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PART THREE

Design of Production Systems

Satisfying the customer begins with product and service design. Moreover, decisions made in this area impact on operations and on the organization's overall success.

Similarly, process selection and capacity planning impact on the ability of the production system to perform and to satisfy customers. Flexibility, production time, and cost are key considerations in process design.

Process selection and layout are closely related. Layout decisions involve the arrangement of the workplace, which affects the flow of work through a system and impacts productivity, cost, and flexibility. Layout decisions are influenced by decisions made in product and service design.

Capacity and location decisions influence operating costs and the ability to respond to customer demand. Location decisions also impact transportation costs, labor availability, material costs, and access to markets.

Work design focuses on the human element in production systems. Increasingly, managers are realizing that workers are a valuable asset and can contribute greatly to the organization's success. Strategic planning is beginning to incorporate employee participation to help improve production systems.

Design decisions have strategic significance for business organizations. Many of these decisions are not made by the operations manager. Nonetheless, because of the important links between operations and each strategic area, it is essential to the success of the organization to involve all of the functional areas of the organization in design decisions.

Production system design encompasses decisions involving:

CHAPTER FOUR

Product and Service Design

CHAPTER OUTLINE

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Discuss the importance of product and service design.
2. Describe the design process.
3. Explain the concept of standardization and discuss its advantages and disadvantages.
4. Discuss the concept of modular design, including its advantages and disadvantages.
5. Describe the contributions of R&D to product and service design.
6. Define reliability and suggest possible ways of improving reliability.

www.mccormick.com

As more and more women join the workforce and more families rely on two incomes, the spending and eating habits of Americans are changing. Quick meals have replaced leisurely meals. There is an increased awareness of healthy foods. And spicy foods have replaced plain foods. Fast-food chains, food companies, and supermarkets are scrambling to meet the challenge.

Spice giant McCormick is finding that sales of traditional spices are down. To compensate, the company is promoting seasoning mixes which are designed to save time. Salsa is becoming very popular, and Mexican restaurants are springing up all over. Supermarkets are offering a wide array of already prepared foods (see the Wegmans Tour in Chapter 1) as well as recipes for quick meals in their stores and on their web pages.

For these and other companies, from high tech to no tech, product and service design plays an important role in their profitability and their very survival.

The essence of any organization is the products or services it offers. There is an obvious link between the *design* of those products or services and the *success* of the organization. Organizations that have well-designed products or services are more likely to realize their goals than those with poorly designed products or services. Hence, organizations have a vital stake in achieving good product and service design.

In this chapter you will find many interesting insights into product and service design. Among the topics covered are the need for product and service design or redesign, sources of ideas for design or redesign, legal, environmental, and ethical issues, and design elements for both manufacturing and service.

Product and service design—or redesign—should be closely tied to an organization's strategy. It is a major factor in cost, quality, time to market, customer satisfaction, and competitive advantage.

Introduction

In this section you will learn what product and service designers do, the reasons for design (or redesign), and the objectives of design.

WHAT DOES PRODUCT AND SERVICE DESIGN DO?

A range of activities fall under the heading of product and service design. The activities and responsibilities of product and service design include the following (functional interactions are shown in parentheses):

1. Translate customer wants and needs into product and service requirements. (marketing)
2. Refine existing products and services. (marketing)
3. Develop new products and/or services. (marketing, operations)
4. Formulate quality goals. (quality assurance, operations)
5. Formulate cost target. (accounting)
6. Construct and test prototypes. (marketing, operations)
7. Document specifications.

Product and service design involves or affects nearly every functional area of an organization. However, marketing and operations have major involvement.

Figure 4–1 offers a humorous look at some of the ways various departments in the design process might interpret a "design." The point is that sufficient information must be obtained to clearly determine what the customer wants, and this must be communicated to those responsible for designing, producing, and marketing a particular product or service.

