moreover, the information is better used and documented;
* QFD shortens time-to-market. The four-matrix QFD approach is pictured in Figure 2.

VALUE ENGINEERING

The society of American Value Engineering defines value engineering as "the systematic application of recognized techniques, which identify the function of

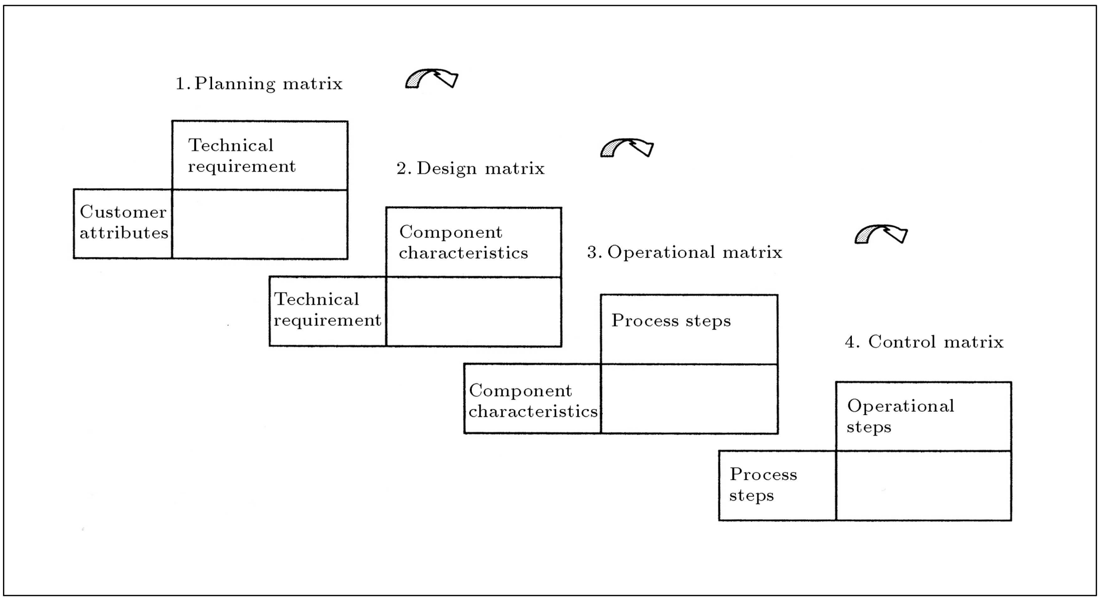

Figure 2. The four-phase approach of QFD.

product or service, establishes a monetary value for that function and provides the necessary function reliability at the lowest overall cost". In VE, the term "Function" refers to what makes a product work or sell. Elias [10] and Cheah and Ting [11] discussed that it is more beneficial to apply VE at the earlier stages of development, namely; the preliminary design stage. They reported successful achievement of VE analysis in design cost management.

By applying VE for a project or product, one can be sure that all different alternatives that are candidates for satisfying the "Function", have been considered. It has been suggested in this paper that the best alternative should be chosen, based on customer preferences and their associated cost. In this article, the integration of VE and QFD has been proposed, which means that simply presenting different alternatives for the required "Function" is not enough and that customer opinion for these alternatives should be taken into account. This task would be performed using the QFD technique.

TARGET COSTING

For more than a decade, target costing has been recognized as an important tool for lowering costs and increasing competitiveness [12-14]. The target costing process is identified by its famous formula as follows:

target cost = target price − desired profit.

Figure 3 summarizes the target costing process. Target Costing should be recognized as a totally new accounting philosophy. It concentrates on the selling price of the product from the very beginning phase of the design process. Many firms, especially Toyota, reported successful application of the target costing process.

