EFFECTIVE PRODUCT AND PROCESS DEVELOPMENT USING QUALITY FUNCTION DEPLOYMENT

Rohit Verma

DePaul University

Todd Maher

DePaul University

Madeleine Pullman

Southern Methodist University

Introduction

Designing new products and/or modifying the attributes of existing products to satisfy the needs of customers in the marketplace has captured the attention of engineering, business, and product development researchers for the last several decades. Therefore, a number of books and journals continue to publish research articles highlighting different steps of the product development process (see e.g., Green and Krieger,[5] Ulrich and Eppinger,[10] Urban and Hauser,[11] and Wheelwright and Clark[12]). The national and international conferences of several professional organizations (e.g., Product Development and Management Association, American Production and Inventory Control Society, Decision Sciences Institute, Production and Operations Management Society) also conduct multiple sessions on designing and developing products based on customers preferences.

During recent years, quality function deployment (QFD) has been recognized as an effective method for product and process development.[1] Quality function deployment is a structured approach for integrating the *voice of the customer* into the product design/development process.[6-7] The purpose of QFD is to ensure that customer requirements are factored into every aspect of product development from planning to production floor. Quality function deployment uses a series of matrices, which look like houses, to deploy customer input throughout design, manufacturing, and delivery of products. The premise is that cooperation and communication among marketing, manufacturing, engineering, and R&D leads to greater new-product success.

As mentioned earlier, QFD connects the *voice of the customer* into the design, development, and production process. The *voice of the customer* is a generic term representing a hierarchical set of customer needs where each need (or set of needs) has assigned to it a priority, which indicates its importance to the customer. The first QFD matrix, called the *house of quality,* links the voice of the customer to the product design attributes (*voice of the engineer).* The second matrix (*design matrix)* of QFD links the design attributes to the product components or features. The *operating matrix* further links the product components to process decisions. And, finally, the *control matrix* links the operating processes to production planning and control decisions.

Since the publication of Hauser and Clausing's[7] article, the customer preferences aspect of QFD has received a lot of attention in the literature. A number of published articles have documented the benefits of using the *house of quality* and/or shown how to collect data for constructing the house of quality. For example, Griffin and Hauser6 present a comparison of different approaches for collecting customer preferences in QFD. Kim et al.[8] developed a decision support system for QFD using fuzzy multicriteria methodologies. Their models allow the product designer to consider tradeoffs among various customer attributes, as well as to simultaneously consider the inherent fuzziness in the associated relationships. Chakravarty and Ghose3 demonstrate the need and use of system theory-related paradigms for developing quantitative and qualitative models for tracking product/ process interactions in QFD.

Even though a number of publications stress the usefulness of the house of quality, none of the well-cited articles shows an example of the complete QFD process. To successfully integrate the voice of the customer into the product design and development process, it is critical that the house of quality information is translated downstream to the other three matrices. Both new and existing products are made of several components, which are manufactured by multiple processes. Completing all four matrices will allow managers to identify and control the critical process parameters and will therefore lead to effective product and process development. Therefore, this chapter explains the main ideas behind the QFD process and presents an extended example of the use of QFD in manufacturing electrical transformers. This example will show how customer preferences can be deployed throughout product design and process development using quality function deployment.

Quality Function Deployment Process

Mitsubishi's Kobe Shipyard is credited for developing and using QFD for the first time as a product/process design tool in 1972. Shortly thereafter, building on earlier efforts at Mitsubishi, Toyota developed advanced QFD concepts and has used the technique since 1977 with very impressive results. According to Evans and Lindsay,[4] between 1977 and 1979 Toyota realized a 20 percent reduction in startup costs on the launch of a new van. The startup costs were down 38 percent in 1982 and were down 61 percent in 1984, with respect to 1977 costs. Additionally, the new product development lead time for Toyota was reduced by one-third and the product quality improved dramatically. Since then, a number of companies in Japan, the United States, Europe, and the rest of the world have implemented QFD with good results. Xerox and Ford initiated the use of QFD in the United States in 1986. Since then, a number of leading companies, including General Motors, Motorola, Kodak, IBM, Procter & Gamble, AT&T,

and Hewlett-Packard, have successfully used QFD for product/process design and development.[4] An overview of the QFD process in presented in Table 12.1.

Figure 12.1 shows the relationship between the four QFD matrices. The QFD concepts presented in Table 12.1 and Figure 12.1 can be implemented for almost any manufacturing product and/or process. Here we present a QFD example for the design and manufacture of electrical transformers. This manufacturing company is located in the midwestern United States and will be refered to as Electric Equipment Company throughout the chapter.

