

CHAPTER 6

QUALITY FUNCTION DEPLOYMENT AND PROCESS MODELS

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1. INTRODUCTION

Products should be designed to assure the highest possible quality and to facilitate manufacturing and assembly in a short time and at a low cost. The engineering design process is to deliver high quality products and systems, often subject to stringent time constraints.

Quality is an abstract term, often defined as the extent to which the customers (users) believe the product meets their requirements and expectations. One of the techniques for improving products and processes is the quality function deployment (QFD), known also as the house of quality (see Figure 1). Toyota has used the QFD approach since 1977, following four years of training and preparation. Using 1977 as a base, Toyota reported a 20% reduction in a start-up cost on the launch of the new van in 1979, a 38% reduction in 1982, and a cumulative 61% reduction in 1984. During this period, the product development cycle was reduced by one third with a corresponding improvement in quality, largely due to the reduced number of engineering changes.

The basic idea of QFD is to transform customer requirements into specific design requirements. The information in the various QFD matrices requires that different groups of individuals reach consensus on the product, process, and design requirements necessary to effectively meet customer requirements.

QFD begins by obtaining the customer requirements (CR_i) with respect to the product being designed. These requirements are not specifically related to the customer's product, but to the entire market (Keats 1990). Next, the current or projected design features from the customer perspective are compared with the list of technical descriptions of the product. The technical descriptions (TD_j) might be linked with other elements of the product life cycle process, including design activities (DA_j). The comparison of competitive products may be on the basis of ratings indicating how well the design requirements are met. The product features are then related to themselves in the roof of the diagram using correlation symbols. As a result of this process, features with the conflicting design requirements become apparent. This implies that some trade-off may be necessary and QFD has identified it early in the design process. The next step is to benchmark the product as viewed by the customer with the products of selected competitors with respect to meeting customer requirements using a scale of same,

better, or worse. Enhancements to the QFD process include adding importance measures to the customer requirements, including target values for product design features and relating product design features to part and mechanism characteristics. Figure 1 shows a typical QFD matrix that is the foundation of QFD practices (Bossert 1991).

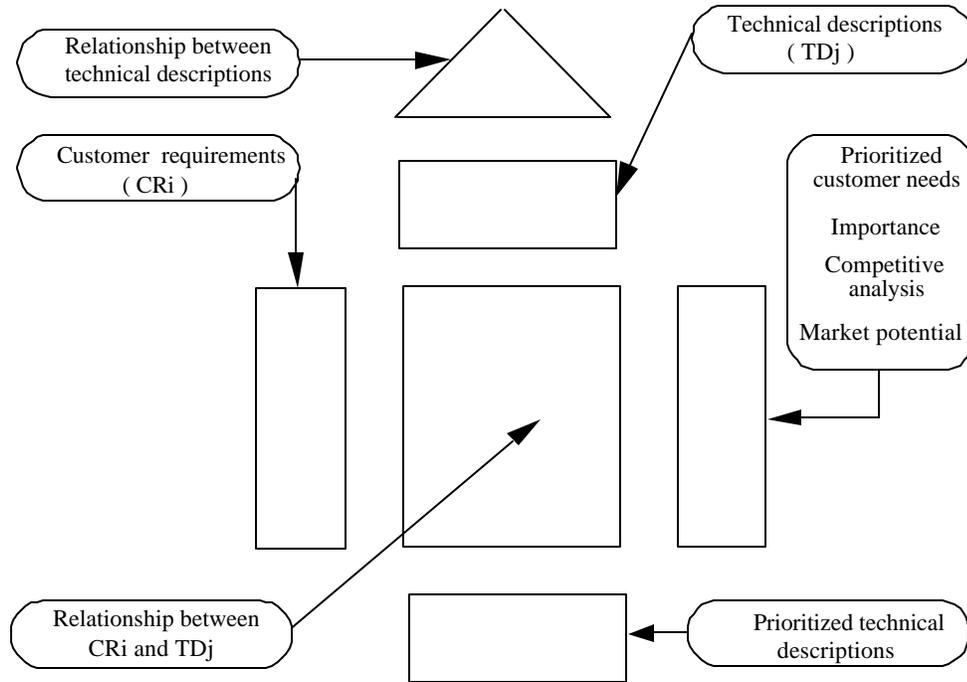


Figure 1. The quality function deployment (QFD) matrix

The rows of the matrix in Figure 1 are the customer requirements, i.e., what the customer wants in the product. The columns of the matrix show what the manufacturer does to ensure the quality of the product. The right side of the matrix contains the planning information, i.e., the importance rating, competitive analysis, target value, amount of scaling up necessary, and the sales points. The relationships between customer requirements and design requirements are categorized in the body of the matrix. The important goal of QFD is to turn the design requirements into the detailed design activities. A full implementation of the QFD concept allows the customer requirements (CR_i) to be cascaded down through the technical descriptions (TD_j) and functional descriptions (FD_j) to design activities (DA_j) as illustrated in Figure 2.

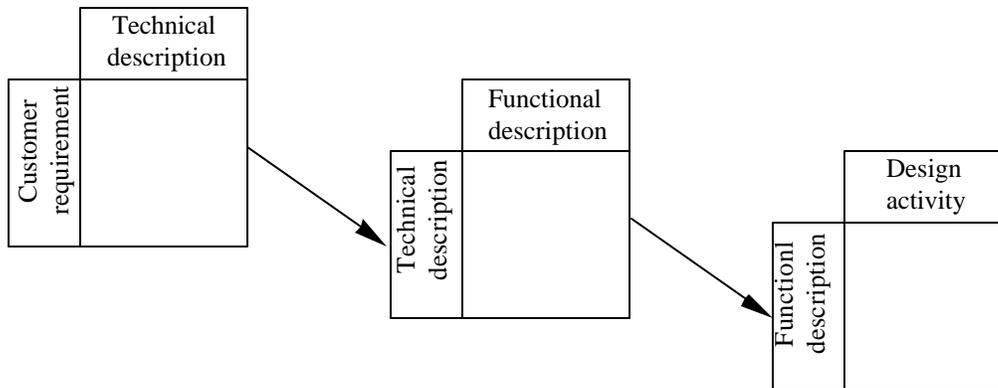


Figure 2. QFD cascade

The following six steps summarize forming a QFD matrix.

