CHAPTER 6

Understanding the Problem and the Development of Engineering Specifications

KEY QUESTIONS

- Why emphasize developing engineering specifications?
- How can you identify the "customers" for a product?
- Why is it so important to understand the voice of the customer and work to translate this into engineering specifications?
- How can you best benchmark the competition to understand design and business opportunities?
- How can you justify taking time at the beginning of a project to do specification development instead of developing concepts immediately?

6.1 INTRODUCTION

Understanding the design problem is an essential foundation for designing a quality product. "Understanding the design problem" means to *translate customers' requirements into a technical description of what needs to be designed.* Or, as the Japanese say, "Listen to the voice of the customer." This importance is made graphically clear in the cartoon shown in Fig. 6.1. Everyone has a different view of what is needed by the customer and it takes work to find out what this really is.

Surveys show that poor product definition is a factor in 80% of all time-to-market delays. Further, getting a product to market late is more costly to a company than being over cost or having less than optimal performance. Finding the "right" problem to be solved may seem a simple task; unfortunately, often it is not.

Besides finding the right problem to solve, an even more difficult and expensive problem for most companies is what is often called "creeping specifications."

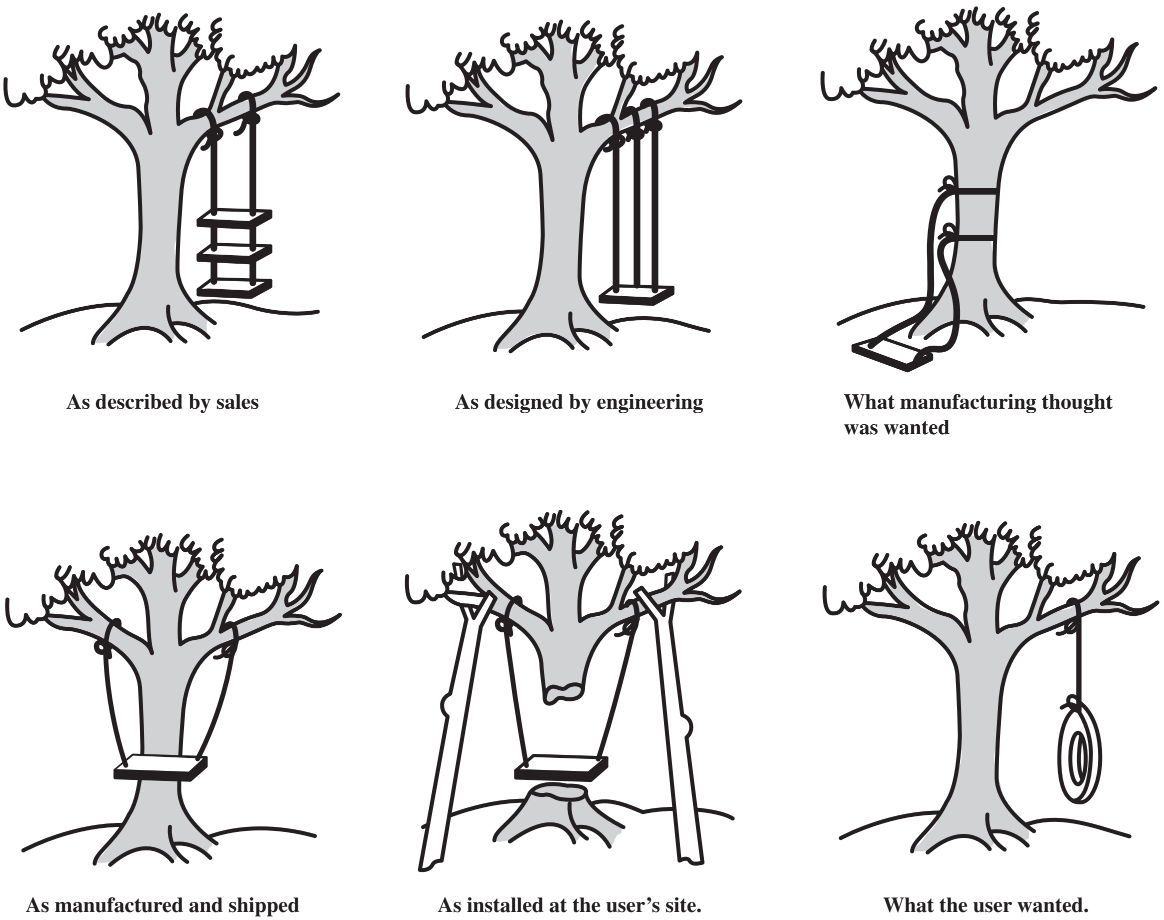


Figure 6.1 Understanding the product need.

Creeping specifications change during the design process. It is estimated that fully 35% of all product development delays are directly caused by such changes. There are three factors that cause creeping specifications. First, as the design process progresses, more is learned about the product and so more features can be added. Second, since design takes time, new technologies and competitive products become available during the design process. It is a difficult decision whether to ignore these, incorporate them (i.e., change the specifications), or start all over (i.e., decide that the new developments have eliminated the market for what you are designing). Third, since design requires decision making, any specification change causes a readdressing of all the decisions dependent on that specification. Even a seemingly simple specification change can cause redesign of virtually the whole product. The point is that when specification changes become necessary, they should be done in a controlled and informed manner.

All design problems are poorly defined.

The importance of the early phases of the design process has been repeatedly emphasized. As pointed out in Chap. 1, careful requirements development is a key feature of an effective design process. In this chapter, the focus is on understanding the problem that is to be solved. The ability to write a good set of engineering specifications is proof that the design team understands the problem.

There are many techniques used to generate engineering specifications. One of the best and currently most popular is called *Quality Function Deployment (QFD).* What is good about the QFD method is that it is organized to develop the major pieces of information necessary to understanding the problem:

1. Hearing the voice of the customers
2. Developing the specifications or goals for the product
3. Finding out how the specifications measure the customers' desires
4. Determining how well the competition meets the goals
5. Developing numerical targets to work toward

The QFD method was developed in Japan in the mid-1970s and introduced in the United States in the late 1980s. Using this method, Toyota was able to reduce the costs of bringing a new car model to market by over 60% and to decrease the time required for its development by one-third. It achieved these results while improving the quality of the product. A recent survey of 150 U.S. companies shows that 69% use the QFD method and that 71% of these have begun using the method since 1990. A majority of companies use the method with cross-functional teams of ten or fewer members. Of the companies surveyed, 83% felt that the method had increased customer satisfaction and 76% indicated that it facilitated rational decisions.

Before itemizing the steps that comprise this technique for understanding a design problem, consider some important points:

1. No matter how well the design team thinks it understands a problem, it should employ the QFD method for all original design or redesign projects. In the process, the team will learn what it does not know about the problem.
2. The customers' requirements must be translated into *measurable design targets for identified critical parameters.* You cannot design a car door that is "easy to open" when you do not know the meaning of "easy." Is easiness measured by force, time, or what? If force is a critical parameter, then is "easy" 20 N or 40 N? The answer must be known before much time and resources are invested in the design effort.
3. The QFD method can be applied to the entire problem and any subproblem. (Note that the design of a door mechanism in the previous point is a subproblem in automobile design.)

4. It is important to first worry about *what* needs to be designed and, only after that is understood, to worry about *how* the design will look and work. Our cognitive capabilities generally lead us to try to assimilate the customers' functional requirements (what is to be designed) in terms of form (how it will look); these images then become our favored designs and we get locked onto them. The QFD procedure helps overcome this cognitive limitation.
5. This method takes time to complete. In some design projects, about one-third of the total project time is spent on this activity. Ford spends 3–12 months developing the QFD for a new feature. Experimental evidence has shown that designers who spend time here end up with better products and do not use any more total time when compared to others who do a superficial job here. Time spent here saves time later. Not only does the technique help in understanding the problem, it also helps set the foundation for concept generation.