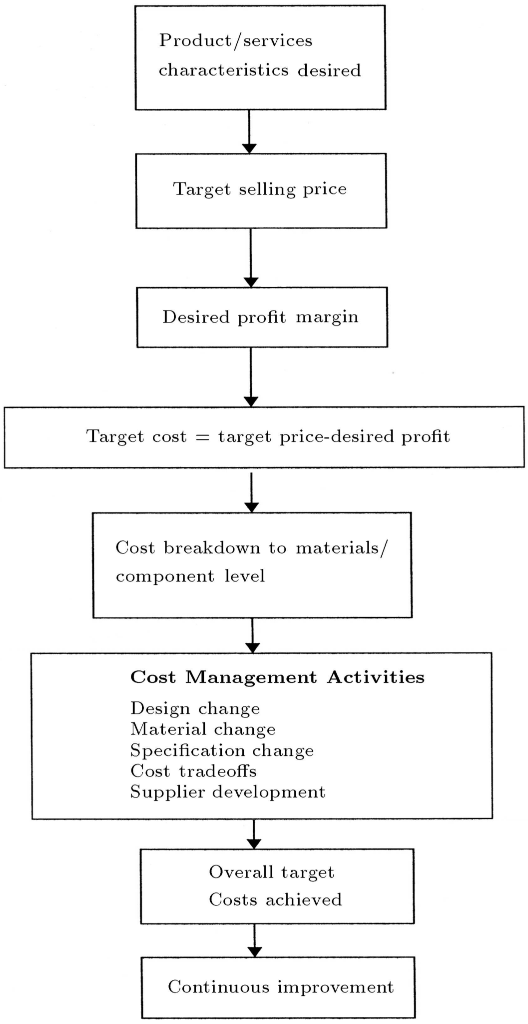

Figure 3. Target costing process [13].

MODEL INTEGRATION

As discussed earlier, each method performs very well in the area of cost management. Here, an attempt has been made to incorporate these approaches into the mathematical programming model, in order to achieve the benefits of each approach. The roadmap for this integration is shown in Figure 4.

As discussed earlier, it is more beneficial to apply VE at the earlier stage of the design process. The output of the VE analysis would be some design solutions. It is proposed to put these solutions into the second matrix of QFD. Therefore, different levels of the solution exist for each component characteristics at the House Of Quality (HOQ). HOQ, in this format, is shown in Figure 5.

It means that the first column of the matrix is partitioned into three levels, namely, L_{11}, L_{12} and

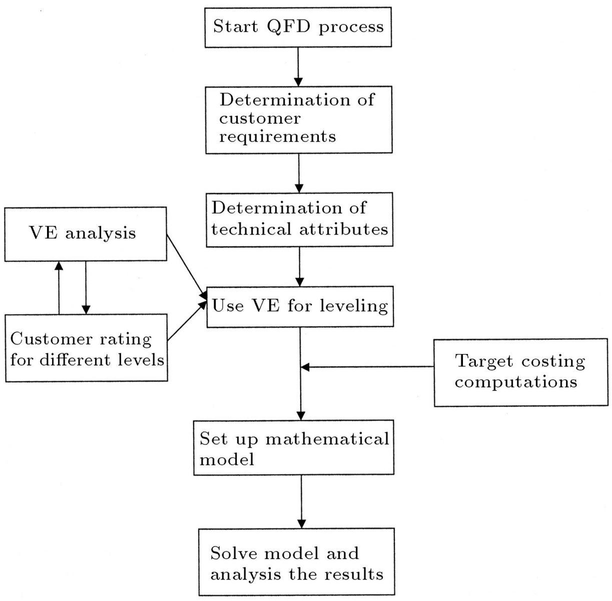

Figure 4. Model integration.

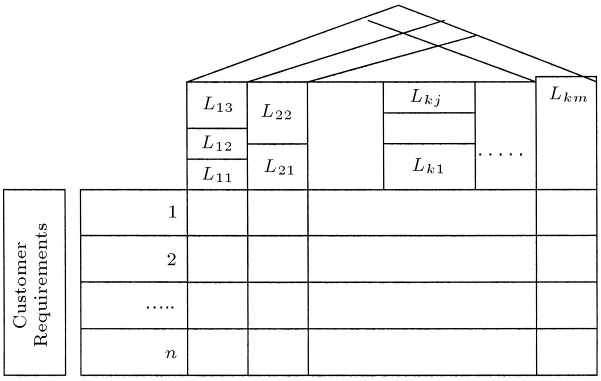

Figure 5. HOQ including leveling.