Step 1. The primary customer requirements are normally expanded into secondary and tertiary requirements using, for example, an AND/OT tree. The information usually comes from a variety of sources such as marketing groups, dealers, sales departments, customer opinion surveys, and so on. This step is critical and it is usually difficult, as it requires obtaining and expressing what the customer truly wants.

Step 2. The technical descriptions must be related to the customer requirements and should be selectively deployed throughout the manufacturing, assembly, and service process to manifest themselves in the final product performance and customer acceptance.

Step 3. Developing a matrix describing the customer requirements and the technical descriptions is accomplished. As they are correlated to a different degree, numbers are used to express the significance of the relationships. A simple four-grade scale can be used to define strong, medium, weak, and negative relationship. Of course, other scales for expressing the relationship are possible.

Step 4. Market evaluation that covers the customer-expressed importance ratings, requirements listed and competitive products are evaluated. Market evaluations are compared with the design requirements to determine areas of inconsistency between the customer requirements and strategy of the company.

Step 5. The target for each technical description is defined. These target values are based on the customer importance index or strengths and weaknesses of the competing products. These values should be measurable. The conformance with these targets is to be measured at each stage of the product development and prove-out processes such as the evaluation of mechanical and functional prototypes, engineering sign-offs, and units produced with production tooling just prior to production, and on the first units at the beginning of production.

Step 6. Selection of the best solution should be deployed through the approach discussed later in this chapter. Implementing QFD is a challenge for any company, but it requires significant effort in the early design stages.

QFD brings several benefits to companies willing to undertake the study and training required implementing the system:

- Product objectives based on customer requirements are not misinterpreted at the subsequent stages.
- Particular marketing strategies or sales points do not become lost or blurred during the translation process from marketing through planning to execution.

- Important production control points are not overlooked - everything necessary to achieve the desired outcome is understood and in place.
- Efficiency is improved as the misinterpretation of design objectives, marketing perception, critical control points, and the need for changes are minimized.

Integrated product and process design is a key aspect of concurrent engineering. One of the objectives of concurrent engineering is to ensure that serious errors do not go undetected and that the design intent is fully captured. Due to the simultaneous consideration of many factors, experts from different functional groups need to contribute towards the design goal. In effect, teams perform the design activities with members representing various disciplines. A design team can effectively utilize the concurrent engineering approach only when it works cooperatively and consistently.

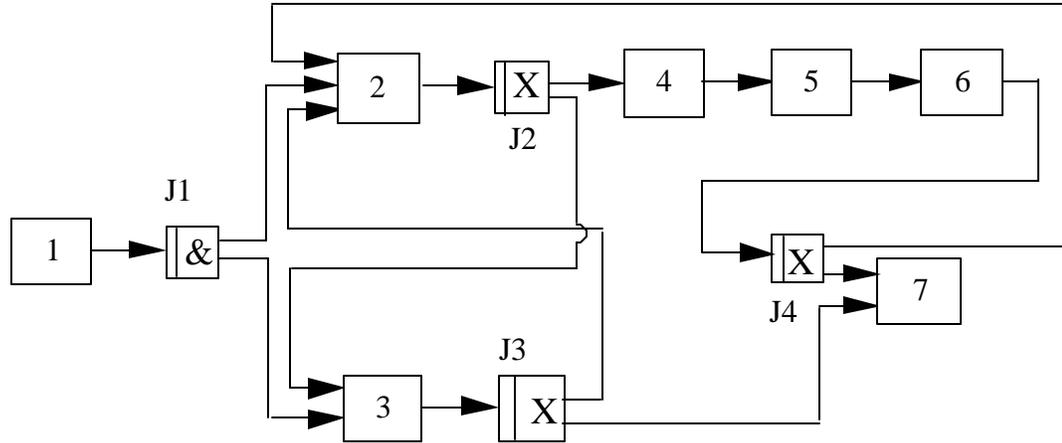
The design process consists of several phases ranging from the analysis of customer requirements to manufacturing of the product. Each of these phases can in turn be decomposed into a set of interrelated design activities. The main purpose of this decomposition is to gain control over total duration of the design process and attain a proper utilization of resources during planning and execution of design activities, so that the total cost is minimized (Pahl and Beitz 1988).

The quality function deployment (QFD) approach enables organizations to translate customer requirements into relevant requirements throughout the design process. The house of quality is a tool for recording and communicating product information to the groups that contribute to the realization of the product (Hauser and Clausing, 1988). In the house of quality, certain design criteria are defined only, which are important in evaluating the product. These criteria are related qualitatively to the engineering domain and identify the relationship between the customer wants and what engineering must perform to deliver them. The aim of this research is to use the house of quality to assess the performance of the product development process.

The house of quality is modified to capture the relationships between design process attributes and control variables (Locascio and Thurston 1994). These qualitative relationships are then transformed into quantitative expressions. The expressions can either be used to examine the effect of change of variable values on the design process attributes or they can be used as constraints to optimize certain quality criteria in the design activity network.