TABLE 12.1 Quality Function Deployment Process

Step	Activity
1	Identification of customer needs and preferences
2	Relationship between customer needs and engineering design characteristics
3	Interrelationships between the engineering design characteristics
4	Competitive evaluation of competing products and targets for design attributes
5	Linking engineering design characteristics and component characteristics
6	Linking component characteristics and the process operations
7	Linking process operations and control parameters
8	Implementation and continuous improvement

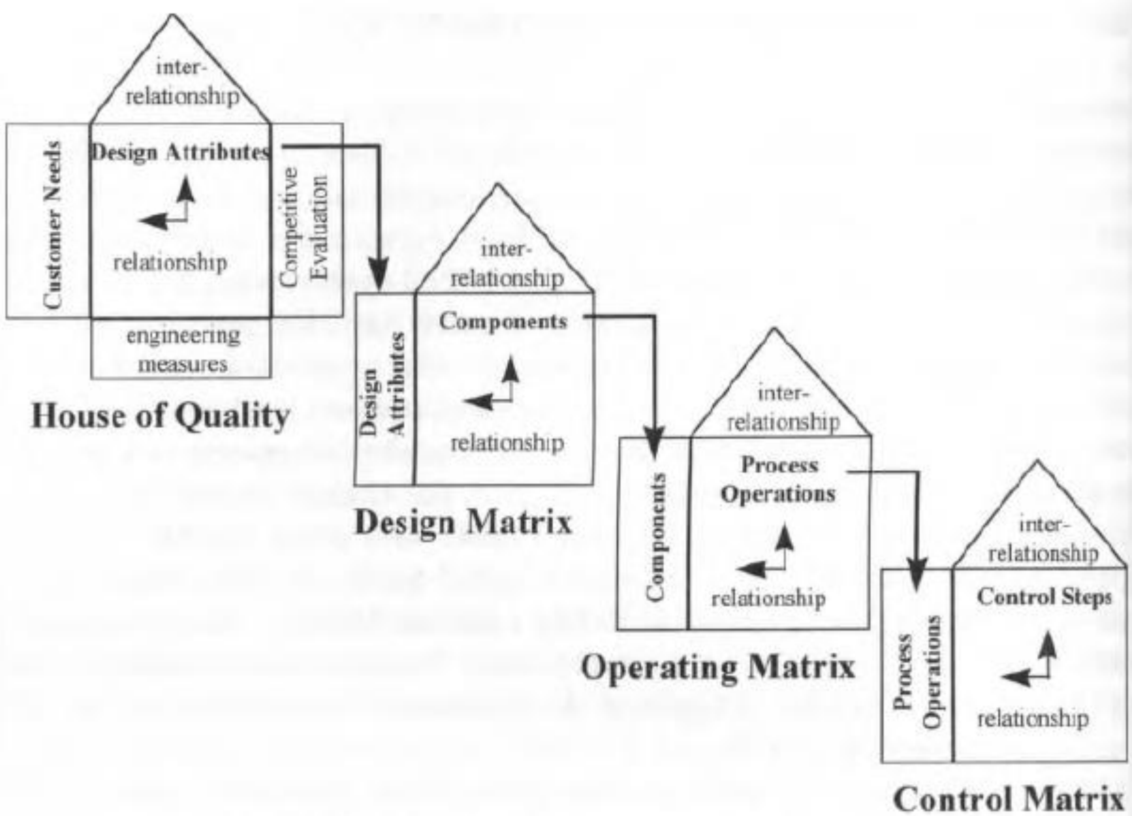


Figure 12.1 Quality function deployment process.

Electric Equipment Company (EEC) designs and manufactures custom ferroresonant (regulating) transformers, linear/isolation transformers, induc- tors/chokes, and mercury vapor ballasts. It has been in business for over 25 years, primarily in magnetic technology. Electric Equipment Company uses just-in-time (JIT)/continuous-flow production concepts in a cellular manufacturing environment, stressing the Kaizen philosophy of continuous improvement. The following sections show how QFD concepts were implemented at EEC.