L_{13}, using VE analysis. For column k, therefore, this partitioning results into j levels $(L_{k1}, L_{k2}, \cdots, L_{kj})$. This is the point of interaction between VE and QFD.

With these changes, HOQ now has three dimensions. It means that for each customer requirements and at each level, there exists a customer rating in the table.

On the other hand, the computations for calculating the target cost have been performed and the output is prepared to feed the mathematical model.

MATHEMATICAL MODEL

In this paper, the approach is the same as [15], which was developed for manpower planning and the authors modified it to consider the cost.

Here, there are:

- i: ith customer requirements, $i = 1, \cdots, n$,
- k: kth technical attribute, $k = 1, \cdots, m$,
- L_{kL}: number of level for kth technical attribute, $L = 1, \cdots, L_k$,
- u_{ikL}: the intensity that the Lth level of the kth technical attributes has on ith customer requirements (u_{ikL} are the elements of HOQ),
- w_i: weight for ith customer requirements,
- x_{kL}: decision variable:
  - 1 if kth technical attribute performs at level L
  - 0 Otherwise,
- C_{kL}: the cost for performing in level L for kth technical attribute,
- y_i: the summation of effects of technical attributes for ith customer requirements (notice for its computation in the formula),
- γ_{ikj}: the relation between technical attributes (roof of HOQ).

The point that should be made here is that, now, one has a cubic of quality instead of House of Quality. It means that for each level of technical attribute and each customer requirement, one has the value of u_{ikL} (u_{ikL} can have the value 1-3-9 as the regular HOQ). Now, one has the following mathematical programming:

$$\max Z = \sum_{i=1}^{n} w_i y_i, \tag{1}$$

Subject to:

$$\sum_{L=1}^{L_k} x_{kL} = 1, \qquad k = 1, 2, \cdots, m, \tag{2}$$

$$y_i = \sum_{k=1}^{m} \sum_{L=1}^{L_k} u_{ikL} x_{kL} + \sum_{k=1}^{m-1} \sum_{j=k+1}^{m} \sum_{L=1}^{L_k} \sum_{\nu=1}^{L_j} \gamma_{ikj} x_{kL} x_{j\nu}, \qquad i = 1, \cdots, n, \tag{3}$$

$$\sum_{L=1}^{L_k} C_{kL} x_{kL} \leq \mathrm{TC}_k, \qquad k = 1, \cdots, m, \tag{4}$$

$$\sum_{i=1}^{m} \mathrm{TC}_i \leq \text{Target cost}, \tag{5}$$

$$x_{kL} \in \{0, 1\}. \tag{6}$$

To describe the above mathematical programming, Equation 1 as an objective function, maximizes customer satisfaction. y_i, which is computed by Equation 3, reflects the impact of customer preference by the first term. The second term reflects the impact of the roof of the House of Quality. γ_{ikj} represents the interaction between the technical attribute, k, and j for the ith customer requirement. When the second term is the product of two x's and each x is the number between zero and one, the second term does not dominate the first term [15].

Equations 4 and 5 together guarantee that the total cost of all subsystems does not exceed the previously computed target cost.

It should be mentioned here that this method can be applied equally for each of the four QFD matrixes. As discussed earlier, the best matrix for applying VE is the second matrix where the different design alternatives will be presented.

In some cases, in real world situations, the decision variables, x_{kL}, can assume two or more levels from each TA. It means that some percentages of each level optimize customer satisfaction and that is why the model is called mixed integer zero-one nonlinear programming.

Another point that should be mentioned here is concerning the C_{kL} parameters. C_{kL} can be interpreted as the price of a specified solution or as the cost of developing this solution. These two interpretations of C_{kL} enhance the efficiency of the model.