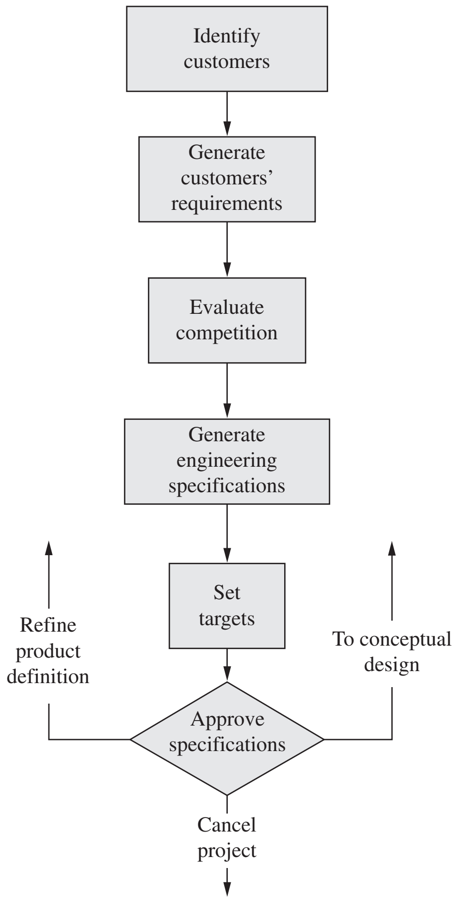


Figure 6.2 The Product Definition phase of the mechanical design process.

The QFD method helps generate the information needed in the engineering Product Definition phase of the design process (Fig. 4.1). That phase is reproduced in Fig. 6.2. Each block in the diagram is a major section in this chapter and a step in the QFD method.

Applying the QFD steps builds the *house of quality* shown in Fig. 6.3. This house-shaped diagram is built of many rooms, each containing valuable information. Before we describe each step for filling in Fig. 6.3, a brief description of the figure is helpful. The numbers in the figure refer to the steps that are detailed in the sections below. Developing information begins with identifying *who* (step 1) the customers are and *what* (step 2) it is they want the product to do. In developing this information, we also determine to whom the "what" is important—*who versus what* (step 3). Then it is important to identify how the problem is solved *now* (step 4), in other words, what the competition is for the product being designed. This information is compared to what the customers desire—*now versus what* (step 4 continued)—to find out where there are opportunities for an improved product. Next comes one of the more difficult steps in developing the house, determining *how* (step 5) you are going to measure the product's

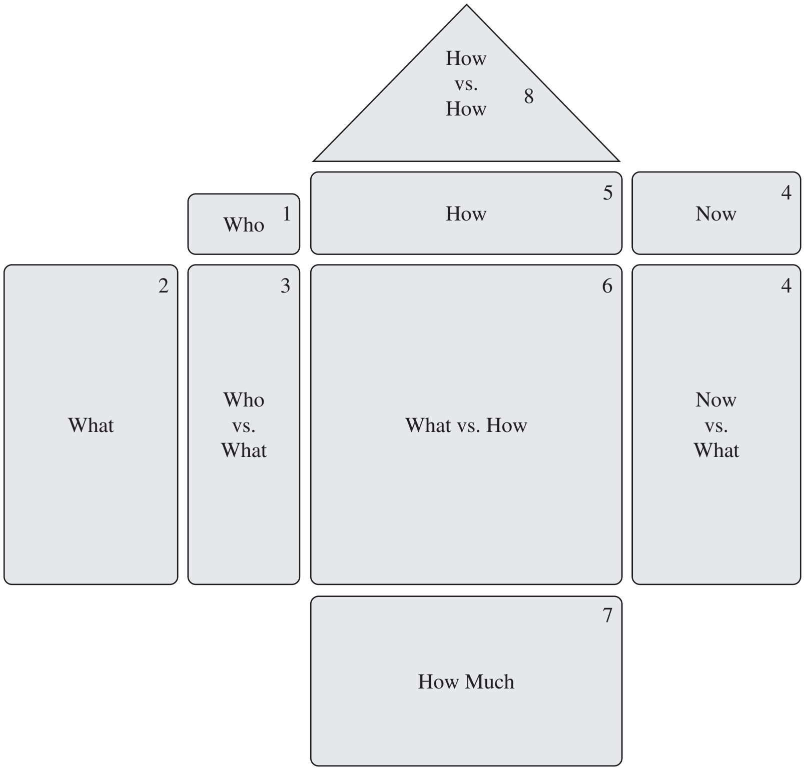


Figure 6.3 The house of quality, also known as the QFD diagram.

ability to satisfy the customers' requirements. The hows consists of the engineering specifications, and their correlation to the customers' requirements is given by *whats versus hows* (step 6). Target information—*how much* (step 7)—is developed in the basement of the house. Finally, the interrelationship between the engineering specifications are noted in the attic of the house—*how versus how* (step 8). Details of all these steps and why they are important are developed in Sections 6.2 through 6.9. Postage stamp-size versions of Fig. 6.3 tie the steps together.

The QFD method is best for collecting and refining functional requirements, hence the "F" in its name. However, in the material presented here, it will be used to help ensure that all requirements are collected and refined. In each step, the design of an "aisle chair" will be used as an example. This example is taken from a project to design a wheelchair to rapidly help passengers board and deplane from a Boeing 787 Dreamliner. This type of wheelchair is brought into the waiting area, the passenger transfers from their regular wheelchair to the aisle chair, which is then wheeled to the plane and down the aisle to the assigned seat where the passenger transfers out of the aisle chair into their seat. The process is reversed at the end of the flight. Aisle chairs are narrower than regular chairs so they can fit between the rows on an aircraft. A typical aisle chair is shown in Fig. 6.4.

The design effort for the Dreamliner chair resulted in the QFD shown in Fig. 6.5. This House of Quality developed during this project contained over 60 customer requirements and over 50 engineering specifications. This effort, although time consuming, resulted in the increased project understanding that was essential to develop a product that was superior to those already on the market.

The entire House is too large to read or make for a good example, so a reduced version of it will be used (Fig. 6.6). This example contains all the important points used in the larger, complete QFD. The contents of this house are developed in the following sections.

Figure 6.4 A typical aisle chair. (Reprinted with permission of Columbia Medical.)