REASONS FOR PRODUCT OR SERVICE DESIGN OR REDESIGN

Organizations become involved in product or service design for a variety of reasons. An obvious one is to be competitive by offering new products or services. Another one is to

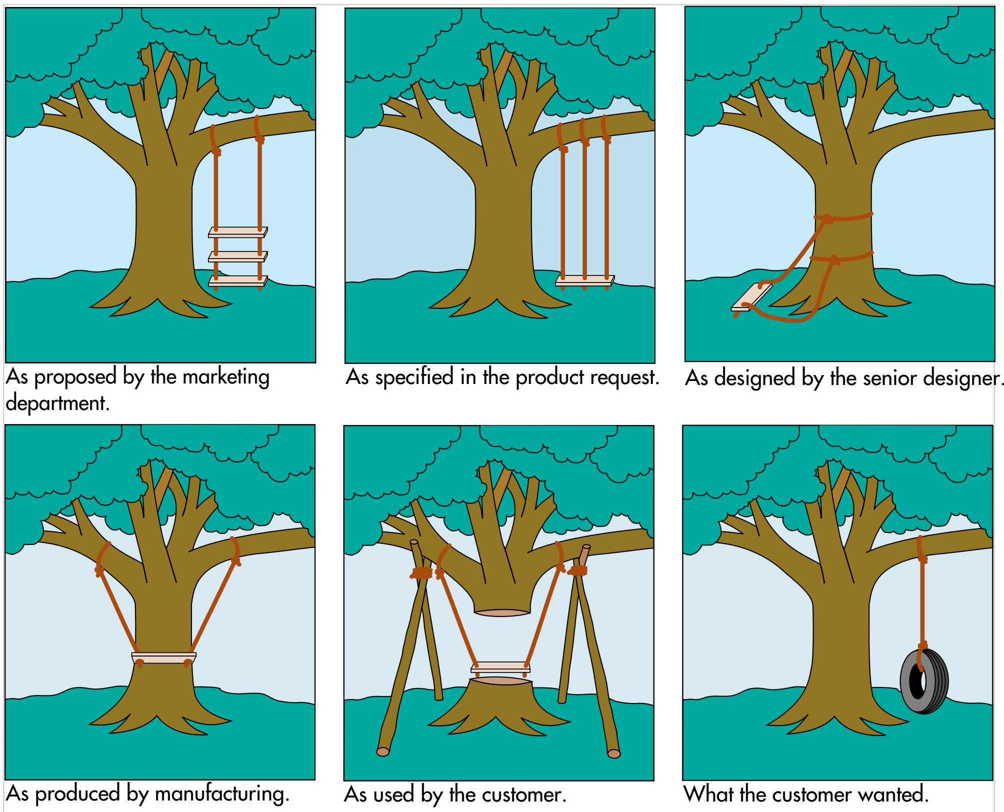


FIGURE 4–1

Differing views of design created through lack of information

Source: *Educational Center Newsletter,* Minneapolis, Minnesota.

At the General Motors Tech Center in Warren, Michigan, designers carve a clay model of their new model styling.

www.gm.com

make the business grow and increase profits. Furthermore, the best organizations try to develop new products or services as an alternative to downsizing. When productivity gains result in the need for fewer workers, developing new products or services can mean adding jobs and retaining people instead of letting them go.

Sometimes product or service design is actually *redesign*. This, too, occurs for a number of reasons such as customer complaints, accidents or injuries, excessive warranty claims, or low demand. The desire to achieve cost reductions in labor or materials can also be a motivating factor.

OBJECTIVES OF PRODUCT AND SERVICE DESIGN

The objectives of product design and service design differ somewhat, but not as much as you might imagine. The overall objective for both is to satisfy the customer while making a reasonable profit.

It is important to note that although profit is generally the overall measure of design effectiveness, because the time interval between the design phase and profit realization is often considerable, more immediate measures come into play. These typically include development time and cost, the product or service cost, and the resulting product or service quality.

Quality, of course, is typically high on the list of priorities in product and service design. At one time, having high quality was enough for a product or service to stand out; now it is the norm, and those that fall below this norm are the ones that stand out.