2. DESIGN PROCESS

Consider the IDEF3 model of an electro-mechanical product shown in Figure 3 (Belhe and Kusiak 1996). The first activity is to prepare system specification from the customer requirements. Once this specification is ready, an activity to generate preliminary design begins which continuously interacts with the activity to evaluate cost of different alternatives. This relationship is shown by the *AND* logical junctions, J1 and *EOR* junctions J2 and J3. For the model clarity, only the fan-in logical junctions have been incorporated. Once the preliminary design is ready, a prototype is built and then different tests are performed on this prototype. The types of tests to be performed on this prototype depend on the type of module to be designed. The test data is analyzed to confirm the suggested design. If the suggested design is not acceptable, then it needs to be modified. Otherwise, the preliminary design data is used in conjunction with cost estimates to finalize the design details. An *EOR* logical junction, J4, indicates this relationship.



1. Prepare system specifications
2. Generate preliminary design
3. Evaluate cost of different alternatives
4. Build prototype
5. Perform tests on prototype
6. Analyze test data
7. Finalize design details

Figure 3. IDEF3 design process model of an electro-mechanical product

Different types of logical relationships between design activities result in alternative paths through the model. These alternate paths are associated with certain probabilities that may change over time. One can not exactly predict the path followed through the model or the number of iterations in the design process. The number of iterations depends, for example, on the quality of performing the design tasks and quality of the results of these tasks, however, the quantitative dependence can not be obtained.

In addition, the number of iterations taking place throughout the design process is not deterministic. This number may largely vary from one project to the other and it may not be possible to collect data and fit a distribution for the duration of different design phases. Also, the nature of the design process changes over time due to new developments in technology, organizational improvements and so on. The duration of some of the design activities may also depend upon the availability of resources which itself may change over time. Due to such dynamic nature of the design process, each design project is unique in terms of its time requirements. The quality of schedule depends on the accuracy with which the activity duration and the set of successor activities is determined. The predictability and standardization found in well planned manufacturing systems is not present to the same degree in product development process. In design projects, uncertainty and diversity seem to be the predominant features. Therefore, relationships between various design process attributes and variables can not be captured quantitatively. In this paper, the house of quality is used to qualitatively express these relationships.

3. RELATIONSHIP BETWEEN DESIGN PROCESS ATTRIBUTES AND VARIABLES

An effort is required to improve attributes associated with this design process. An attribute is a function of design process variables and is normally an element of a performance measure or a simple performance measure itself.

In the house of quality, design criteria are qualitatively related to the engineering domain, identifying the relationships between what the customer wants and what engineering must do to provide it. In this paper, it is proposed that a modified version of the house of quality be used to establish the qualitative relationships between various design process attributes and the corresponding design process variables. In this “modified” house of quality, design process attributes replace customer attributes and design process variables replace engineering characteristics.

The design process attributes are defined so that they clearly represent the management's objectives. Two attributes are combined when each is too specific and their total effect on the design process can be represented by a single goal. An attribute is eliminated if it is not relevant to the goal. An attribute is decomposed into two subattributes, when it can be better represented by two distinct goals. It is required to redefine a design process attribute when it is possible to describe the corresponding goal on a measurable scale.

A number of variables are involved in the design process. The level of these variables can be directly controlled. The exact analytical relationship between these variables and the attributes identified is not easy to establish. However, the qualitative impact of each of the design process attributes on the variables can be established. It is assumed that the variables affect the attributes according to the degree of dependency between them. The design process variables selected from the IDEF3 process model may interact with each other.

For example, consider the design process model in Figure 3. The activities in this model are at a high level of abstraction. One of the main advantages of using IDEF methodology is that it allows us to decompose an activity at high level of abstraction into lower level activities. The activity “Prepare system specifications” in Figure 3 can be decomposed into the activities in Figure 4, listed also in Table 1.