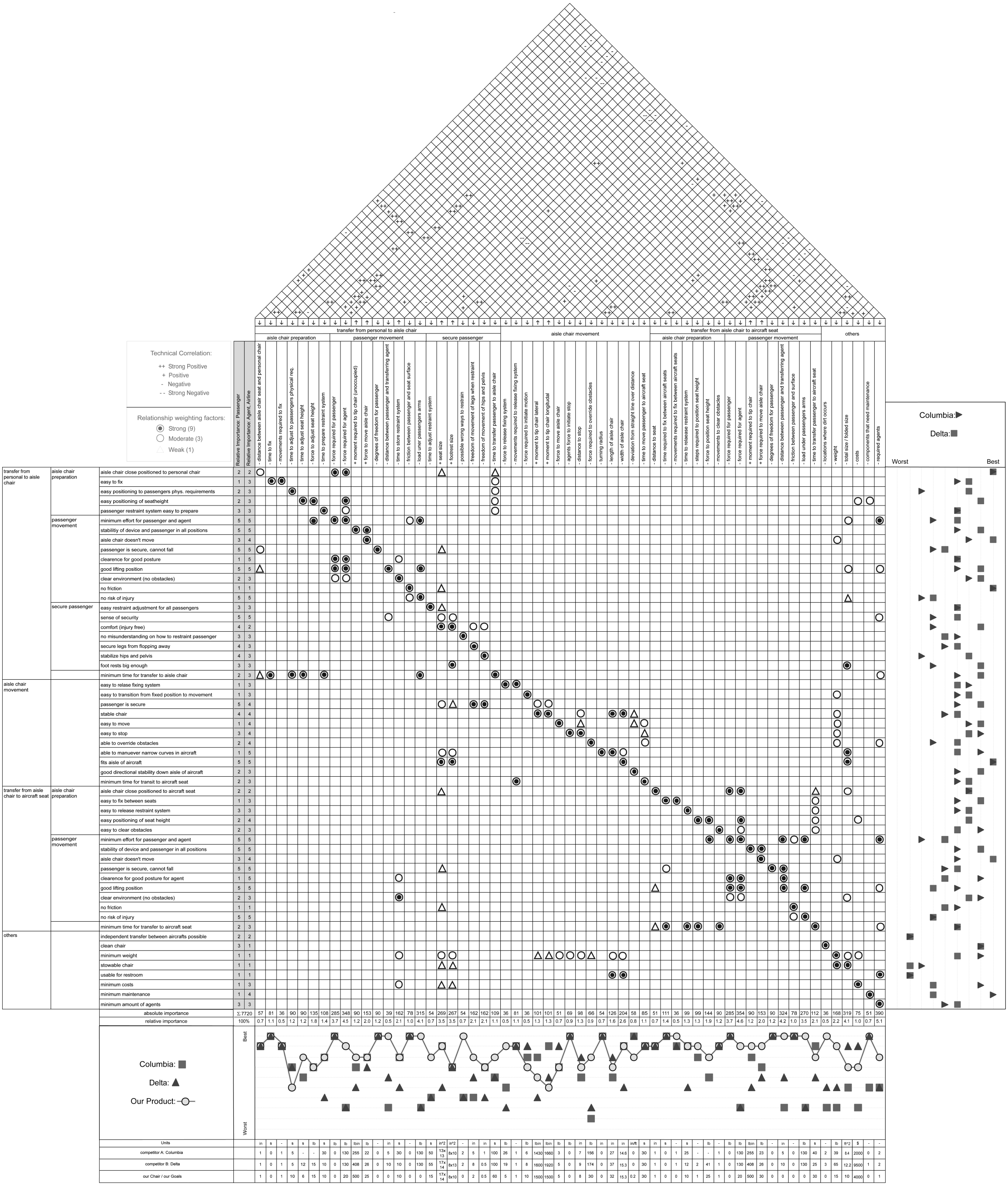
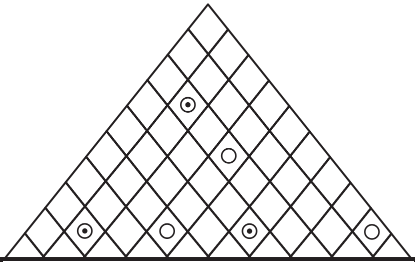


Figure 6.5 Aisle chair QFD (original available on book web site).



⊙ = 9
○ = 3
Δ = 1

1 = very bad
5 = very good

▶ Colub
■ Deltor

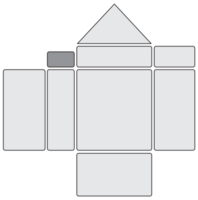
What			Who: Passenger	Who: Agent	How: Seat width relative to frame width	Steps to adjust seat height	Force to adjust seat height	Force to slide 95% male passenger	Lifting force required for agent	Push force over 2 cm bump	Force to push aisle chair	Time to transfer between seats	Fore/aft tipping force at handles	Side tipping force at handles	Now: 1	2	3	4	5
					↑	↑	↓	↓	↓	↓	↓	↓	↑	↑					
					%	steps	N	N	N	N	N	sec	N	N					
Transfer from personal to aisle chair	Aisle chair preparation	Easy positioning of seat height	4	4		⊙	⊙									▶	■		
		Easy to position chairs	6	10	⊙												▶ ■		
	Passenger movement	Minimum effort for all	15	10				⊙	⊙							■	▶		
		Good lifting position	10	12	○													▶	■
		Minimum time for transfer	3	14		Δ						⊙				▶ ■			
Aisle chair movement		Easy to move	7	8						⊙	⊙		○	○		■			▶
		Fits in aircraft aisle	-	-													▶	■	
		Good stability	24	10									⊙	⊙	▶	■			
Transfer from aisle chair to seat	Aisle chair preparation	Aisle chair close to aircraft seat	6	2	⊙											▶	■		
		Easy positioning of seat height	5	8		⊙	⊙										▶ ■		
	Passenger movement	Minimum effort for all	15	12		○	○				⊙					▶	■		
		Minimum transfer time	5	10		Δ						⊙				▶	■		
Importance (Passenger)					10	9	8	9	9	4	14	5	16	16					
(Agent)					11	13	11	7	7	5	14	16	8	8					
Colub					85	2	3	20	15	11	7	15	20	15					
Deltor					87	3	5	27	25	22	15	18	15	10					
Target (Delighted)					90	1	2	20	10	8	7	15	15	10					
Threshold (Disgusted)					85	2	4	25	15	12	10	18	20	12					

Figure 6.6 Example aisle chair QFD.

Your decisions, good or bad, affect everyone downstream.

The House of Quality can be easily built on a spreadsheet with the exception of the roof portion at the top. A simple method to construct this also on a spreadsheet is given in step 8.

6.2 STEP 1: IDENTIFY THE CUSTOMERS: WHO ARE THEY?



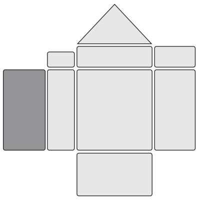
For most design situations, there is more than one customer; for many products, the most important customers are the consumers, the people who will buy the product and who will tell other consumers about its quality (or lack thereof). Sometimes the purchaser of the product is not the same as its user (e.g., gym equipment, school desks, and office desks). Some products—a space shuttle or an oil drill head—are not consumer products but still have a broad customer base.

For all products it is important to consider customers both outside the organizations that design, manufacture, and distribute the product—external customers—and those inside of them—internal customers. For example, beyond the consumer, the designer's management, manufacturing personnel, sales staff, and service personnel must also be considered as customers. Additionally, standards organizations should be viewed as customers, as they too may set requirements for the product. For many products, there are five or more classes of customers whose voices need to be heard.

One method to make sure you have identified all the customers is to consider the entire life of the product (see Fig. 1.7). Pretend you are the product; visualize all the people that encounter you as you go through the internal and external phases itemized in life cycle diagram.

For the aisle chair, the main customers are the passengers being transported and the airline agents who assist in transporting the passengers on and off the airplane. Note that neither of these two customers purchases the aisle chair. Nor do they maintain it, clean it, or disassemble it. In Fig. 6.6 the only customers shown are the passenger and agent as "who" examples. The area below the "passenger" and "agent" will be filled in during Step 3.

6.3 STEP 2: DETERMINE THE CUSTOMERS' REQUIREMENTS: *WHAT* DO THE CUSTOMERS WANT?



Once the customers have been identified, the next goal of the QFD method is to determine *what* is to be designed. That is, what is it that the customers want?

- Typically, as shown by the customer survey in Table 1.1, the *consumers* want a product that works as it should, lasts a long time, is easy to maintain, looks attractive, incorporates the latest technology, and has many features.

> You only think you know what your customers want.