NUMERICAL EXAMPLE

A simple automobile design example was designed to show the performance of the model. There are five customer requirements and six technical attributes as follows:

Customer requirements:

1. Suitable acceleration,
2. Suitable seats,
3. Internal Beauty,
4. Fuel Economy,
5. Safety.

Technical Attributes:

1. Proper performance of engine,
2. Ergonomical considerations,
3. Proper gear box,
4. Industrial design considerations,
5. Proper break system,
6. Strength of body.

For each technical attribute, VE analysis is used to identify different solutions or, in other words, different levels. For instance, in this case, for the first technical attribute (proper performance of engine), the solutions are to use either a 1600 cc engine, a 1800 cc engine or a 2000 cc engine. In the same manner, different levels (solutions) for each technical attribute were categorized as follows; parameter C_{kL}, for each level of TA, will also be identified:

1. Proper performance of engine = {1600, 1800, 2000}

   L_{11} L_{12} L_{13}
   $C_{11} = 5000$ $C_{12} = 8000$ $C_{13} = 10000$,

2. Ergonomical consideration = {use external consultant, use current model}

   L_{21} L_{22}
   $C_{21} = 15000$ $C_{22} = 0$,

3. Proper Gearbox ={Optimization of Gearbox, use current Gearbox}

   L_{31} L_{32}
   $C_{31} = 10000$ $C_{32} = 0$,

4. Industrial design consideration. This TA will perform at two levels: ={redesign all features, modify some features}

   L_{41} L_{42}
   $C_{41} = 10000$ $C_{42} = 5000$,

5. Proper break system. This TA also performs at two levels: ={use ABS system, modify current system}

   L_{51} L_{52}
   $C_{51} = 5000$ $C_{52} = 8000$,

6. Strength of body. This TA performs at three levels: ={modify current structure, redesign structure, reinforce the structure}

   L_{61} L_{62} L_{63}
   $C_{61} = 5000$ $C_{62} = 9000$ $C_{63} = 3000$.

Voice of Customer or u_{ijk} Parameters

After the determination of solutions or levels by VE analysis, at the next step, the voice of the customer, u_{ikL} parameters or the relationship matrix of the HOQ are gathered as an input for the model. These are the elements of the HOQ matrix, which in the presented model are three-dimension and cannot be represented as surface.

u_{111} means that, for the first ($i = 1$) customer requirement, if one uses the first ($k = 1$) TA and if it performs at the first ($L = 1$) level, then, the customer satisfaction would be u_{111}. In this case:

$i = 1 - - \rightarrow$ suitable acceleration,

$k = 1 - - \rightarrow$ proper performance of engine,

$L = 1 - - \rightarrow$ use 1600 cc engine.

Then, the customer expresses his desire for instance 9, then $u_{111} = 9$.

Other u_{ikL} also would be identified by the customer. For the present example, the value of u_{ikL} is in Appendix A. When there is a strong positive relation between the second and fourth TA, then $\gamma_{i24} = 9$, for all i. In this case, the customer weights for his preference are:

$$(w_1, w_2, w_3, w_4, w_5) = (4, 3, 3, 4, 5).$$

The complete mathematical program for the example is in Appendix B.

Different target costs for the problem were examined and different solutions were achieved, as shown in Table 1. For each TA, the solution shows which level should be chosen to maximize customer satisfaction.

Table 1. Solutions of the model for different target costs.

	TA								
Target Cost	**1**	**2**	**3**	**4**	**5**	**6**	**No. Iteration**	**CPU Time**	**Objective Function**
60000	1	1	1	1	1	3	4	0.04	451
40000	1	2	1	1	1	3	25	1.164	403
30000	1	2	1	2	1	3	26	1.617	361
20000	1	2	2	2	1	3	22	0.467	297
15000							Infeasible		

Each row in Table 1 shows the answer for associated target cost. It means that, if one has the target cost of 40,000, then, the first TA should perform at level one, the second TA should perform at level two and so on.

MODEL ASSUMPTIONS

The assumption for the mathematical model is to assume that the VE analysis generates different discrete solutions. This assumption is not severe in practice and does not limit the application of the model very much.