Customer Needs and Preferences

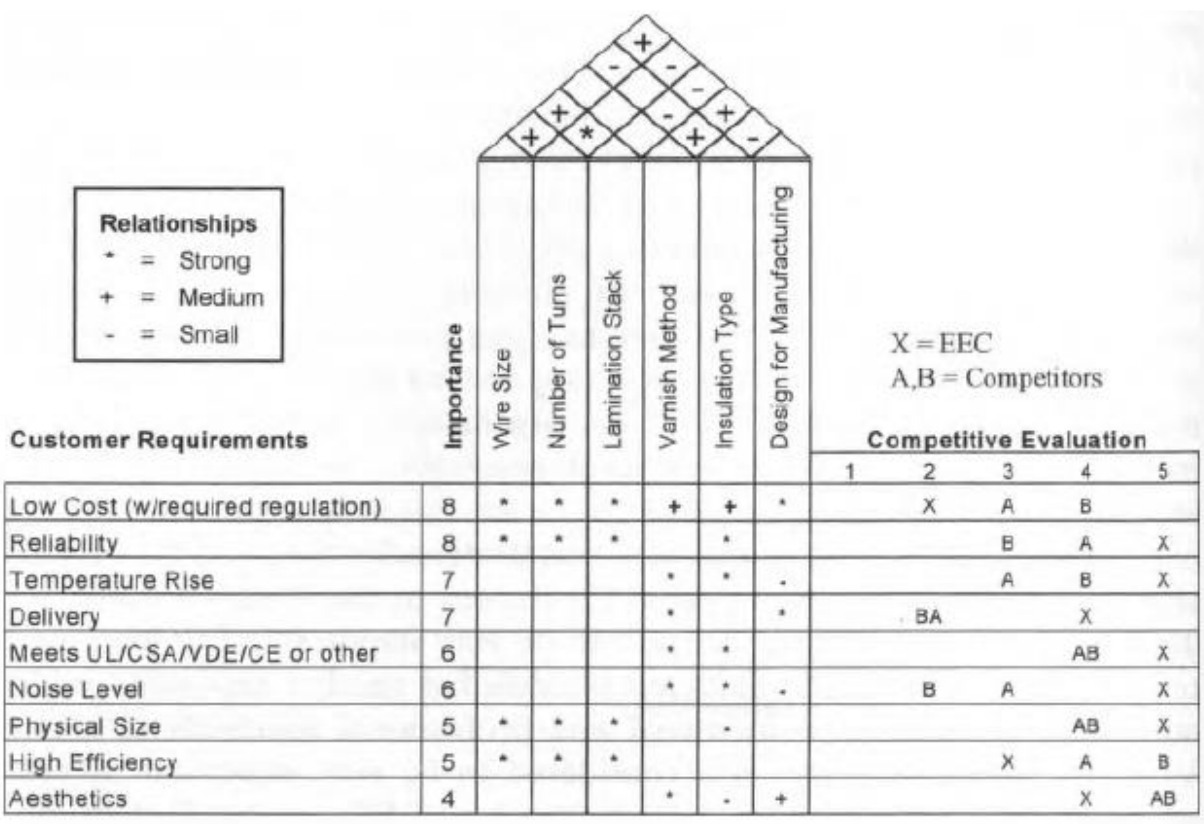
The QFD process starts with the identification of the needs of the customers. A customer need is a description, in the customer's own words, of the benefit to be fulfilled by a product. Identifying and prioritizing customer needs are extremely important for effective product development because, generally, consumers evaluate product(s) on more than one criterion.[2,9] Therefore, the QFD process starts with the collection of qualitative and/or quantitative information from the customer about his or her needs and preferences.

Companies can use a variety of methods or "listening posts" to collect information from customers. Griffin and Hauser[6] consider the gathering of customer information to be a qualitative task (including personal interviews, group interviews, and focus groups). In a typical study, between 10 and 30 customers are interviewed for approximately one hour each in a one-to-one setting. The interviewer probes the customer, searching for a better description of his or her needs. The interview ends when the interviewer feels that no new needs can be articulated from the customer. Group interviews and/or focus groups can also be used to identify the needs of customers. A focus group is a randomly selected panel of individuals who answer questions about a product(s) and discuss the attributes of the products that satisfy the customer needs. In a recent study, however, Griffin and Hauser6 found both person-to- person and focus groups to be equally effective in articulating customer needs.