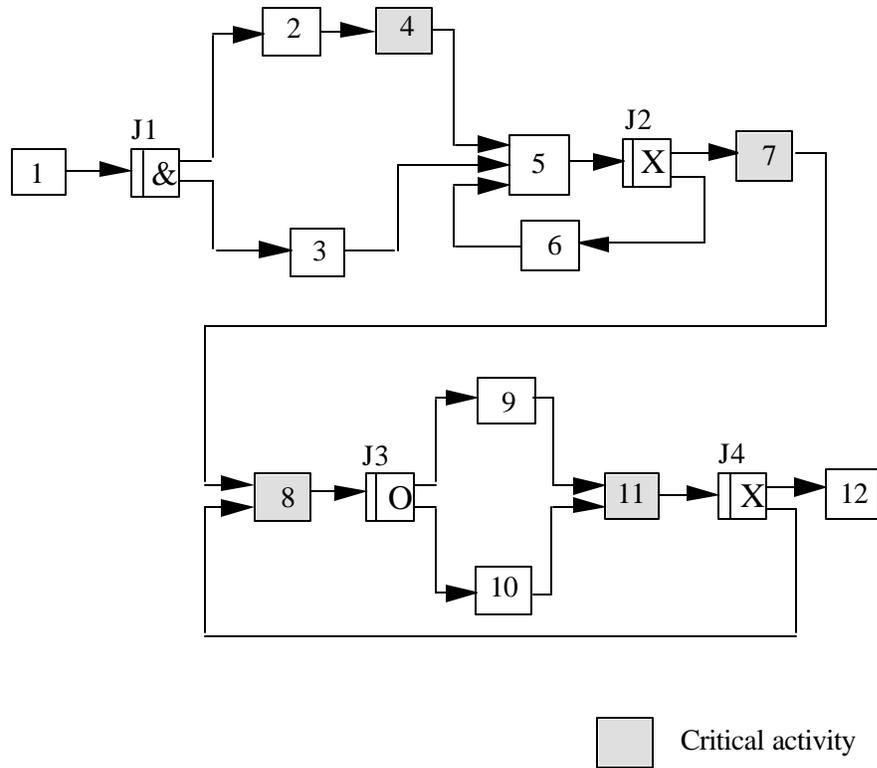


Figure 4. A process model with critical activities

A design project following the design process model shown in Figure 4 may undergo a number of iterations. As a result, the last activity in the model may or may not be completed before the required due date. The design activities have certain resource requirements, without which they can not be performed. The total number of resources available is limited and that may cause resource conflict between different activities in the design activity network. The duration of design activities is not fixed. It is directly or indirectly influenced by the way design activities are performed. The stochastic duration of design activities affects the length of the critical path. These characteristics of the process are important from the point of view of the management of the design process, however, they can not be controlled directly. In the approach presented in this chapter, the characteristics of the IDEF3 model are treated as design process attributes.

Table 1. List of Activities of the Design Process in Figure 4

Activity No.	Activity Name
1	Perform project planning
2	Review and analyze customer requirements
3	Develop project coordination document
4	Define design requirements
5	Establish system design goals
6	Perform system tradeoffs
7	Finalize product requirements

8	Develop system requirements
9	Conduct internal requirements review
10	Review requirements with customer
11	Analyze modifications of system specifications
12	Finalize the system specifications

Unlike the design process attributes, the design process variables can be directly controlled. For example, in the design model in Figure 4, the number of resources made available and number of design projects undertaken simultaneously can be controlled. Similarly, the way the design effort is performed, i.e., the level of interaction and involvement of different functional groups can also be directly controlled. These control variables have an impact on one or more of the design process attributes. However, the exact quantitative relationships between these design process attributes and the design process variables are not known. Therefore, we use the house of quality to represent these relationships (see Figure 6) using symbols shown in Figure 5. The house of quality in Figure 6 allows analyzing the relationship between design process variables and designing process attributes.

Relationship Matrix	
●	Strong positive
○	Medium positive
▽	Weak positive
✕	Negative

Interaction Matrix	
○	Positive
✕	Negative

Figure 5. Symbols used in the house of quality for design process attributes and variables

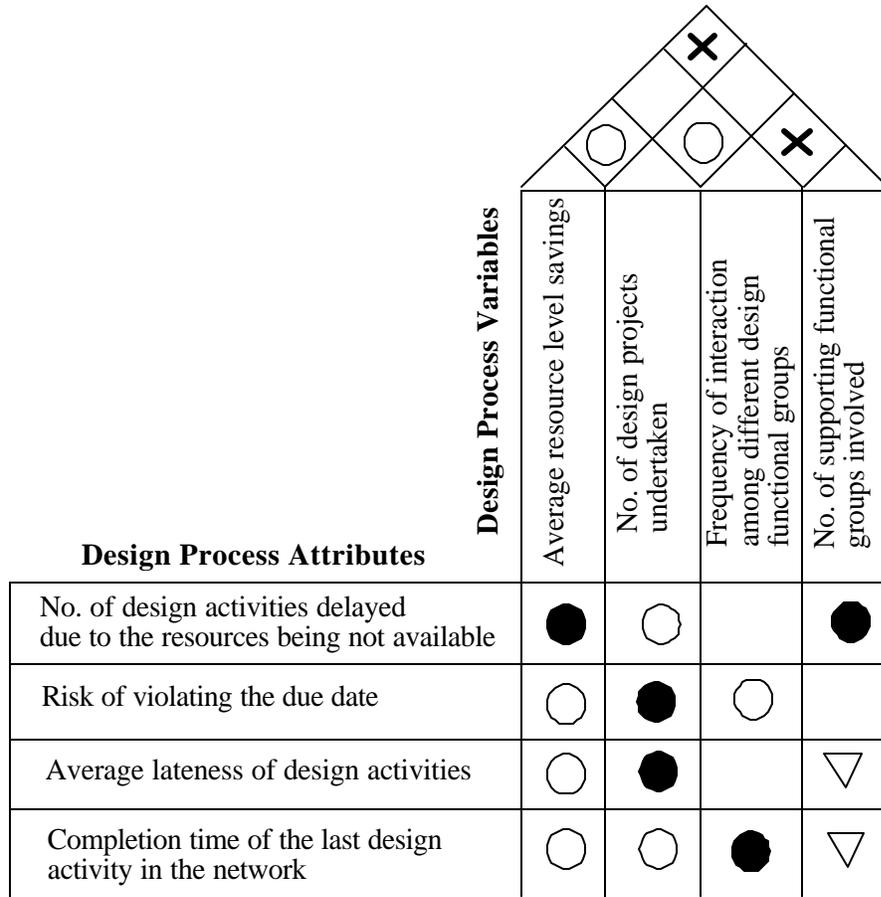


Figure 6. House of quality for a design process

Let n be the total number of attributes. The value of the design process attributes are given by the vector:

$$\mathbf{y} = (y_1, y_2, \dots, y_n)$$

For attribute value y_i , the lower limit and upper limit on its values are denoted by y_{iL} and y_{iU} , respectively. Therefore, the feasible range for y_i is:

$$y_{iL} = y_i = y_{iU}$$

The design process attributes and their feasible ranges for this example are given in Table 2. These ranges can be obtained from the past data.

Table 2. Design Process Attributes and Their Feasible Ranges

Attribute	Range
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y ₁	No. of design activities delayed due to shortage of resources	0 = y ₁ = 8
y ₂	Risk of violating the due date	0 = y ₂ = 1
y ₃	Average lateness of design activities	2.5 = y ₃ = 9.4
y ₄	Completion time of the last design activity of the process	18 = y ₄ = 35

Now, let m be the total number of design process variables. The vector gives values of the design process variables:

$$\mathbf{x} = (x_1, x_2, \dots, x_m)$$

For variable value x_i , the lower limit and upper limit on its values are indicated by x_{iL} and x_{iU} , respectively. Therefore, the feasible range for x_i is:

$$x_{iL} = x_i = x_{iU}$$

The design process variables and their feasible ranges for this example are given in Table 3.