For future work, the same procedures that were applied for the second QFD matrix can be applied for the third QFD matrix. In this scenario, the output of VE analysis is a different distinct production process and, therefore, the mathematical model can be used as a "Process Selection" tool and the result would be useful accordingly.

CONCLUSION

It was proposed to incorporate three approaches, called QFD, VE and TC, into a mathematical model. It was shown that with a reasonable amount of computational effort, one can achieve the best arrangement of TAs. If the methods perform the problem one-by-one, then, there is a chance of an under-optimality condition because the methods interact with each other and affect the parameters of the problem. This incorporating overcomes this drawback.

It is proposed that the second matrix of QFD is the best choice for applying the VE approach. In future work, an analysis of how the VE approach could be applied for the third and fourth matrix of QFD could be undertaken.

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APPENDIX A

$u_{111} = 1$	$u_{112} = 9$	$u_{113} = 3$	$u_{131} = 9$	$u_{132} = 1$
$u_{221} = 9$	$u_{222} = 1$	$u_{241} = 9$	$u_{242} = 3$	
$u_{321} = 9$	$u_{322} = 1$	$u_{341} = 9$	$u_{342} = 1$	
$u_{411} = 9$	$u_{412} = 1$	$u_{413} = 1$	$u_{431} = 9$	$u_{432} = 1$
$u_{551} = 9$	$u_{552} = 3$	$u_{561} = 1$	$u_{562} = 3$	$u_{563} = 3$

All other u_{ijk} are 0.

APPENDIX B

$$\max Z = 4y_1 + 3y_2 + 3y_3 + 4y_4 + 5y_5,$$

S.t.

$$x_{11} + x_{12} + x_{13} = 1,$$

$$x_{21} + x_{22} = 1,$$

$$x_{31} + x_{32} = 1,$$

$$x_{41} + x_{42} = 1,$$

$$x_{51} + x_{52} = 1,$$

$$x_{61} + x_{62} + x_{63} = 1,$$

$$y_1 = x_{11} + 9x_{12} + 3x_{13} + 9x_{31} + 1x_{32} + 9x_{21}x_{41} + 9x_{21}x_{42} + 9x_{22}x_{41} + 9x_{22}x_{42},$$

$$y_2 = 9x_{21} + x_{22} + 9x_{41} + 3x_{42} + 9x_{21}x_{41} + 9x_{21}x_{42} + 9x_{22}x_{41} + 9x_{22}x_{42},$$

$$y_3 = 9x_{21} + x_{22} + 9x_{41} + x_{42} + 9x_{21}x_{41} + 9x_{21}x_{42} + 9x_{22}x_{41} + 9x_{22}x_{42},$$

$$y_4 = 9x_{11} + x_{12} + x_{13} + 9x_{31} + x_{32} + 9x_{21}x_{41} + 9x_{21}x_{42} + 9x_{22}x_{41} + 9x_{22}x_{42},$$

$$y_5 = 9x_{51} + 3x_{52} + x_{61} + 3x_{62} + 3x_{63} + 9x_{21}x_{41} + 9x_{21}x_{42} + 9x_{22}x_{41} + 9x_{22}x_{42},$$

$$5000x_{11} + 8000x_{12} + 10000x_{13} \leq \mathrm{TC}_1,$$

$$15000x_{21} \leq \mathrm{TC}_2,$$

$$10000x_{31} \leq \mathrm{TC}_3,$$

$$10000x_{41} + 5000x_{42} \leq \mathrm{TC}_4,$$

$$5000x_{51} + 8000x_{52} \leq \mathrm{TC}_5,$$

$$5000x_{61} + 9000x_{62} + 3000x_{63} \leq \mathrm{TC}_6,$$

$$\mathrm{TC}_1 + \mathrm{TC}_2 + \mathrm{TC}_3 + \mathrm{TC}_4 + \mathrm{TC}_5 + \mathrm{TC}_6 \leq 30000,$$

$$x_{kL} \in \{0,\ 1\}$$