The customer needs for EEC were determined jointly by staff members in the marketing, sales, and engineering divisions, as all three groups interact with the customer. The information was obtained through interviews, surveys, and brainstorming over several months. One production manager at EEC was responsible for information collection and for developing the four QFD matrices, while other members of the organization provided feedback (in individual or group settings) whenever necessary. The customers of EEC identified cost and product reliability to be the two most important attributes of the transformers. They emphasized that the transformers should be reliable and should conform to government regulations at the lowest possible cost. They also regarded on-time delivery to be very important. The low rate of temperature rise in transformers was identified as another important product attribute. Conforming to industrial and professional standards (UL/CSA/ VDE/CE and others) was also considered to be very important. Because several types of transformers manufactured by EEC are installed in other electronic products (e.g., the power supply for medical diagnostic equipment), a low noise level was very important to customers. Additionally, the customers identified efficiency, small size, and aesthetics as other important attributes.

After the identification of product attributes, it is important to prioritize them based on their relative importance to consumers. A number of quantitative techniques can be used in combination with the qualitative methods described previously to prioritize the customer needs. For example, marketing professionals have used rating and/or ranking methods to identify the relative importance of product attributes for a long time. Refer to the text by Urban and Hauser[11] for detailed discussions on various marketing research methods. Other techniques for prioritizing customer requirements include conjoint analysis and discrete-choice analysis, which are based on factorial experimental design procedures and econometric models.[2-9] Electric Equipment Company used traditional customer surveys in addition to qualitative information collected during interviews to prioritize customer requirements on a scale of 1 to 10 (1 = least important, 10 = extremely important). The project team chose not to use other sophisticated techniques (conjoint and/or discrete- choice analyses) because of time and resource constraints. The objective of this QFD project was to understand the relationships among customer preferences, design attributes, process operations, and control parameters. Therefore, the project team decided to first develop the four QFD matrices and understand the interrelationships between various product/process parameters before undertaking considerable quantitative data collection efforts.

Figure 12.2 shows a completed house of quality for transformer manufacturing. The prioritized customer information is presented on the left-hand side of the house on a scale of 1 to 10 (10 = extremely important, 1 = least important). For the sake of clarity, only the more



Customer Requirements	Importance	Wire Size	Number of Turns	Lamination Stack	Varnish Method	Insulation Type	Design for Manufacturing	Competitive Evaluation 1	2	3	4	5
Low Cost (w/required regulation)	8	*	*	*	+	+	*		X	A	B	
Reliability	8	*	*	*		*				B	A	X
Temperature Rise	7				*	*	-			A	B	X
Delivery	7				*		*		BA		X	
Meets UL/CSA/VDE/CE or other	6				*	*					AB	X
Noise Level	6				*	*	-		B	A		X
Physical Size	5	*	*	*		-					AB	X
High Efficiency	5	*	*	*						X	A	B
Aesthetics	4				*	-	+				X	AB

Figure 12.2 House of quality.

important attributes are presented in Figure 12.2. Cost and reliability were identified as the two most important attributes, followed by temperature and delivery performance. The next sections explain how these customer preferences were linked to the engineering design attributes of the transformer.

Engineering Design Characteristics

The information collected in the previous QFD step presents the prioritized needs of the customer. For effective product design and development, it is necessary to translate those customer requirements into the relevant engineering design attributes of the product. A careful analysis by members from the engineering, product development, manufacturing, and marketing departments is often necessary to identify all relevant product attributes that affect customer preferences.

An electrical transformer consists of metallic coil(s) (mostly copper or copper alloys) tightly wound over a stack of metallic lamination sheets. The finished transformer is used as a device for controlling electrical current and/ or voltage in the power module for various products (e.g., audio systems, medical equipment, and power supply lines). Even though the exact engineering specifications are different for different types of transformers, the following six product elements were identified (by the engineering staff at EEC) to be the most important for all types of transformers: wire size, number of wire turns, lamination stack size, varnish method, insulation type, and design for manufacturability. The wire size, the number of turns, and the lamination stack directly affect the properties of the electromagnetic field generated in the transformer. The varnish and insulation processes are required for controlling the quality of the transformer properties. Finally, it is necessary for the transformer design to be manufacturable.

The engineering design attributes are presented on the roof of the house of quality, as shown in Figure 12.2. Such an arrangement of customer preferences and engineering characteristics makes it very easy to graphically represent the relationship between the two sets of variables. The middle part of the house of quality (Fig. 12.2) shows the relationship between the customer preferences and engineering design attributes for EEC. For example, the wire size, number of turns, and lamination stack are strongly related to the cost, reliability, size, and efficiency of the transformer. Similarly, the varnish method strongly affects the temperature rise, aesthetics, and noise level of the transformer. Specific varnish methods are necessary to meet various industrial standards. Varnishing is a time-consuming process and therefore affects the delivery performance. The type of insulation used in the transformers strongly affects reliability, temperature rise, noise level, and conformance to industrial standards. The insulation is also related to cost and transformer size. Finally, design for manufacturability affects the cost and delivery performance and is also related to temperature rise, noise level, and aesthetics.