The design process variables are not required to be independent. The interaction among these variables is shown in the roof of the house of quality in Figure 7.

Table 3. Design Process Variables and their Feasible Ranges

	Variable	Range
x ₁	Average savings in resource level	3.2 = x ₁ = 8.4
x ₂	Number of design projects pursued	4 = x ₂ = 10
x ₃	Frequency of interaction between different functional design groups	2 = x ₃ = 6
x ₄	Number of supporting functional groups involved	5 = x ₄ = 10

The lower and upper limits on the design attributes as well as on the design process variables represent their possible minimum and maximum values, respectively. For example, the risk of violating the due date is the probability with which the due date is violated and hence it ranges between 0 and 1. Similarly, in this specific example, there are at least 5 functional groups involved but it is not feasible to include more than 10 functional groups.

Once the ranges on the values of the design process attributes and the design process variables are established, one may want to quantify the relationships between the attributes and variables of this process to examine the effect of increasing or reducing the values of certain design variables on the attribute of interest. The commonly used conversion values for symbols in the house of quality are shown in Table 4.

Table 4. Conversion of Symbols

Symbol	Coefficient Value
●	+9
○	+3
▽	+1
×	-3

The value of y_i , the design process attribute i , is represented as a function of the design process variables.

$$y_i = f(\mathbf{x}) \quad (1)$$

Following the scheme presented in Locascio and Thurston (1994), this functional relationship includes first order effects from the relationship matrix and second order effects from interaction matrix. The design process variables are scaled on to the range of 0 to 1 to obtain the vector of relative design process variable values:

$$\mathbf{x}' = (x_1', x_2', \dots, x_m')$$

When the relative values of the design process variables, \mathbf{x}' , are used in place of the original values of process variables, \mathbf{x} , in equation (1), the relative values of design process attribute are obtained:

$$y_i' = f(\mathbf{x}') \quad (2)$$

This transformation from original values to the relative values is done to capture the relationship between variables and attributes captured in the house of quality. The use of this relationship is discussed next.

The functional relationship between design process attributes and design process variables can be further expressed by considering the conversion of symbols in Table 4. For example, the expression for “Risk of violating the due date” y_2' as a function of scaled process variables is expressed as:

$$y_2' = 3x_1' + 9x_2' + 3x_3' + 3x_1'x_2' + 3x_2'x_3' \quad (3)$$

Similarly, the expressions for the remaining relative attributes are given by :

$$y_1' = 9x_1' + 3x_2' + 9x_4' + 3x_1'x_2' - 3x_1'x_4' \quad (4)$$

$$y_3' = 3x_1' + 9x_2' + x_4' + 3x_1'x_2' - 3x_1'x_4' \quad (5)$$

$$y_4' = 3x_1' + 3x_2' + 9x_3' + x_4' + 3x_1'x_2' + 3x_2'x_3' - 3x_1'x_4' + 3x_2'x_4' - 3x_3'x_4' \quad (6)$$

The allowable range for each relative design process variable is [0, 1]. The allowable range for the relative design process attribute is computed by minimizing and maximizing the expressions for the relative design process attributes.

When one wants to determine the attribute value corresponding to a specific combination of values assigned to the design process variables, the values of the relative design process variables are determined first. Then the value of the relative design process attribute is determined. This value is then mapped back on to the original range of the design process attribute to obtain the actual value of the design process attribute.

For example, the minimum (maximum) values 0 (21) of y_2' is obtained by minimizing (maximizing) expression (3).

Therefore, the expression for y_2 is:

$$y_2 = 0 + ((1 - 0) (3x_1' + 9x_2' + 3x_3' + 3x_1'x_2' + 3x_2'x_3') / 21) \quad (7)$$

Suppose that one is interested in assessing the change in “Risk of violating the due date” when values of design process variables changed to a new set of values. The old values of the design process variables and the corresponding new values are provided in Table 5.

Table 5. The Values of Design Process Variables

Design Variable	Old Value		New Value	
	x_i	x_i'	x_i	x_i'
Average savings in resource level	5.6	0.46	6.8	0.69
Number of design projects pursued	6	0.33	6	0.33

Frequency of interaction between different functional design groups	3	0.25	5	0.75
Number of supporting functional design groups involved	8	0.6	8	0.6

The value of y_2 is determined from equation (7). Initially, the value of y_2 was 0.28 and after increasing the value of variables “Average resource level savings” and “Frequency of interaction between different functional groups” (see Table 5), the new value of y_2 is 0.42.

Similar to expression (7), the equations for other design process attributes are obtained:

$$y_1 = (8 - 0)(9x_1' + 3x_2' + 9x_4' + 3x_1'x_2' - 3x_1'x_4') / 21 \tag{8}$$

$$y_3 = 2.5 + (9.4 - 2.5)(3x_1' + 9x_2' + x_4' + 3x_1'x_2' - 3x_1'x_4') / 13 \tag{9}$$

$$y_4 = 18 + ((35 - 18)(3x_1' + 3x_2' + 9x_3' + x_4' + 3x_1'x_2' + 3x_2'x_3' - 3x_1'x_4' + 3x_2'x_4' - 3x_3'x_4') / 19 \tag{10}$$

The approach presented above allows to analyze the impact of a change of any variable value on the values of design process attributes by deriving quantitative relationships from the house of quality for the design process. Based on these relationships, any desired changes in the values of design process attributes can be implemented by making appropriate changes in the design process variables.