Last, but certainly not least, it is *crucial* for designers to take into account the capabilities of the organization to produce or deliver a given product or service. This is sometimes referred to as **design for operations.** When the operations involve manufacturing, the term often used is **manufacturability:** the ease with which design features can be achieved by manufacturing. Failure to take this into consideration can result in reduced productivity, reduced quality, and increased costs. For these reasons, it is wise for design to solicit input from manufacturing people throughout the design process. Likewise, in the design of services, it is important to involve service people in the design process to reduce the risk of achieving a design that looks good on paper, but doesn't work in the real world.

design for operations Taking into account the capabilities of the organization in designing goods and services.

manufacturability The ease of fabrication and/or assembly.

Sources of Ideas for New or Redesigned Products and Services

Ideas for new and improved products or services can come from a wide range of sources, both from within the organization and from outside it.

Employees—including those who make products or deliver services to customers, salespeople, and purchasing agents, can be a rich source of ideas, if they are motivated to offer suggestions. In addition to these are two more primary sources of ideas: marketing and research. Along with assessing current needs of customers, marketing people typically are aware of problems with products or services. Marketing people are often sources of ideas based on their studies of markets, buying patterns, and familiarity with demographics. Also, marketing can help craft a vision of what customers are likely to want in the future. Some organizations have research and development departments, another source of ideas.

External sources of ideas include customers, competitors, and suppliers. Customers may submit suggestions for improvements or new products, or they may be queried through the use of surveys or focus groups. One such approach is *quality function deployment,* which seeks to incorporate the "voice of the customer" into product and service design. It is described later in the chapter. Customer complaints can provide valuable insight into areas that need improvement. Similarly, product failures and warranty claims indicate where improvements are needed. One of the strongest motivators for new and improved products or services is competitors' products and services. By studying a competitor's products or services and how the competitor operates (pricing policies, return policies, warranties, location strategies, etc.), an organization can glean many ideas. Beyond that, some companies purchase a competitor's product and then carefully dismantle and inspect it, searching for ways to improve their own product. This is called **reverse engineering.** The Ford Motor Company used this tactic in developing its highly successful Taurus model: It examined competitors' automobiles, searching for best-in-class components (e.g., best hood release, best dashboard display, best door handle). Sometimes reverse engineering can enable a company to "leapfrog" the competition by developing an even better product. Suppliers are still another source of ideas, and with increased emphasis on supply chains and supplier partnerships, suppliers are becoming an important source of ideas.

reverse engineering Dismantling and inspecting a competitor's product to discover product improvements.

Chrysler's 1.3 mile automated durability track simulates bad roads and is used to test the integrity of automobiles and trucks. Chrysler vehicles are "guided" by computer-controlled robots.

A milestone crash test performed at Ford Motor Corporation is used to plan for new side-impact head and chest air bags.

In general, design, production or operations, and marketing must work closely together, keeping each other informed and taking into account the wants and needs of the customer. In addition, legal, environmental, and ethical considerations can influence the design function.

The next section describes research and development, followed by a section on legal, ethical, and environmental issues.

RESEARCH AND DEVELOPMENT

research and development (R&D) Organized efforts to increase scientific knowledge or product innovation.

Research and development (R&D) refers to organized efforts that are directed toward increasing scientific knowledge and product or process innovation. Most of the advances in semiconductors, medicine, communications, and space technology can be attributed to R&D efforts at colleges and universities, research foundations, government agencies, and private enterprises.

R&D efforts may involve *basic research, applied research,* or *development*.

Basic research has the objective of advancing the state of knowledge about a subject, without any near-term expectation of commercial applications.

Applied research has the objective of achieving commercial applications.

Development converts the results of applied research into useful commercial applications.

Basic research, because it does not lead to near-term commercial applications, is generally underwritten by the government and large corporations. Conversely, applied research and development, because of the potential for commercial applications, appeals to a wide spectrum of business organizations.

The benefits of successful R&D can be tremendous. Some research leads to patents, with the potential of licensing and royalties. However, many discoveries are not patentable, or companies don't wish to divulge details of their ideas so they avoid the patent route. Even so, the first organization to bring a new product or service to the market generally stands to profit from it before the others can catch up. Early products may be priced higher because a temporary monopoly exists until competitors bring their versions out.