Interrelationships among Engineering Design Characteristics

For a majority of products, it is often difficult to change one engineering design attribute without affecting others. For example, transformer insulation is related to the varnish method used and vice versa. The roof of the house of quality presents such interrelationships among the engineering design attributes. The construction of the roof involves a careful engineering study of the design variables and an understanding of how one attribute affects the other. Companies can use a variety of methods to determine such interrelationships. Brainstorming sessions might be enough for identifying the relationships among a few variables, whereas others might require design experiments or analysis of production data. However, the exact choice of the method depends on the specific product and the processes used to manufacture it. At EEC the interrelationships were identified jointly by the engineering and manufacturing staff. Formal experiments were not conducted but production data for the last few months were analyzed. For example, the relationship between the number of turns and the lamination stack is strongest among the engineering attributes. Figure 12.2 shows other medium and small relationships among the engineering attributes.

Competitive Evaluation

This step includes identifying existing competing products and evaluating them for each of the customer preferences. Such evaluation helps in highlighting the relative strengths and weaknesses of the current product offerings and provides directions for improvements to the product development personnel. It also gives an opportunity to identify the "selling points." For example, the right-hand side of Figure 12.2 shows the competitive evaluation of transformers manufactured by EEC (labeled *X)* and two of its major competitors *(A* and *B*) on a scale of 1 to 5 (5 = best, 1 = worst). The competitive evaluation of the customer requirements was conducted by feedback received from customers by sales, engineering, and quality control staff. The evaluation of the technical requirements was completed by performing a benchmarking study, as well as by customer feedback. The transformer manufactured by EEC is better than its competitors for almost all customer-based attributes except cost and efficiency. The delivery performance and low noise level for EEC transformers are much better than its competitors and therefore are "selling points" for the company. Because EEC's transformers have better quality than that of its competitors in more than one dimension, it can target its products to the high end of the market.

The "basement" of the house of quality presents the engineering targets for process improvement. This space can also be utilized to develop a competitive evaluation of the competing products on the basis of engineering design attributes. Often this step involves benchmarking and/or "reverse engineering" the competitors' products. The target levels and competitive engineering evaluation further provide guidelines for translating customer information to the rest of the product/process development procedures. The EEC manufacturing staff evaluated the engineering design attributes by performing a benchmarking study. *(Note:* Because of the proprietary nature of the engineering process, Figure 12.2 does not show the completed "basement" for transformer manufacturing at EEC.)

The preceding four steps complete the first QFD matrix: the house of quality. Next we present a description of completing the other three QFD matrices.