- Typically, the *production customer* wants a product that is easy to produce (both manufacture and assemble), uses available resources (human skills, equipment, and raw materials), uses standard parts and methods, uses existing facilities, and produces a minimum of scraps and rejected parts.
- Typically, the *marketing/sales customer* wants a product that meets consumers' requirements; is easy to package, store, and transport; is attractive; and is suitable for display.

The key to this QFD step is collecting information from customers. There are essentially three methods commonly used: observations, surveys, and focus groups.

Fortunately, most new products are refinements of existing products, so many requirements can be found by *observing* customers using the existing product. For example, automobile manufacturers send engineers into shopping center parking lots to observe customers putting purchases into cars to better understand one aspect of car door requirements.

Surveys are generally used to gather specific information or ask people's opinions about a well-defined subject. Surveys use questionnaires that are carefully crafted and applied either through the mail, over the telephone, or in face-to-face interviews. Surveys are well suited for collecting requirements on products to be redesigned or on new, well-understood product domains. For original products or to gather the customers' ideas for product improvement, focus groups are best.

The *focus-group* technique was developed in the 1980s to help capture customers' requirements from a carefully chosen group of potential customers. The method begins by identifying seven to ten potential customers and asking if they will attend a meeting to discuss a new product. One member of the design team acts as moderator and another as note taker. It is also best to electronically record the session. The goal in the meeting is to find out what is wanted in a product that does not yet exist, and so it relies on the customers' imaginations. Initial questions about the participants' use of similar products are followed with questions designed to find performance and excitement requirements. The goal of the moderator is to use questions to guide the discussion, not control it. The group should need little intervention from the moderator, because the participants build on each other's comments. One technique that helps elicit useful requirements during interviews is for the moderator to repeatedly ask "Why?" until the customers respond with information in terms of time, cost, or quality. Eliciting good information takes experience, training, and multiple sessions with different participants. Usually the first focus group leads to questions needed for the second group. It often takes as many as six sessions to obtain stable information.

Later in the design process, surveys can be used to gather opinions about the relative merit of different alternatives. Observation and focus groups can be used both to generate ideas that may become alternatives and to evaluate alternatives. All these types of information gathering rely on questions formulated ahead of time. With a survey, the questions and the answers must be formalized. Both surveys and observations usually use closed questions (i.e., questions with predetermined answers); focus groups use open-ended questions.

Regardless of the method used, these steps will help the design team develop useful data:

Step 2.1: Specify the Information Needed Reduce the problem to a single statement describing the information needed. If no single statement represents what is needed, more than one data-collecting effort may be warranted.

Step 2.2: Determine the Type of Data-Collection Method to Be Used Base the use of focus groups, observations, or surveys on the type of information being collected.

Step 2.3: Determine the Content of Individual Questions A clear goal for the results expected from *each question* should be written. Each question should have a single goal. For a focus group or observation, this may not be possible for all questions, but it should be for the initial questions and other key questions.

Step 2.4: Design the Questions Each question should seek information in an unbiased, unambiguous, clear, and brief manner. Key guidelines are

Do not assume the customers have more than common knowledge.
Do not use jargon.
Do not lead the customer toward the answer you want.
Do not tangle two questions together.
Do use complete sentences.

Questions can be in one of four forms:

- Yes–no–don't know. (Poor for focus groups.)
- Ordered choices (1, 2, 3, 4, 5; strongly agree, mildly agree, neither agree nor disagree, mildly disagree, strongly disagree; or A = absolutely important, E = extremely important, I = important, O = ordinary, or U = unimportant [AEIOU]). Be sure that any ordered list is complete (i.e., that it covers the full range possible and that the choices are unambiguously worded). Scales with five gradations, as in the examples here, have proven best.
- Unordered choices (a, b, and/or c).
- Ranking (a is better than b is better than c).

The best questions ask about attributes, not influences. Attributes express what, where, how, or when. *Why* questions should lead to what, where, how, or when as they describe time, quality, and cost.

Step 2.5: Order the Questions Order the questions to give context. This will help participants in focus groups or surveys follow the logic.

Step 2.6: Take Data It usually takes repeated application to generate usable information. The first application of any set of questions should be considered a test or verification experiment.

Step 2.7: Reduce the Data A list of customers' requirements should be made in the customers' own words, such as "easy," "fast," "natural," and other abstract terms. A later step of the design process will be to translate these terms into engineering parameters. The list should be in positive terms—what the customers want, not what they don't want. We are not trying to patch a poor design; we are trying to develop a good one.

To gather information for the aisle chairs, focus groups of passengers were used. These began with a free discussion of people's experiences traveling by air. There is no way that an able-bodied person can understand the challenges of traveling when a wheelchair is involved, and once a group of wheelchair-bound travelers start trading stories, much is learned about what will be needed to make their experience tolerable. It is better that travel should be a "Wow" experience, as discussed in Kano's model (Section 4.4.2) than a "tolerated" experience. A similar focus group was held with agents. Finally, a researcher went to the airport and observed over 20 people boarding and off-loading using wheelchairs.

A sampling of the results of the focus groups and observations are (in no particular order)

- Easy positioning of seat height of the aisle chair so that it matches the wheelchair and the plane's seat so that the passenger can easily slide from on to the other.
- Once in the aisle chair it should be easy to move and stable.
- The aisle chair should fit in all aircraft aisles
- When transferring between chairs, the passenger with possibly some help from the agent must lift their weight enough to slide from chair to chair, so there needs to be a good lifting position for both of them so they can exert minimal effort.
- All want the transfer from seat to seat to be as fast as possible.
- It should be easy to position chairs next to each other and have them not slide apart.

To make sense of these results it is best to organize them into a hierarchical structure. In reviewing the observations it is evident that there are three main phases to the use of the aisle chair: (1) transfer the passenger from their personal wheelchair to the aisle chair, (2) move the aisle chair from the waiting area to the assigned seat, and (3) transfer the passenger from the aisle chair to the assigned seat. The same basic functions have to occur when deplaning. This is a simple form of functional modeling, which will be covered in detail in Chap. 7. Further, the action of transferring to the aisle chair requires two steps, prepare the chair and move the passenger. This decomposition of the function leads to a structure for organizing the results of voice of the customer. This can be organized like an outline (below) and also entered into the QFD as shown in Fig. 6.6.

Transfer from personal to aisle chair

1. Aisle chair preparation

   a. Easy positioning of seat height
   b. Easy to position chairs

2. Passenger movement

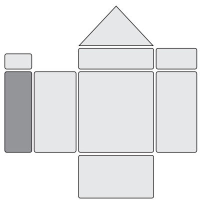
   a. Minimum effort for all
   b. Good lifting position
   c. Minimum time for transfer

Building a hierarchy like this can help you look for completeness. If the structure has discontinuities, these may be indicators of needed information. The aisle chair has only one major function and thus the hierarchy is fairly simple. Products that have multiple uses may have multiple hierarchies.

Suggestions to get the best possible customers' requirements

- #1—Do not assume you know what the customer wants.
- If customer requirements are too vague (e.g., product must be durable), then go back to the customer and flesh these out a little more in the customer's words. What is "durability"? Does that mean you can jump up and down on it? Does it mean that it lasts more than a minute?
- Frequently, customers will try to express their needs in terms of *how* the need can be satisfied and not in terms of *what* the need is. This limits consideration of development alternatives. You should ask *why* until you truly understand what the root need is. Do keep in mind that the only way they may have of expressing what they want is in terms of analogies and comparisons to other products.
- Use Kano's model to help you steer away from basic requirements to performance and excitement requirements.
- Break down general requirements into more specific requirements by probing what is needed.
- Challenge, question, and clarify requirements until they make sense and you can put them in an outline format—a hierarchy. This helps understand function and look for completeness.
- Document situations and circumstances to illustrate a customer need.