4. OPTIMIZING THE QUALITY OF CRITICAL DESIGN ACTIVITIES

The quality of results of design activities depends upon the quality of performing these activities. A design engineer may select activities that are critical to the quality of the design. For example, in the design activity network, shown in Figure 5, activities 4, 7, 8, and 11 are critical.

In this section, we analyze the relationship between the quality of performance of critical design activities and the design process control variables. In the house of quality, the critical design activities replace the design process attributes and the corresponding design process variables are determined. In order to measure the quality of the critical design activities, quality indices are used. The quality index for each design activity is in the range of 0 to 1, where 1 corresponds to the best quality and 0 corresponds to the lowest quality. The design process attributes y_1 , y_2 , y_3 , and y_4 and the corresponding ranges are shown in Table 6.

Table 6. Critical Design Activities and Their Limits

Activity No.	Critical Activity Name	Limits
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y1	4	Define design requirements	$0 = y_1 = 1$
y2	7	Finalize product requirements	$0 = y_2 = 1$
y3	8	Develop system requirements	$0 = y_3 = 1$
y4	11	Analyze modifications of system specifications	$0 = y_4 = 1$

The set of design process variables includes two of the previously defined variables, “Frequency of interaction between different functional groups” and “Average resource level”. In addition, “Level of expertise” is used as a design process variable. This variable refers to the average experience of a designer in terms of number of similar projects handled in the past. Since the designers are also assigned other responsibilities and these may affect the quality of input from the team member, “Number of resource preemptions” is used as a variable. The information required by the designer may become available from a variety of sources. The designer may try to minimize the risk of using wrong information by referring to more than one source of information so that he / she can verify the information obtained from other sources. Therefore, “Number of information sources” is treated as a variable affecting quality of performance of certain design activities. The variables and the corresponding limits are listed in Table 7.

Table 7. Variables Impacting Quality of a Design Process and Their Limits

	Variable	Limits
x1	Average level of expertise	$0 = x_1 = 8$
x2	Average resource level	$4.6 = x_2 = 12.34$
x3	Frequency of interaction between different functional design groups	$1 = x_3 = 5$
x4	Number of resource preemptions	$8 = x_4 = 25$

x5	Number of information sources	$3 = x_5 = 11$
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The next step is to construct the relationship matrix and the interaction matrix for the relationships between the quality indices of the critical design activities and the corresponding design process variables. The house of quality is shown in Figure 7.

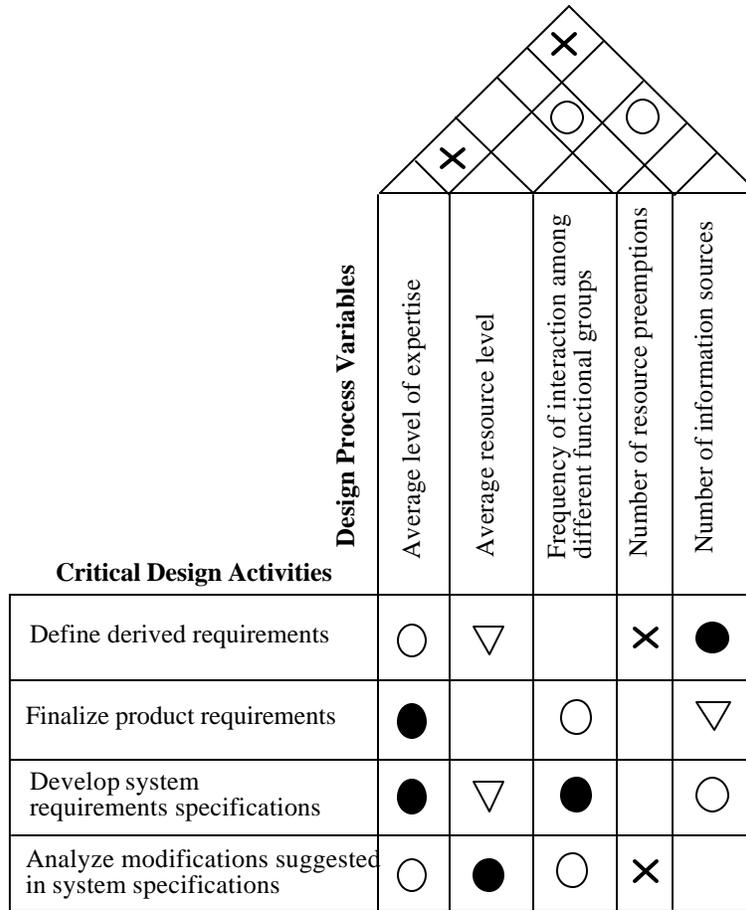


Figure 7. The house of quality for relationships between critical activities and process variables

As previously discussed, expressions for each of the attributes in terms of the process variables and their interaction are developed. The values of the design process variables are scaled to [0, 1]. The quality indices for each critical design activity in terms of the relative design process variables are obtained. These expressions are as follows :

$$y_1 = 0 + (1 - 0)(3x_1' + x_2' - x_4' + 9x_5' - x_1'x_2' - x_1'x_5' + 3x_2'x_4') / 13 \quad (11)$$

$$y_2 = 0 + (1 - 0)(9x_1' + 3x_3' + x_5' - x_1'x_5' + 3x_3'x_5') / 15 \quad (12)$$

$$y_3 = 0 + (1 - 0)(9x_1' + x_2' + 9x_3' + 3x_5' - x_1'x_2' - x_1'x_5' + 3x_3'x_5') / 23 \quad (13)$$

$$y_4 = 0 + (1 - 0)(3x_1' + 9x_2' + 3x_3' - x_4' - x_1'x_2' + 3x_2'x_4') / 16 \quad (14)$$