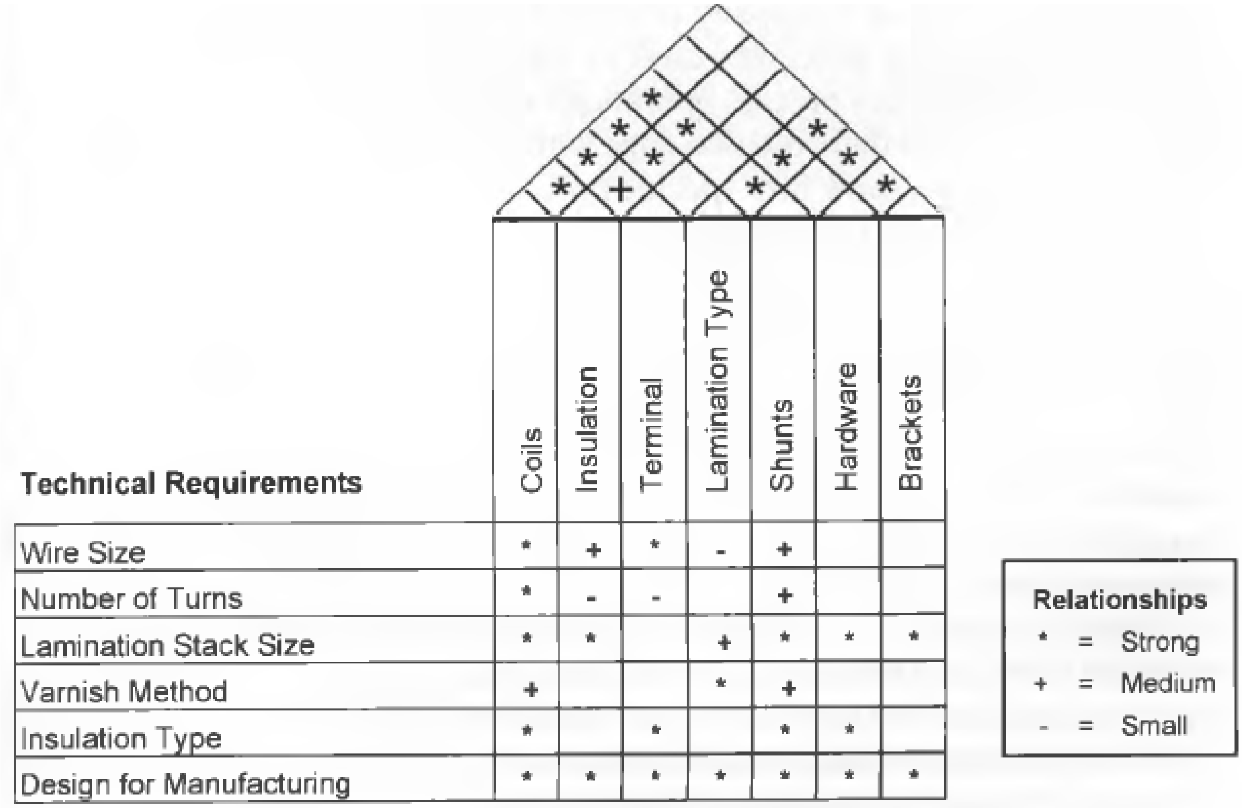
Design Matrix

The second QFD matrix, the *design matrix,* links the engineering design attributes to the individual components of the product. This matrix can be constructed either for all engineering design attributes (from the house of quality) or for a selected few important attributes. Similar to the house of quality, the design matrix requires a careful analysis of the product, its components, and manufacturing processes. The roof of the design matrix presents the interrelationships among the component characteristics. Similar to the house of quality, the basement of the design matrix can be used for engineering targets for the components.

The design matrix for EEC was constructed by determining the component characteristics of the transformer and comparing those characteristics with the engineering design requirements of the house of quality. The engineering department was primarily responsible for determining the component characteristics. The next step was to determine the relationships between design requirements and the component characteristics, followed by the interrelationships among the component characteristics. Designing a transformer always involves trade-offs and, by constructing this matrix, engineering can make design decisions based on how they will affect the attributes that are important to the customer.

Figure 12.3 shows a completed design matrix for transformers. The engineering team at EEC identified the following seven components, which are related to the design characteristics: coils, insulation, terminal, lamination type, shunts, hardware components, and brackets. The type of coils used in the transformer affects all of the engineering design characteristics. For example, the coil type determines the size of the wire and how many turns it should be wound on a lamination stack of a given size; the insulation material used depends on the size of the lamination stack; the type of electrical terminal attached to the transformer is associated with wire size and insulation type; the lamination type used determines the varnish method and insulation type; and so on. The roof of the design matrix presents the interrelationships among the transformer components. As shown in Figure 12.3, coils, lamination type, and brackets are related to most of the other components.

The design matrix shows how the components affect and are affected by each other and by the design requirements of a product. By understanding these relationships, management can effectively trade off the less important attributes for the more relevant ones. For example, Figure 12.3 shows that the type of coils used is related to most of the engineering design attributes and also to the other components. Therefore, the selection of appropriate coils should precede the selection of other components. Similar analyses can also be conducted for other components. In other words, the design matrix effectively breaks down each product into its components. Because individual components are fabricated and assembled at manufacturing stations, the design matrix eliminates the need for directly linking each product with each production process. The next two sections show how components can be linked to the process operations and to the control parameters.



Technical Requirements	Coils	Insulation	Terminal	Lamination Type	Shunts	Hardware	Brackets
Wire Size	*	+	*	-	+		
Number of Turns	*	-	-		+		
Lamination Stack Size	*	*		+	*	*	*
Varnish Method	+			*	+		
Insulation Type	*		*		*	*	
Design for Manufacturing	*	*	*	*	*	*	*

Figure 12.3 Design matrix.