6.4 STEP 3: DETERMINE RELATIVE IMPORTANCE OF THE REQUIREMENTS: *WHO VERSUS WHAT*



The next step in the QFD technique is evaluating the importance of each of the customers' requirements. This is accomplished by generating a weighting factor for each requirement and entering it in Fig. 6.6. The weighting will give an idea of how much effort, time, and money to invest in achieving each requirement. Two questions are addressed here: (1) to whom is the requirement important? and (2) how is a measure of importance developed for this diverse group of requirements?

Since a design is "good" only if the customers think it is good, the obvious answer to the first question is, the customer. However, we know that there may be more than one customer. In the case of a piece of production machinery, the desires of the workers who will use the machine and those of management may not be the same. This discrepancy must be resolved at the beginning of the design process or the requirements may change partway through the job. Sometimes a designer's hardest job is determining whom to please.

The region of the house of quality labeled "who vs. what" in Fig. 6.3 is for the input of the importance of each requirement. It is essential to understand which requirements each type of customer thinks is important. Note that, in most cases, less than half of the requirements have most of the importance. The best way to represent importance is with a number showing its *weight* relative to the other requirements.

Traditionally, weighting has been done by instructing the customers to rate the requirements on a scale of 1 to 10 with 10 being important and 1 being unimportant. Unfortunately, often these methods result in everything being scored 8, 9, or 10—everything is important.

A better method, the fixed sum method, is to tell each customer that they have 100 points to distribute among the requirements. Using the fixed sum of 100 forces the customer to rate some of the requirements low if they want others to be high. This method works much better than just telling them to rate requirements on a scale of 1 to 10.

To aid in weighting, write each requirement on a piece of self-stick note paper, put the notes on a wall, and ask each customer to arrange them in order of importance. If two or more requirements seem to be equally important, be sure that they don't measure the same thing, that they are independent. Once the notes are in order, allocating the 100 points should be easier.

If there are more than 30 requirements, allocating weights can be very difficult. It is suggested that the large group of requirements be broken into smaller groups using the hierarchy, weighting each, and then renormalizing across all the requirements.

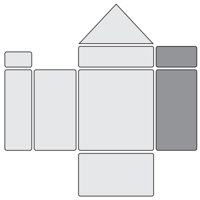
If you collect weightings from more than one representative of a customer group and they are in fairly good agreement with each other, then just average them. If weightings are significantly different from each other, then this is a signal that you have two different types of customers and you need to revisit the step 1.

The results of weighting the requirements for the aisle chair are shown in Fig. 6.6 for the passenger and the agent. The fixed sum method was used to set the weights. Note that the requirement "Fits in aircraft aisle" was not weighted. It was realized that this was a basic requirement (in Kano's terminology) as an

> One man's treasure is another's trash.
> Both will judge your work.

aisle chair that does not fit in the aisle is not a viable product. Requirements that measure basic needs are not helpful. Before you eliminate them, however, go back and ask if the requirement can be reworded so that it addresses performance or excitement. Also note that the passenger is more concerned about ease of use and the agent more focused on time. This is as expected.

6.5 STEP 4: IDENTIFY AND EVALUATE THE COMPETITION: HOW SATISFIED ARE THE CUSTOMERS *NOW*?



The goal here is to determine how the customer perceives the competition's ability to meet each of the requirements. Even though you may be working with a totally new design, there is competition, or at least products that come close to filling the same need that your product does. The purpose for studying existing products is twofold: first, it creates an awareness of what already exists (the "now"), and second, it reveals opportunities to improve on what already exists. In some companies, this process is called *competition benchmarking* and is a major aspect of understanding a design problem. In benchmarking, each competing product must be compared with customers' requirements (now versus what). Here we are concerned only with a subjective comparison that is based on customer opinion. Later, in step 8, we will do a more objective comparison. For each customer's requirement, we rate the existing design on a scale of 1 to 5:

1. The product does not meet the requirement at all.
2. The product meets the requirement slightly.
3. The product meets the requirement somewhat.
4. The product meets the requirement mostly.
5. The product fulfills the requirement completely.

Though these are not very refined ratings, they do give an indication of how the competition is perceived by the customer.

This step is very important as it shows opportunities for product improvement. If all the competition rank low on one requirement, this is clearly an opportunity. This is especially so if the customers ranked that specific requirement highly important in step 3. If one of the competitors meets the requirement completely, this product should be studied and good ideas used from it (note patent implications as discussed in Section 7.5).

If your organization already makes a product and you are redesigning this product, then the current product is one benchmark. If it ranks high on an important requirement, don't change the features that helped it meet that requirement. In

> To steal from one person is plagiarism, to be influenced by many is good design.

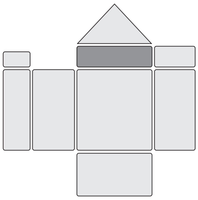
other words—Don't fix what aint broken! This step in the QFD method can help avoid needless work and product weakening.

The results of this step for the aisle chair are shown in Fig. 6.6. Here two competitor's chairs were evaluated (note that names have been changed). To determine how well the competitors met the requirements, the design team used questionnaires to evaluate them. The average results from passengers are shown in the "now vs. what" section of Fig. 6.6.

Important points to note are that

1. Both competitors have good lifting position when transferring the passenger from the personal chair to the aisle chair—study what makes this work well.
2. Both products have poor stability. Clearly, this is a market opportunity.
3. The Colub is easy to move and Delton is not, need to determine why and do what Colub does or better.
4. For most of adjustment requirements, neither of the competitors score above 3, leaving room for the development of a superior product in these areas.

There used to be a commercial on television for a family van in which the manufacturer bragged that its product was so good that one of its competitors bought and studied it. The commercial showed the competitor's technicians in white coats disassembling the van. What the commercial did not say was that the advertiser also bought and studied its competitor's product and that this is just good design practice.



6.6 STEP 5: GENERATE ENGINEERING SPECIFICATIONS: *HOW* WILL THE CUSTOMERS' REQUIREMENTS BE MET?

The goal here is to develop a set of *engineering specifications* from the customers' requirements. These specifications are the restatement of the design problem in terms of parameters that can be measured and have target values. Without such information the engineers cannot know if the system being developed will satisfy the customers. Engineering specifications consist of parameters of interest and targets for parameters. The parameters are developed in this step, and the target values for them are developed in step 8. In reality this step and the following one happen concurrently as will be made clear.

These specifications are a translation of the voice of the customer into the voice of the engineer. They serve as a vision of the ideal product and are used as criteria for design decisions. Conversely, this part of the QFD also builds a picture

> Find the target before you empty your quiver.

of how design decisions affect the customer's perception of the quality of their product. We will make use of this in Chap. 10, where the effect of trading off the ability to meet one specification for the inability to meet another is addressed.

In this step, we develop parameters that tell *how* we know if customers' requirements have been met. We begin by finding as many engineering parameters as possible that indicate a level of achievement for customers' requirements. For example, a requirement for "easy to attach" can be measured by (1) the number of steps needed to attach it, (2) the time to attach it, (3) the number of parts, and (4) the number of standard tools used. Note that a set of units is associated with each of these measures—step count, time, part count, and tool count. *If units for an engineering parameter cannot be found, the parameter is not measurable and must be readdressed.* Each engineering parameter must be measurable and thus must have units of measure. However, "time to attach" may not be a reliable measure as it will be dependent on the skill and training of the customer. Either the customer's skill level needs to be defined or this parameter eliminated.