The costs of R&D can be high. Kodak, for example, has spent more than $1 million *a day* on R&D. Large companies in the automotive, computer, communications, and pharmaceutical industries spend even more. Even so, critics say that many U.S. companies spend too little on R&D, a factor often cited in the loss of competitive advantage.

www.kodak.com

It is interesting to note that some companies are now shifting from a focus primarily on *products* to a more balanced approach that explores both product and *process* R&D. One reason is that in too many instances, product innovations (e.g., for televisions, VCRs, and microwave ovens) made by U.S. companies have ended up being produced more competitively by foreign companies with better processes.

In certain instances, research may not be the best approach, as explained in the following reading. The second reading illustrates a research success.

READING

Manager's Journal: When Customer Research Is a Lousy Idea

Willard I. Zangwill

www.sony.com

Customer research is often touted as a necessary precursor to product introduction. The problem—especially for innovative products—is that it often proves wrong. For example, hair styling mousse is now a massive hit. Yet in its initial market tests in the U.S., it flopped. "Goopy and gunky" was what people said about it, and they did not like its feel when it "mooshed" through their hair.

Similarly, when the telephone answering machine was consumer tested, it faced an almost universally negative reaction. Back then, most individuals felt that using a mechanical device to answer a phone was rude and disrespectful. Today, of course, many people regard their answering machines as indispensable, and consider scheduling their daily activities without them as impossible. In the same vein, the computer mouse in its initial testing flunked, being evaluated by potential customers as awkward and unnecessary.

Because of these difficulties, some companies have gone so far as to eliminate customer research for their innovative products. According to Sony executive Kozo Ohsone, "When you introduce products that have never been invented before, what good is market research?" The Walkman was launched without the standard customer research, as is typical at Sony.

With customer research not only costly, but often in error, how can a manager determine the innovations customers want? The solution may be design-for-purpose, a new approach in which a firm uses speed and flexibility to gain customer information instead of, or in addition to, standard customer research.

To illustrate, Sony obtains information from the actual sales of various Walkman models and then quickly adjusts its product mix to conform to those sales patterns. Specifically, the process design of each Walkman model is based on a core platform containing the essential technology. But the platform is designed to be flexible, which allows a wide range of models to be easily built on it, such as a beach model, a child's model, one that attaches to the arm, and so on.

Depending upon which models sell, the models or features are changed, but the platform remains the same. If pink is a hot selling color, they make more pink models. If beach models sell well, they make more of the existing models and also expand the line. This technique is far more accurate than deciding what to make using traditional customer research.

Similarly, without customer research, every season Seiko "throws" into the market several hundred new models of its watches. Those that customers buy, it makes more of; the others, it drops. Capitalizing on the design-for-response strategy, Seiko has a highly flexible design and production process that lets it quickly and inexpensively introduce products. Do they worry if a high percentage of the watches they introduce fail, rejected by the customers? No (unless the failure rate is extremely high), because their fast, flexible product design process has slashed the cost of failure.

When creating a new magazine, Hearst Magazines also follows this approach. Hearst learned that it was almost impossible to customer test the magazine ideas, and that it was better to launch the magazine and see what happens. To do this, Hearst has created a special group of editors with the talent and flexibility to launch almost any new magazine. Based upon the initial sales of the new magazine, they will either revise the content and format or drop the publication. Any new magazine that proves successful is spun off to run independently.

Crucial to this approach, however, is reducing the cost of the failures by keeping expenses down. Hearst accomplishes this by initially hiring one overall editor on a short-time basis, using stringers as writers, and borrowing advertising people. Also, with experience it has discovered the tricks of launching new magazine products inexpensively. For example, it has learned how to test different cover designs efficiently, and how to test sales in different markets, such as newsstands or subscribers.

Many other firms also follow the strategy of using customer research data less and fast-flexible response more, with the food industry in the lead. One of the problems with customer research into foods is that a person's desire for food is powerfully influenced by the ambiance, the dining companions and what foods were eaten recently, all of which confound and confuse the results of the customer research. Even more erratic are the results with children's food, say a new cereal or snack. The responses of kids are strongly swayed by how well they like the people doing the test and the playthings available. Worse, kids quickly change their minds, and in a taste test of several foods a child can judge one food the best but one hour later proclaim the same food as "icky."