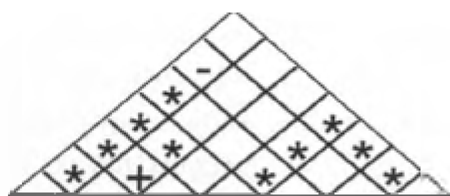
Operating Matrix

The third QFD matrix, the *operating matrix,* connects the components to the key process operations. Usually, the manufacturing staff (managers, production supervisors, line workers) are actively involved in the process of developing this matrix. It is interesting to note that for a large variety of industries the same basic process operations manufacture all the components. The same processes are mixed and matched in various configurations to generate the product line for a company. Therefore, identifying the critical processes and linking them to the components (from the design matrix) allows managers to connect the customer requirements (from the house of quality) directly to the manufacturing operations. In other words, the operating matrix provides a road map from plant level operations to the customer needs.

Electric Equipment Company developed the third matrix by determining the critical operating processes used to manufacture the components of the transformers. Once key process operations were identified, their interrelationships (the roof) and their relationships with the components were developed. These relationships show how specific processes are related to each other and to various transformer components.

Transformer manufacturing at EEC involves seven key processes: winding process, coil finishing, lamination assembly, lamination test, varnish process, final assembly, and final test. For example, the winding process involves taking the appropriate type and size of wire and winding it (to a prespecified length) on a lamination stack. Similarly, the lamination assembly process requires a specified number of precut lamination sheets of a given size and shape. The varnish process involves baking the coil assembly at a high temperature in a large oven for several hours.

Figure 12.4 shows the completed operating matrix for transformer manufacturing at EEC. It shows that the winding process strongly affects the coils, the insulation, and the lamination type used. The lamination assembly process is the only process related to all components and therefore requires special attention. It can be clearly seen from Figure 12.4 that all components are related to more than one process. We believe that the development of



Component Characteristics	Winding Process	Coil Finishing	Laminationa Assembly	Lamination Test	Varnish Process	Final Assembly	Final Test
Coils	*	*	*	+	-		+
Insulation	*	*	*	*	*	-	+
Terminal	+	*	-	+		*	*
Lamination Type	*	*	*	+	*		-
Shunts	+	+	*	*			+
Hardware			*			*	
Brackets			*		-	+	

Relationships		
*	=	Strong
+	=	Medium
-	=	Small

Figure 12.4 Operating matrix.

the operating matrix is the key to successful product/process development because it translates the requirements into the actual processes used to manufacture components.

Additionally, because a few key processes are used to manufacture a multitude of components, the control of these operations will lead to effective operations management. The last QFD matrix (the controls matrix) develops the control parameters for the key processes.

Control Matrix

The role of the fourth QFD matrix, the *control matrix,* is to develop specific quality control plans for the key operating processes (from the operating matrix). Developing control parameters for the key process operations is necessary for effective operations management because these processes manufacture the components for the products that satisfy the customer needs. A careful analysis of the processes and the identification of critical operating parameters are necessary to develop this matrix. A good control matrix is more than just a small part of a large method—it is the first step toward the process of continuous improvement.

Seven critical control points were determined for transformer manufacturing at EEC: coil dimensions, terminals check, winding turns test, mechanical requirements check, electrical testing, varnish curve plot, and final testing. These control parameters are universal to all types of transformers manufactured by EEC. For example, the winding turns test ensures that the length of the coil equals the specifications. This is very important because the coil length determines the electromagnetic properties of the transformer. Similarly, the critical baking process is monitored by the varnish curve plot, which shows how the coil temperature changes inside the oven.

Based on the key process operations and the relevant control parameters, a control matrix was developed by EEC, as shown in Figure 12.5. Except the varnish process, which is monitored by the curve plot, all other processes have multiple control parameters. For example, the critical winding turns test is related to the winding process, the coil finishing process, the lamination assembly, and the lamination test. In other words, a “pass” in the winding turns test confirms that the previous four processes were operating within established parameters.

The control matrix is very valuable for process improvement because it identifies the parameters that can and should be monitored for effective operations management. For example, from the completed control matrix, EEC determined the most important areas to work on were the winding turns test, electrical testing, and final testing. The need to test the turns of the windings in the winding process caused EEC to look at the existing equipment and determine a method to check turns in the coil-winding process. This led to the development of a programmable handwinding machine that not only checks turns in the windings, but also automatically slows down and stops the machine after the required number of turns. Ensuring that the number of turns is correct (as the coil is being wound) eliminates the need to check the coils after they have been wound. This improvement drastically improved the quality of the winding process and virtually eliminated all defects associated with it.