An important point here is that every effort must be made to find as many ways as possible to measure customers' requirements. If there are no measurable engineering parameters for customers' requirements, then the customer's requirement is not well understood. Possible solutions are to break the requirement into finer independent parts or to redo step 2 with specific attention to that specific requirement.

When developing the engineering specifications, carefully check each entry to see what nouns or noun phrases have been used. Each noun refers to an object that is part of the product or its environment and should be considered to see if new objects are being assumed. For example, if one specification in the aisle chair problem was for "easy to adjust seat height" then an adjustable seat height (a noun phrase) has been assumed as part of the solution. If the design team has made a decision that there is to be an adjustable seat height, this is acceptable. However, if no such assumption has been made, the product solution has been unknowingly limited. Paying attention to the objects that are part of the product is a major topic in concept generation.

Also shown on Fig. 6.6 are the units for each specification and the direction of improvement—the "sense" where either more is better (↑) or less is better (↓). These arrows tell whether more of the feature or parameter measured good, or bad. For example less "force required for agent" is good (↓). More "side tipping force" is desired (↑). A third option, not shown in the example is whether a specific target is best. Targets will be further discussed in step 7.

To help find specifications a checklist of the major types is given in Table 6.1. Comparing this list with the list of specifications developed for a product can reveal missing information. The major types of specifications in this list are detailed next.

Table 6.1 Types of engineering specifications

Functional performance	Life-cycle concerns (continued)
Flow of energy	Diagnosability
Flow of information	Testability
Flow of materials	Reparability
Operational steps	Cleanability
Operation sequence	Installability
Human factors	Retirement
Appearance	Resource concerns
Force and motion control	Time
Ease of controlling and sensing state	Cost
Physical requirements	Capital
Physical properties	Unit
Available spatial envelope	Equipment
Reliability	Standards
Mean time between failures	Environment
Safety (hazard assessment)	Manufacturing/assembly requirements
Life-cycle concerns	Materials
Distribution (shipping)	Quantity
Maintainability	Company capabilities

Functional performance requirements are those elements of the performance that describe the product's desired behavior. Although the customers may not use technical terms, function is usually described as the flow of energy, information, and materials or as information about the operational steps and their sequence. In Chap. 7 we develop concepts by building a functional model, based on the flow of energy, information, and materials. We will see that *developing functional requirements with the QFD and building a functional model of the product are often iterative.* The more the function is understood, the more complete are the requirements that can be developed.

Any product that is seen, touched, heard, tasted, smelled, or controlled by a human will have *human factors requirements* (see App. D for details on human factors). This includes nearly every product. One frequent customers' requirement is that the product "looks good" or looks as if it has a certain function. These are areas in which a team member with knowledge about industrial design is essential. Other requirements focus on the flow of energy and information between the product and the human. Energy flow is usually in terms of force and motion, but can take other forms as well. Information flow requirements apply to the ease of controlling and sensing the state of the product. Thus, human factors requirements are often functional performance requirements.

Physical requirements include needed physical properties and spatial restrictions. Some physical properties often used as requirements are weight; density; and conductivity of light, heat, or electricity (i.e., flow of energy). Spatial constraints relate how the product fits with other, existing objects. Almost all new design efforts are greatly affected by the physical interface with other objects that cannot be changed.

In the *Time* magazine survey on quality quoted in Chap. 1, the second most important consumer concern was "Lasts a long time," or the product's *reliability.* It is important to understand what acceptable reliability means to the customer. The product may only have to work once with near-absolute certainty (e.g., a rocket), or it may be a disposable product that does not need much reliability. As discussed in Chap. 11, one measure of reliability is the *mean time between failures.*

A part of reliability involves the questions, what happens when the product does fail? and, what are the *safety* implications? Product safety and hazard assessment are very important to the understanding of the product, and they are covered in Chap. 8.

An often overlooked class of requirements is the class of those relating the product life cycle other than product use. All specification types listed in Table 6.1 were taken from life cycle phases in Fig. 1.7. In designing the first BikeE, one of the design requirements set by sales/marketing was that the bicycle had to be shipped by a commercial parcel service. Such services have weight and size limits, which greatly affected the design of the product. If the advantages of distributing the product by commercial parcel service had not been realized early, extensive redesign might have been necessary. The same applies to the other life-cycle phases listed in Table 6.1 and Fig. 1.7.

A limited resource on every design project is time. *Time requirements* may come from the consumer; more often they originate in the market or in manufacturing needs. In some markets there are built-in time constraints. For example, toys must be ready for the summer buyer shows so that Christmas orders can be taken; new automobile models traditionally appear in the fall. Contracts with other companies might also determine time constraints. Even for a company without an annual or contractual commitment, time requirements are important. As discussed earlier, in the 1960s and 1970s Xerox dominated the copier market, but by 1980 its position had been eroded by domestic and Japanese competition. Xerox discovered that one of the problems was that it took it twice as long as some of its competitors to get a product to market, and Xerox put new time requirements on its engineers. Fortunately, Xerox helped its engineers work smarter, not just faster, by introducing techniques similar to those we talk about here.

Cost requirements concern both the capital costs and the costs per unit of production. Included in capital costs are expenditures for the design of the product. For a Ford automobile, design costs make up 5% of the manufacturing cost (Fig. 1.2). Many product ideas never get very far in development because the initial requirements for capital are more than the funds available. (Cost estimating will be covered in detail in Section 11.2.)

Standards spell out current engineering practice in common design situations. The term *code* is often used interchangeably with *standard.* Some standards serve as good sources of information. Other standards are legally binding and must be adhered to—for example, the ASME pressure vessel codes. Although the actual information contained in standards does not enter into the design process in this early phase, knowledge of which standards apply to the current situation are important to requirements and must be noted from the beginning of the project.

Standards that are important to design projects generally fall into three categories: performance, test methods, and codes of practice. There are *performance standards* for many products, such as seat-belt strength, crash-helmet durability, and tape-recorder speeds. The *Product Standards Index* lists U.S. standards that apply to various products; most of those referenced are also covered by ANSI (American National Standards Institute), which does not write standards but is a clearinghouse for standards written by other organizations.

Test method standards for measuring properties such as hardness, strength, and impact toughness are common in mechanical engineering. Many of these are developed and maintained by the American Society for Testing and Materials (ASTM), an organization that publishes over 4000 individual standards covering the properties of materials, specifying equipment to test the properties, and outlining the procedures for testing. Another set of testing standards that are important to product design are those developed by the Underwriters Laboratories (UL). This organization's standards are intended to prevent loss of life and property from fire, crime, and casualty. There are over 350 UL standards. Products that have been tested by UL and have met their standards can display the words "Listed UL" and the standard number. The company developing the product must pay for this testing. Consumer products are usually not marketed without UL listing because the liability risk is too high without this proof of safe design.

Codes of practice give parameterized design methods for standard mechanical components, such as pressure vessels, welds, elevators, piping, and heat exchangers.

It is important for the design team to ensure that requirements imposed by *environmental concerns* have been identified. Since the design process must consider the entire life cycle of the product, it is the design engineer's responsibility to establish the impact of the product on the environment during production, operation, and retirement. Thus, requirements for the disposal of wastes produced during manufacture (whether hazardous or not), as well as for the final disposition of the product, are the concern of the design engineer. This topic is further discussed in Chap. 11.

Some of the *manufacturing/assembly requirements* are dictated by the quantity of the design to be produced and the characteristics of the company producing it. The quantity to be produced often affects the kind of manufacturing processes to be used. If only one unit is to be produced, then custom tooling cannot be amortized across a number of items and off-the-shelf components should be selected when possible (see Chap. 9). Additionally, every company has internal manufacturing resources whose use is preferable to contracting work outside the company. Such factors must be considered from the very beginning.