Arthur D. Little & Co. discovered that of all new cereals introduced to the market, 92 percent had failed. Since using the full array of customer research techniques produces a success rate of only 8 percent, more and more companies are revising their thinking about doing customer research as usual. Innovative firms such as Keebler and the leading cereal makers are reducing their expenditure for customer research and instead are vigorously cutting the cost of launching new products, including making their manufacturing processes more flexible.

Design-for-response enables firms not only to employ customer research when beneficial but also to respond quickly to what the customers really want, keeping the firm on top of market shifts and surprises.

NOTE: Mr. Zangwill is a professor at the Graduate School of Business, University of Chicago, and author of *Lightning Strategies for Innovation* (Lexington, 1992).

(See related letter: "Letters to the Editor: Testing the Waters Before the Launch" *WSJ*—April 1, 1993)

READING

Vlasic on a Roll with Huge Pickle Slices

Michele Darnell

www.vlasic.com

Many were skeptical of Frank Meczkowski's plan to develop a pickle so big that a single slice could cover a hamburger.

After all, whoever saw a pickle that big—except maybe in the *Guinness Book of World Records?*

Meczkowski and his team of food researchers at Vlasic Foods International were convinced the project—given the code name Frisbee—could fly.

For about four years, they labored to cultivate a jumbo cucumber with the taste, shape and crunch to be a perfect pickle.

Made only at the company's plant in Millsboro, the monster-sized slices seem to have captured the pickle lover's fancy. They've become one of Vlasic's best-selling products since their introduction in supermarkets last March. And, the better-than-anticipated sales have helped to reverse a three-year decline in consumption of Vlasic pickles.

Hamburger Stackers are about 10 time bigger that traditional pickle chips and come in dill and bread-and-butter varieties.

"They said it just couldn't be done."

Making a bigger pickle may not sound like that big of a deal. You just grow a bigger cucumber, right?

There is more to it than that. The folks at Vlasic soon learned how tough it was to deal with gigantic cucumbers as they developed the new product and as they retooled the Delaware plant.

Meczkowski came up with the idea for the mammoth pickle slices soon after Vlasic's 1994 introduction of its Sandwich Stackers—regular-size pickles sliced lengthwise so they can be draped on sandwiches.

The 'Hamburger Stacker' on the burger at left dwarfs a traditional pickle slice. Stackers are 'genetically designed' using cucumbers that grow to over 3 inches in diameter and weigh five pounds.

Sandwich Stackers currently account for 20 percent of all Vlasic pickle sales.

Vlasic is the No. 1 seller of pickles in the United States, with a 32 percent share of the $800 million retail pickle market, beating out brands such as Claussen, Heinz and Peter Piper's.

To develop Hamburger Stackers, Meczkowski worked with seed researchers and others to scour the globe looking for oversized varieties of cucumbers. Most weren't in commercial production.

Vlasic's team grew different varieties in greenhouses, looking for one that would get big enough yet still make a good pickle.

It had to taste like a regular cucumber, stay crisp when pickled, have a small seed cavity and be straight enough so that it could be cut mechanically.

"We wanted it to really be a cucumber," said Meczkowski, who has worked as a food researcher for 22 years and is based at Vlasic's headquarters in New Jersey.

He said Vlasic also had to decide just how big Hamburger Stackers should be. At one point, it asked consumers who were participating in focus groups to bring in their own homemade burgers so the company could determine the perfect size for its new pickles.

Eventually, Vlasic officials found what they were looking for—a now-patented cucumber that grows 3.25 inches in diameter, easily reaches 12 to 16 inches in length and weighs about five pounds.

It looks like the watermelon's skinny runt brother.

Once the company settled on a cucumber, it had to work out details of how to get Hamburger Stackers into commercial production. One challenge was to grow the cucumbers in fields, rather than in a greenhouse.

Randy Spence, Vlasic's manager of manufacturing services, said the jumbo cucumbers grew quicker than anyone expected.

"Early on, we expected the bigger ones to grow slower, but that hasn't been the case," he said.