Assume that w_i , $i = 1, 2, 3, 4$ are the weights assigned to four critical design activities listed in Table 6. These weights are assigned to the critical design activities. Our goal is to determine the values of design process variables to maximize the combination of the quality indices of the critical activities. The optimization problem can be modeled as follows :

$$\begin{aligned} &\text{Maximize} && w_1y_1 + w_2y_2 + w_3y_3 + w_4y_4 && (15) \\ &\text{s.t.} && (11) - (14) && \\ &&& 0 \leq x_i' \leq 1 && \text{for } i = 1, 2, 3, 4 \end{aligned}$$

The objective function (15) is the weighted sum of the quality indices of the critical design activities. The expressions (11) - (14) form the constraints for the problem, where the relative design process variables used in these expressions have a range [0, 1]. The constraints (11) - (14) can be substituted to the objective function. The resulting constrained geometric programming problem can then be solved using standard techniques. The optimal solution to this problem are the values for the relative design process variables x_i' , $i = 1, 2, 3, 4$. These values can be mapped back on to their original ranges.

Example

Consider $w_1 = 10$, $w_2 = 35$, $w_3 = 20$, $w_4 = 15$

The resulting problem is:

$$\begin{aligned} &\text{Maximize} && 10y_1 + 35y_2 + 20y_3 + 15y_4 \\ &\text{s.t.} && (11) - (14) \\ &&& 0 \leq x_i' \leq 1 && \text{for } i = 1, 2, 3, 4 \end{aligned}$$

Substituting (11) - (14) to the objective function the following program is obtained:

$$\begin{aligned} &\text{Maximize} && 39.94x_1' + 10.38x_2' + 21.47x_3' - 1.71x_4' + 13.74x_5' \\ &&& -2.88x_1'x_2' - 4.63x_1'x_5' + 5.12x_2'x_4' + 11.6x_2'x_5' && (16) \\ &\text{s.t.} && 0 \leq x_i' \leq 1 && \text{for } i = 1, 2, 3, 4 && (17) \end{aligned}$$

The problem (16) - (17) is a signomial geometric programming problem (see Beightler, 1976 for further details).

The optimal solution for this problem is:

$$x_1' = 0.75, \quad x_2' = 0.93, \quad x_3' = 0.832, \quad x_4' = 0.1, \quad x_5' = 0.95$$

These values of the relative design process variables are then mapped on to their original ranges to obtain the best values for control variables as shown in Table 8.

Table 8. The Values of Variables Affecting the Quality of Critical Design Activities

	Variable	Best Value	Alternative Value
x1	Average level of expertise	6	6
x2	Average resource level	11	9
x3	Frequency of interaction between functional design groups	4	4
x4	Number of resource preemptions	10	10
x5	Number of information sources	9	7
Value of the Objective Function		68.1	59.33

The best set of values for the design process variables shown in Figure 8 indicate that for a fairly high quality performance of design activities, we need high level of expertise, high resource level, reasonable frequency of interaction among functional groups, small resource preemptions, and a high number of information sources. The value of the objective function in (16) is indicative of the overall quality of performance of critical activities. As shown in Table 8, if we slightly reduce the values of variables “Average resource level” (from 11 to 9) and “Number of information sources” (from 9 to 7), then the value of the objective function reduces from 68.1 to 59.33 (by almost 13 %). In this way, optimal values of the design process variables corresponding to a function of design process attributes, with a given set of qualitative relationships between them represented by the house of quality, are determined. This approach also further helps to determine the impact of change in values of design process variables involved on the overall quality of the performance of critical design activities.

5. SUMMARY

In this chapter, the relationships among design process attributes and variables were studied. The design process was represented with an IDEF3 model. Due to the randomness involved in the design process, qualitative relationships between design process attributes and the corresponding variables were established. These relationships were represented by the house of quality, and then transformed into quantitative relationships. It was shown that such quantitative relationships could be used to study the impact of design process variable on the design process attributes. The use of these

quantitative relationships as constraints in maximization of the desired function of the process attributes was discussed.

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QUESTIONS

1. What is the house of quality?
2. How the quality function deployment model differs from the process model?
3. What is common between the quality function deployment model and the process model?
4. What is the quality function deployment cascade? Define it for a product development process.
5. Why a four grade rather than a ten grade scale is used in QFD?

PROBLEMS

1. Transform number x from the interval $[0, 9]$ into number y from the interval $[6, 18]$.
2. Transform number x from the interval $[3, 9]$ into number y from the interval $[6, 18]$.
3. Figure A1 shows the relationship between customer requirements and subsystems of an electrical product in the form of a house of quality. The customer evaluations as well as the current (product model A) and desired (product model B) technical evaluations are provided in the house of quality.
The ranges for each requirement and each technical subsystem are identical integer numbers in the interval $[1, 5]$. The numerical scale for the relationships in the main QFD matrix is (strong positive = 9, medium positive = 3, weak positive = 1).