Guidelines for good specifications are

1. Each specification should measure at least one customers' requirement at the strong relationship level (see step 7). Ideally, each specification should

measure multiple requirements. If you have a diagonal of scores in step 7, you need to revisit the specifications.

2. Each specification should be measurable. Every specification should be written as if you were going to give instructions to someone to go down to the lab and measure something. It should be clear what they are going to measure. For example, the specification "Fore/aft tipping force" is a good title for a specification, but to be measurable it needs many more words. Thus, it is suggested that for each specification list, a full description of how to measure it also be developed. For example:

   Fore aft tipping force = The force needed at the push handles to tip over the aisle chair when moving forward at 1 km/hr with 78.5-kg passenger (a 50% male, see App. D).

   If a good statement like this cannot be developed, then the specification is not clear and needs to be reworked.

3. If the units are not clear, the specification is not clear.

4. If the sense (↑ or ↓) is not obvious, then the specification is not clear.

5. If you need to measure something like "looks good" try transforming it into a testable measure such as "High score on 5-point attractiveness scale by >65% of passengers." This means that you set up a 5-point attractiveness scale (units = "points") such as 1 = ugly, 2 = tolerable, 3 = acceptable, 4 = attractive, 5 = captivating. Obviously the sense is (↑). And the target (to be set in Step 7 will be $\geq$ 4).

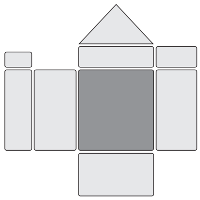
Specifications for the aisle chair are shown in Fig. 6.6. Some comments about them in light of the guidelines are

1. The first specification "seat width relative to frame width" is not clear. What is to be measured here?

2. Two points about specifications that are in terms of "number of steps": (1) steps are better than time as time varies from individual to individual, and (2) you need to clearly define what a step is. A good guide for determining steps is in Section 11.5.

3. "Seat size" is not clear. What exactly needs to be measured?

6.7 STEP 6: RELATE CUSTOMERS' REQUIREMENTS TO ENGINEERING SPECIFICATIONS: *HOW* TO MEASURE *WHAT?*



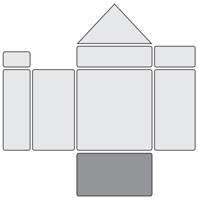
To complete this step, we fill in the center portion of the house of quality. This relationship matrix is completed in parallel to Step 5, and it yields additional knowledge. Each cell of the form represents how an engineering specification relates to a customer's requirement. Many specifications will measure more than one customer's requirement. The strength of this relationship can vary, with some engineering specifications, providing strong measures for a customer's requirement and others providing no measure at all. The relation is conveyed through specific symbols or numbers:

◉ = 9 = strong relationship
○ = 3 = medium relationship
△ = 1 = weak relationship
Blank = 0 = no relationship at all

The 0-1-3-9 values are used to reflect the dominance of strong relationships. The symbols are used in the example (Fig. 6.6) and the number is used in the math that follows for the aisle chair.

Some guidelines for this step are as follows:

- Each customer's requirement should have at least one specification with a strong relationship.
- There is the temptation to make this a diagonal matrix of ◉s or 9s—one engineering specification for each customer requirement. This is a weak use of the method. Ideally, each specification should measure more than one customer requirement.
- If a customer's requirement has only weak or medium relationships (see "Fits in aircraft aisle" or "good lifting position"), then it is not well understood or the specification has not been well thought through. It is evident what is meant by "fits in aircraft aisle." The specification needs work. It is not so evident what "good lifting position" means and thus the customer's requirement needs more effort.



6.8 STEP 7: SET ENGINEERING SPECIFICATION TARGETS AND IMPORTANCE: *HOW MUCH IS GOOD ENOUGH?*

In this step we fill in the basement of the house of quality. Here we set the targets and establish how important it is to meet each of them. There are three parts to this effort, as shown in Fig. 6.6, calculate the specification importance, measure how well the competition meets the specification, and develop targets for your effort.

6.8.1 Specification Importance

The first goal in this step is determining the importance for each specification. If a target is important, then effort needs to be expended to meet the target. If it is not important, then meeting the goal can be more easily relaxed. In the development of products, it is seldom that all targets can be met in the time available and so this effort helps guide what to work on. The method to find importance is as follows:

Step 2.1: For each customer multiply the importance weighting from step 3 with the 0-1-3-9 relationship values from step 6 to get the weighted values.

Step 2.2: Sum the weighted values for each specification. For specification "steps to adjust seat height" in Fig. 6.6, the passenger score is:

$4*9+6*0+15*0+10*0+3*1+7*0+24*0+6*0+5*9+15*3+5*1 = 134$.

Step 2.3: Normalize these sums across all specifications. The sum across all the specifications is 1475 so this specification has importance of $134/1475 = 9\%$.

Figure 6.6 shows the importance from both the passengers' and agents' viewpoints. Note that for the passenger specifications revolving around moving from their chair to the aisle chair are most important. From the agents' viewpoint both these specifications and time measures are important.

6.8.2 Measuring How Well the Competition Meets the Specifications

In step 4, the competitions' products were compared to customers' requirements. In this step, they will be measured relative to engineering specifications. This ensures that both knowledge and equipment exist for evaluation of any new products developed in the project. Also, the values obtained by measuring the competition give a basis for establishing the targets. This usually means obtaining actual samples of the competition's product and making measurements on them in the same way that measurements will be made on the product being designed. Sometimes this is not possible and literature or simulations are used to find values needed here.

The competition values are shown in Fig. 6.6.

6.8.3 Setting Specification Targets

Setting targets early in the design process is important; targets set near the end of the process are easy to meet but have no meaning as they always match what has been designed. However, setting targets too tightly may eliminate new ideas. Some companies refine their targets throughout concept development and then make them firm. The initial targets, set here, may have $\pm 30\%$ tolerance on them.

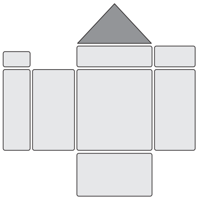
Most texts on QFD suggest that a single value be set as a target. However, once the design process is underway, often it is not possible to meet these exact values. In fact, a major part of engineering design is making decisions about how to manage targets and the tradeoff meeting them. There are two points to be made here. To make them, we will use a simple example.

Say you want to buy a new camera. You want to spend less than \$300 and want at least 7.2 megapixels (your only two specifications). You look online and find a camera with the resolution you want, but it costs $305. Will you buy it? Probably. What if it costs $315?—maybe. What about $400?—probably not. The point here is that most targets are flexible and they may not be met during design. This is not true of all targets. You definitely need to achieve a velocity of 7 m/sec to escape the Earth's gravitational pull. You cannot say 6.5 is good enough. For those targets that have flexibility, a more robust method for setting targets is to establish the levels at which the customers will be delighted and those where they will be disgusted. The delighted value is the actual target and the disgusted is the threshold beyond which the product is unacceptable. For the camera example, the target cost (delighted) is at $300 and the threshold (disgusted) between $315 and $400, say $350. For the resolution, delighted may be 7.2 megapixels and disgusted 6.3 megapixels. Note that for cost, less is better and for resolution, more is better.

A second point is that, as a design engineer you often have to trade off one specification against another. Continuing with the camera example, say there are two cameras available, one has 6.3 megapixels and costs $305 and the other 7.2 megapixels and costs $330. The question is, how much am I willing to trade off cost for resolution? If the targets were single valued, $300 and 7.2 megapixels, then neither camera meets the targets. But, by setting the two targets, delighted and disgusted, you can better judge which camera is best.