These days, most of the gigantic cucumbers are grown in Florida, where they are handpicked because of their size. Depending on the weather, they take about 54 days from seed to harvest.

Once harvested, they're shipped to Vlasic's plant in Sussex County. The plant employs about 260 workers year-round and 300 to 400 others from April to November.

Steven McNulty, director of plant operations at the nearly 30-year-old Millsboro facility, said the size of the new cucumbers meant they couldn't be handled in the same manner as the smaller versions used to make pickle spears and sweet gherkins.

That became obvious when Vlasic tried to process its first batch of the somewhat fragile, jumbo-sized cucumbers.

Officials didn't end up with the Hamburger Stackers they envisioned. Instead, they ended up with a batch of broken big cucumbers.

"On the first run, we broke every one," Spence said.

But it taught the company a lot about some of the retooling they'd have to do to the plant in Millsboro.

Officials at the plant began making months worth of adjustments so one of the facility's four production lines could handle the jumbo cucumbers.

"We've learned a lot," McNulty said. "And we're still learning."

Making Hamburger Stackers requires a mix of automation and the human touch. The process starts when the big cucumbers arrive by truck and are rushed into a cold-storage facility to preserve their flavor.

Once cooled, the cucumbers can be loaded onto the production line and checked for bad spots and other flaws.

They're washed by machine a couple times and sliced.

Then they're sized. Jiggling along a conveyor belt, slices that are too small are weeded out by a worker and a machine. Those that are too big also are sorted out.

Too big?

Yes, the monster-sized cucumbers can get a little too big to fit in the jar.

The cucumber slices that make the cut are mechanically stacked into jars and then topped off by hand.

Ella Mae Wilkerson, who has worked at the Vlasic plant in Millsboro for 17 years, said it takes some fast hands to make certain that outgoing jars have enough pickles packed in.

"The bigger the jar, the harder it is," she said as containers of sweet gherkins being jarred on another production line zipped by on a conveyor belt.

After being packed with pickle slices, the jars of Hamburger Stackers are filled with a combination of water, vinegar, salt and other flavorings and colorings. They are capped, vacuum-sealed and pasteurized before being labeled and packed for global distribution.

Some details of how Hamburger Stackers are made are kept secret. McNulty said that is because the company is certain its rivals would love to figure out how to make their own Hamburger Stackers.

Vlasic is the only pickle-making company with such a product on the market. "We think the competition loves the idea," McNulty said.

Apparently, so does the pickle-eating public.

About $13 million worth of Hamburger Stackers were sold in the first five months after they were introduced.

The company is optimistic that the product will continue to grow in popularity with U.S. consumers who eat about 3.5 billion hamburgers at home annually.

Source: *Rochester Democrat and Chronicle,* December 13, 1999, p. 1F.

Legal, Ethical, and Environmental Issues

Designers must be careful to take into account a wide array of legal and ethical considerations. Moreover, if there is a potential to harm the environment, then those issues also become important. Most organizations have numerous government agencies that regulate them. Among the more familiar federal agencies are the Food and Drug Administration, the

Occupational Health and Safety Administration, the Environmental Protection Agency, and various state and local agencies. Bans on cyclamates, red food dye, phosphates, and asbestos have sent designers scurrying back to their drawing boards to find alternative designs that were acceptable to both government regulators and customers. Similarly, automobile pollution standards and safety features, such as seat belts, air bags, safety glass, and energy-absorbing bumpers and frames, have had a substantial impact on automotive design. Much attention also has been directed toward toy design to remove sharp edges, small pieces that can cause choking, and toxic materials. In construction, government regulations require the use of lead-free paint, safety glass in entranceways, access to public buildings for handicapped persons, and standards for insulation, electrical wiring, and plumbing.

Product liability can be a strong incentive for design improvements. **Product liability** means that a manufacturer is liable for any injuries or damages caused by a faulty product because of poor workmanship or design. Many business firms have faced lawsuits related to their products, including Firestone Tire & Rubber, Ford and General Motors, and toy manufacturers. Manufacturers also are faced with the implied warranties created by state laws under the **Uniform Commercial Code,** which says that products carry an implication of *merchantability* and *fitness*; that is, a product must be usable for its intended purposes.

product liability A manufacturer is liable for any injuries or damages caused by a faulty product.