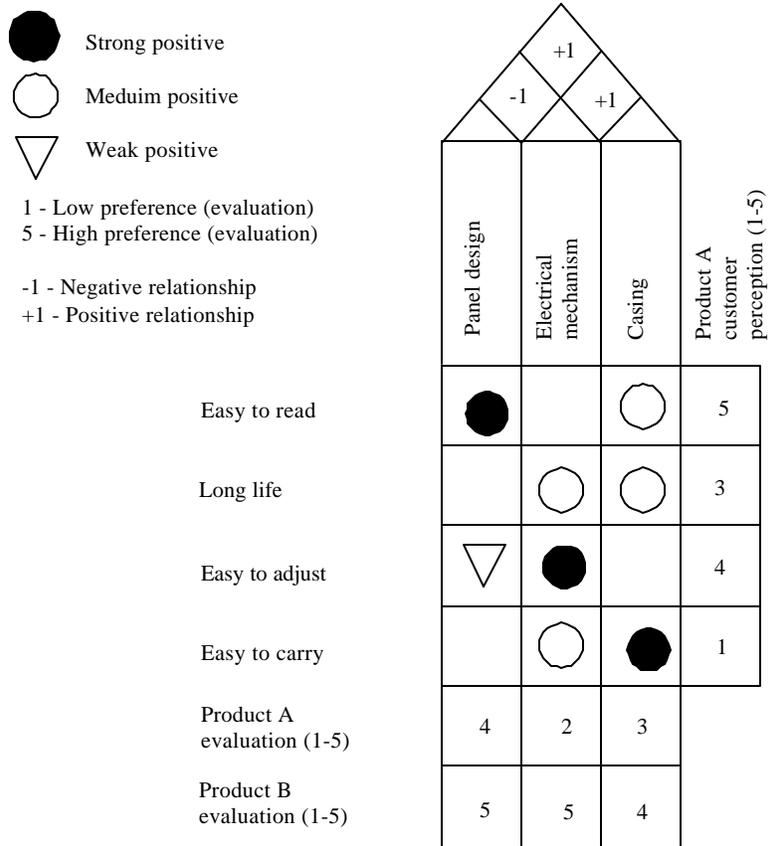


Figure A1. The house of quality for an electrical product

- (a) Determine the values of customer requirements that would meet the new levels of technical product evaluations
 - (b) For the following values of customer requirements [easy to read = 5, long life = 4, easy to adjust = 4, and easy to carry = 4], determine the level of technical product evaluations
4. Figure A2 shows the relationship between customer requirements and technical specifications of a consumer product. The range of values of the customer relationships is (0, 10). The range of values for technical specifications is as follow: Spec 1 (2, 12), Spec 2 (1, 10), Spec 3 (5, 15), and Spec 4 (10, 15).
 The weights associated with the customer requirements are as follows: Low weight (1), High reliability (3), High durability (2), and High functionality (5).

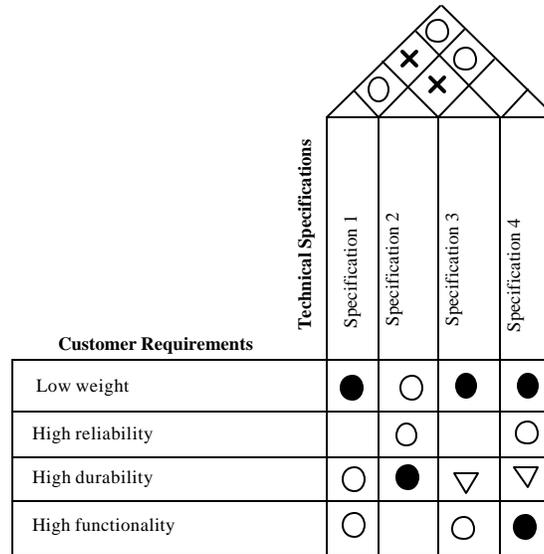


Figure A2. The house of quality of a consumer product

Assuming the usual values of the entries of QFD, formulate a mathematical programming model that maximizes the weighted total of customer requirements while meeting the ranges of values for the technical specifications.

- For the QFD table in Figure A3 for the door of an aircraft set up a model maximizing the total satisfaction of customer requirements. Hint: (1) assume the range for each technical characteristic, (2) assume that each customer requirement is equally important.

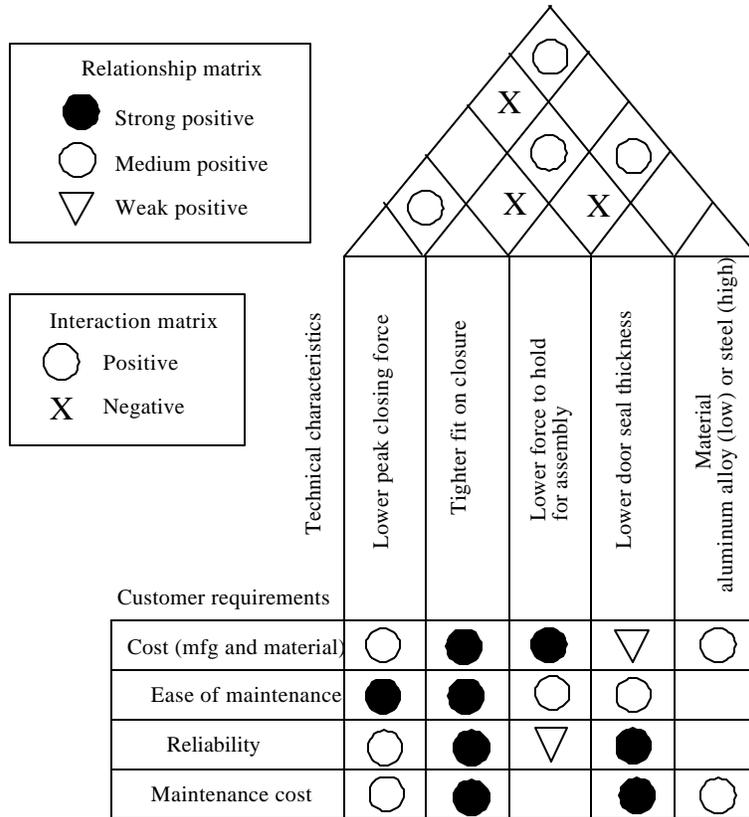


Figure A3. The QFD table for the door of an aircraft