A final comment on target setting is that if a target is much different than the values achieved by the competition, it should be questioned. Specifically, what do you know that the competition does not know? Do you have a new technology, do you know of new concepts, or are you just smarter than your competition? What is possible should fall in the range of the delighted and disgusted targets.

Figure 6.6 shows values for the aisle chair delighted and disgusted targets.



6.9 STEP 8: IDENTIFY RELATIONSHIPS BETWEEN ENGINEERING SPECIFICATIONS: HOW ARE THE *HOWS* DEPENDENT ON EACH OTHER?

Engineering specifications may be dependent on each other. It is best to realize these dependencies early in the design process. Thus, the roof is added to show that as you work to meet one specification, you may be having a positive or negative affect on others.

In Fig. 6.6, the roof for the aisle chair QFD shows diagonal lines connecting the engineering specifications. If two specifications are dependent, a symbol is noted in the intersection. There are many different styles of symbols used. One is to use the same symbols as in Step 6. The simplest method is to use a "+" to denote that improvement in meeting one of the specifications will improve the other (they are synergistic), and to use a "–" to show that improvement in meeting one may harm the other (a compromise may be forced). Some people use ++ and −− to show a strong dependency.

In building a house of quality on a spreadsheet, a good way to simulate the roof is as shown in Fig. 6.7. Here the specifications are listed in both the

	Seat width relative to frame width	Steps to adjust seat height	Force to adjust seat height	Force to slide 95% male passenger	Lifting force required by agent	Push force over 2cm bump	Force to push aisle chair	Time to transfer between seats	Fore/aft tipping force at handles	Side tipping force at handles
Side tipping force at handles										■
Fore/aft tipping force at handles									■	+
Time to transfer between seats								■		
Force to push aisle chair							■			
Push force over 2cm bump						■	+			
Lifting force required by agent					■					
Force to slide 95% male passenger				■	??			–		
Force to adjust seat height			■							
Steps to adjust seat height		■	–					–		
Seat width relative to frame width	■									
	cm	#	kg	kg	kg	cm	kg	sec	kg	kg
	↓	↑	↓	↓	↓	↑	↓	↓	↓	↓

Figure 6.7 Alternative QFD roof for a spreadsheet.

columns and rows and a diagonal matrix used to show the relationships also shown in Fig. 6.6.

Some guidelines for building the roof are

- In the ideal world, all the specifications are independent. However, the reality is that sometimes when you improve one thing, you either improve or hurt something else. These relationships give guidance about trade-offs.
- If the roof has many of the cells full, then the specifications are too dependent and should be revisited.
- If the relationship is not clear, then at least one of the specifications is not clear. This is the case with the relationship between "force required

for the passenger to slide" and "force required by the agent." The lack of clarity is caused by a poor understanding of exactly what force the agent is applying.

6.10 FURTHER COMMENTS ON QFD

The QFD technique ensures that the problem is well understood. It is useful with all types of design problems and results in a clear set of customers' requirements and associated engineering measures. It may appear to slow the design process, but in actuality it does not, as time spent developing information now is returned in time saved later in the process.

Even though this technique is presented as a method for understanding the design requirements, it forces such in-depth thinking about the problem that many good design solutions develop from it. No matter how hard we try to stay focused on the requirements for the product, product concepts are invariably generated. This is one situation when a design notebook is important. Ideas recorded as brief notes or sketches during the problem understanding phase may be useful later; however, it is important not to lose sight of the goals of the technique and drift off to one favorite design idea.

The QFD technique automatically documents this phase of the design process. Diagrams like those in Figs. 6.5 and 6.6 serve as a design record and also make an excellent communication tool. Specifically, the structure of the house of quality makes explaining this phase to others very easy. In one project, a member of the sponsoring organization was blind. A verbal description of the structure helped him understand the project and recommend the QFD method to other sighted colleagues.

Often, when working to understand and develop a clear set of requirements for the problem, the design team will realize that the problem can be decomposed into a set of loosely related subproblems, each of which may be treated as an individual design problem. Thus, a number of independent houses may be developed.

The QFD technique can also be applied during later phases of the design process. Instead of developing customers' requirements, we may use it to develop a better measure for functions, assemblies, or components in terms of cost, failure modes, or other characteristics. To accomplish this, review the steps, replacing customers' requirements with what is to be measured and engineering requirements with any other measuring criteria.

Although QFD seems to imply a waterfall-type development plan, much learning occurs during the design process. The QFD is considered a working document that is reviewed and updated as needed. Thus, it also is important for spirally developed products. The formality and complexity of the technique forces any change to be carefully considered and thus keeps the project moving toward completion. Without a system like QFD, changes in specifications can occur at the whim of a manager or without the design team even realizing it. These changes will lead to a failure to meet the schedule and a potentially poor product.

6.11 SUMMARY

- Understanding the design problem is best accomplished through a technique called Quality Function Deployment (QFD). This method transforms customers' requirements into targets for measurable engineering requirements.
- Important information to be developed at the beginning of the problem includes customers' requirements, competition benchmarks, and engineering specifications complete with measurable benchmarks.
- Time spent completing the QFD is more than recovered later in the design process.
- There are many customers for most design problems.
- Studying the competition during problem understanding gives valuable insight into market opportunities and reasonable targets.

6.12 SOURCES

ANSI standards are available at www.ansi.org

ASTM standards are available at www.astm.org

Cristiano, J. J., J. K. Liker, and C. C. White: "An Investigation into Quality Function Deployment (QFD) Usage in the U.S.," in *Transactions for the 7th Symposium on Quality Function Deployment,* June 1995, American Supplier Institute, Detroit. Statistics on QFD usage were taken from the study in this paper.

Hauser, J. R., and D. Clausing: "The House of Quality," *Harvard Business Review,* May–June 1988, pp. 63–73. A basic paper on the QFD technique.

Index of Federal Specifications and Standards, U.S. Government Printing Office, Washington, D.C. A sourcebook for federal standards.

Krueger, R. A.: *Focus Groups: A Practical Guide for Applied Research,* Sage Publishing, Newbury Park, Calif. 1988. A small book with direct help for getting good information from focus groups.

Roberts, V. L.: *Products Standards Index,* Pergamon, New York, 1986. A sourcebook for standards.

Salant, P., and D. Dillman: *How to Conduct Your Own Survey,* John Wiley & Sons, New York, 1994. A very complete book on how to do surveys to collect opinions.

Software packages

QFD/CAPTURE, http://www.qfdcapture.com/default.asp

QFD Designer, IDEACore, http://www.ideacore.com/v1/Products/QFDDesigner/

Templates for Excel are at http://www.qfdonline.com/templates/

6.13 EXERCISES

6.1 For a design problem (Exercise 4.1), develop a house of quality and supporting information for it. This must include the results of each step developed in this chapter. Make sure you have at least three types of customers and three benchmarks. Also, make a list of the ideas for your product that were generated during this exercise.

6.2 For the features of the redesign problem (Exercise 4.2) to be changed, develop a QFD matrix to assist in developing the engineering specifications. Use the current design as a benchmark. Are there other benchmarks? Be careful to identify the features needing change before spending too much time on this. The methods in Chap. 7 can be used iteratively to help refine the problem.

6.3 Develop a house of quality for these objects.

- **a.** The controls on an electric mixer.
- **b.** A seat for an all-terrain bicycle.
- **c.** An attachment for electric drills to cut equilateral-triangle holes in wood. The wood can be up to 50 mm thick, and the holes must be adjustable from 20 mm to 60 mm per side.
- **d.** A tamper-proof fastener as used in public toilet facilities.

6.14 ON THE WEB

A template for the following document is available on the book's website: www.mhhe.com/Ullman4e

- Voice of the Customer