Recognizing the need for further improvement, the autowinding process was also enhanced. The house of quality pointed out that delivery was important to the customer and that EEC was ahead of its competitors in that area. The previous method of autowinding required an average of 10 minutes to change over from one coil to another. By improving the equipment being used and by modifying the autowinding machine, the changeover currently takes approximately 90 seconds (one-piece flow). Flence, by implementing one-piece flow, the lead time has been reduced, improving delivery performance to the customer. The quality has improved by eliminating batch processing and the work in process. In addition, the process is now more visual and it is easy to determine were there is a problem in the process.

Continuous Improvement

Development of the four QFD matrices is only the beginning of an effective product development process. To continuously meet and exceed a customer's needs at a reasonable price, a company must constantly monitor its operations and strive for improvement. A completed QFD process provides a clear snapshot of the current state of operations from customer needs to product design to process operations. It provides directions for further improvement. However, in order to be the market leader in the future, a company needs to focus on identifying ways to improve its processes. Over the last 10 years or so, a number of process improvement methods and techniques have been identified, which can be easily implemented in combination with, QFD.[4] These methods include management and planning tools (e.g., affinity diagram, interrelationship digraph, tree diagram, prioritization matrices, matrix diagram, process decision program chart, and activity network diagram), continuous improvement tools (e.g., cause-and-effect diagram, run chart, scatter diagram, flowchart, Pareto diagram, histogram, and control chart), and creative thinking tools (e.g., problem definition, brainstorming, brainwriting, mindmapping, word-and-picture association, advanced analogies, and morphological chart).

Conclusions

This chapter presented an overview of the quality function deployment process and showed how it can be implemented for product/process development of a relatively complex electronic product. We reviewed the basic QFD concepts and provided a step-by-step guideline from identifying customer needs to developing critical control points.

As shown in this chapter, QFD provides valuable information with respect to the design and development of products and processes in a very systematic manner. The first QFD matrix, the house of quality, not only shows hierarchical customer needs and their relation to design attributes but also presents an evaluation of competing products and identifies the selling points for a given product. The second QFD matrix extends the design attributes to the components of the products. As discussed earlier in the chapter, the third and fourth QFD matrices provide very useful information relating to the development/ identification of key processes and control parameters.

A number of companies in Japan, the United States, and Europe have used the QFD process and have witnessed improved results. As a final note, we would like to point out that QFD should not be considered a “tactical” method but a “framework” for effective product/process development. The minor details about the individual matrices are not as important as identifying the key relationships, which link the customer needs to various aspects of the product development process.

Acknowledgement

The authors would like to thank the electrical transformer manufacturing company (referred to as EEC in this chapter) for allowing them to conduct and publish the research described in this chapter. Partial funding for this research was provided jointly by APICS E&R Foundation and the Marketing Science Institute.

References

1. Akao, Y., 1994, *Quality Function Deployment: Integrating Customer Requirement into Product Design,* Productivity Press, Portland.

2. Ben-Akiva, M., and S. R. Lerman, 1991, *Discrete Choice Analysis, MIT Press, Boston.*

3. Chakravarty, A. K., and S. Ghose, 1993, Tracking Product-Process Interactions: A Research Paradigm, *Production and Operations Management,* Vol. 2, pp. 72-93.

4. Evans, J. R., and W. M. Lindsay, 1996, *The Management and Control of Quality,* 3rd ed., West Publishing, New York.

5. Green, P. E., and A. M. Krieger, 1989, Recent Contributions to Optimal Product Positioning and Buyer Segmentation, *European J. Oper. Res.,* Vol. 41, pp. 127-141.

6. Griffin, A., and J. R. Hauser, 1993, The Voice of the Customer, *Marketing Sci.,* Vol. 12, pp. 1-27.

7. Hauser, J. R., and D. Clausing, 1988, The House of Quality, *Harvard Business Rev.,* Vol. 66, pp. 63-73.

8. Kim, K., H. Moskowitz, A. Dhingra, and G. Evans, 1993, Fuzzy Multicriteria Methodologies and Decision Support System for Quality Function Deployment, Working Paper, Purdue University.

9. Louviere, J. J., 1988, *Analyzing Decision Making: Metric Conjoint Analysis,* Sage, Newbury Park, CA.

10. Ulrich, K. Y., and S. D. Eppinger, 1995, *Product Design and Development,* McGraw-Hill, New York.

11. Urban, G. L., and J. R. Hauser, 1993, *Design and Marketing of New Products,* 2nd ed., Prentice-Hall, Englewood Cliffs, NJ.

12. Wheelwright, S. C., and K. B. Clark, 1992, *Revolutionizing Product Development: Quantum Leaps in Speed, Efficiency and Quality,* Free Press, New York.