Uniform Commercial Code Products carry an implication of merchantability and fitness.

The suits and potential suits have led to increased legal and insurance costs, expensive settlements with injured parties, and costly recalls. Moreover, increasing customer awareness of product safety can adversely affect product image and subsequent demand for a product.

Thus, it is extremely important to design products that are reasonably free of hazards. When hazards do exist, it is necessary to install safety guards or other devices for reducing accident potential, and to provide adequate warning notices of risks. Consumer groups, business firms, and various government agencies often work together to develop industrywide standards that help avoid some of the hazards.

Ethical issues often arise in the design of products and services; it is important for managers to be aware of these issues and for designers to adhere to ethical standards. Designers are often under pressure to speed up the design process and to cut costs. These pressures often require them to make trade-off decisions, many of which involve ethical considerations. One example of what can happen is "vaporware," when a software company doesn't issue a release of software as scheduled as it struggles with production problems or bugs in the software. The company faces the dilemma of releasing the software right away or waiting until most of the bugs have been removed—knowing that the longer it waits, the longer it will be before it receives revenues and the greater the risk of damage to its reputation.

Organizations generally want designers to adhere to guidelines such as the following:

Produce designs that are consistent with the goals of the organization. For instance, if the company has a goal of high quality, don't cut corners to save cost, even in areas where it won't be apparent to customer.

Give customers the value they expect.

Make health and safety a primary concern. At risk are employees who will produce goods or deliver services, workers who will transport the products, customers who will use the products or receive the services, and the general public, which might be endangered by the products or services.

Don't design something that has the potential to harm the environment.

Other Issues in Product and Service Design

Aside from legal, environmental, and ethical issues, designers must also take into account product or service life cycles, how much standardization to incorporate, product or service reliability, and the range of operating conditions under which a product or service must function. These topics are discussed in this section. We begin with life cycles.

Among the winners of the 2000 Industrial Design Excellence Award sponsored by Business Week. *Orangex Ojex Manual Juicer was produced with employees' ideas for efficiency, low cost and great tasting juice: ASF paper shredder for home use is designed to shred high volumes of paper at one time; Steelcase Leap chair has independently adjustable upper and lower back supports.*

LIFE CYCLES

life cycle Incubation, growth, maturity, saturation, and decline.

Many new products and services go through a **life cycle** in terms of demand. When an item is introduced, it may be treated as a curiosity. Demand is generally low because potential buyers are not yet familiar with the item. Many potential buyers recognize that all of the bugs have probably not been worked out and that the price may drop after the introductory period. Production methods are designed for low volume. With the passage of time, design improvements usually create a more reliable and less costly product. Demand then grows for these reasons and because of increasing awareness of the product or service. Higher production volume will involve different methods and contribute to lower costs. At the next stage in the life cycle, the product or service reaches maturity: there are few, if any, design changes, and demand levels off. Eventually, the market becomes saturated, which leads to a decline in demand. In the last stage of a life cycle, some firms adopt a defensive research posture whereby they attempt to prolong the useful life of a product or service by improving its reliability, reducing costs of producing it (and, hence, the price), redesigning it, or changing the packaging. These stages are illustrated in Figure 4–2.

Consider the products in various stages of the life cycle in the music industry: Digital audio tapes are in the introductory stage, compact disks are in the growth stage, cassettes are moving from the maturity-saturation stage into the decline stage.

Some products do not exhibit life cycles: wooden pencils, paper clips, nails, knives, forks and spoons, drinking glasses, and similar items. However, most new products do.

Services, too, experience life cycles. Often these are related to the life cycles of products. For example, as older products are phased out, services such as installation and repair of the older products also phase out.

Wide variations exist in the amount of time a particular product or service takes to pass through a given phase of its life cycle: some pass through various stages in a relatively short period; others take considerably longer. Often it is a matter of the basic *need* for the item and the *rate of technological change.* Some toys, novelty items, and style items have a life cycle of less than one year, whereas other, more useful items, such as clothes washers and dryers, may last for many years before yielding to technological change.

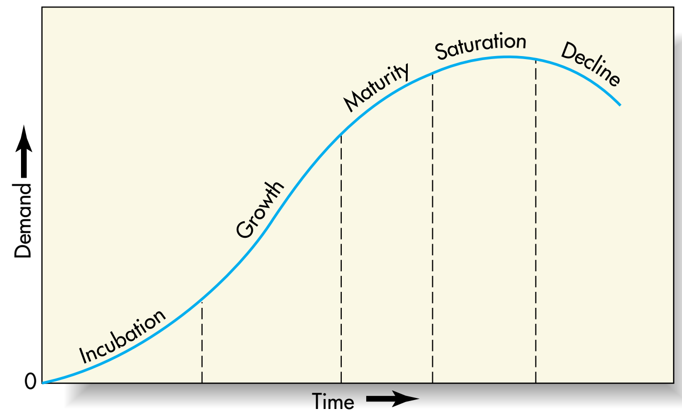


FIGURE 4-2

Products or services may exhibit life cycles over time

STANDARDIZATION

An important issue that often arises in both product/service design and process design is the degree of standardization. **Standardization** refers to the extent to which there is absence of variety in a product, service, or process. Standardized products are made in large quantities of identical items; calculators, computers, and 2 percent milk are examples. Standardized service implies that every customer or item processed receives essentially the same service. An automatic car wash is a good example; each car, regardless of how clean or dirty it is, receives the same service. Standardized processes deliver standardized service or produce standardized goods.

standardization Extent to which there is absence of variety in a product, service, or process.

Standardization carries a number of important benefits as well as certain disadvantages. Standardized products mean *interchangeable parts,* which greatly lower the cost of production while increasing productivity and making replacement or repair relatively easy compared with that of customized parts. Design costs are generally lower. For example, General Motors recently has attempted to standardize key components of its automobiles across product lines; components such as brakes, electrical systems, and other "under-the-skin" parts would be the same for all GM car models. By reducing variety, GM saves time and money while increasing quality and reliability in its products.

www.gm.com

Another benefit of standardization is reduced time and cost to train employees and reduced time to design jobs. Similarly, scheduling of work, inventory handling, and purchasing and accounting activities become much more routine.

Lack of standardization can at times lead to serious difficulties and competitive struggles, particularly when systems running under different conditions are incompatible. Consider a few examples: When VCRs were first introduced, there were two formats for tapes: VHS and Beta. Machines could play one or the other, but not both. This meant that producers needed to make two sets of tapes. High-definition television might have been introduced much earlier in the United States, but three competing—and incompatible—systems were proposed, which led to prolonged debate and study before one system could be agreed upon. The lack of standardization in computer software and operating systems (Macintosh versus IBM) has presented users with hard choices because of the difficulty in switching from one system to the other. And the use by U.S. manufacturers of the English system of measurement, while most of the rest of the world's manufacturers use the metric system, has led to problems in selling U.S. goods in foreign countries and in buying foreign machines for use in the United States. This may make it more difficult for U.S. firms to compete in the European Union. Similarly, U.S. auto manufacturers have complained for years about their inability to freely enter the Japanese market, but only recently have they begun to offer cars with steering wheels on the right side—the universal standard in Japan.

Standardization also has disadvantages. A major one relates to the reduction in variety. This can limit the range of customers to whom a product or service appeals. Customers

TABLE 4–1

Advantages and disadvantages of standardization

Advantages	1. Fewer parts to deal with in inventory and in manufacturing. 2. Reduced training costs and time. 3. More routine purchasing, handling, and inspection procedures. 4. Orders fillable from inventory. 5. Opportunities for long production runs and automation. 6. Need for fewer parts justifies increased expenditures on perfecting designs and improving quality control procedures.
Disadvantages	1. Designs may be frozen with too many imperfections remaining. 2. High cost of design changes increases resistance to improvements. 3. Decreased variety results in less consumer appeal.

may reluctantly accept a product only because nothing else suits their needs. But that creates a risk that a competitor will introduce a better product or greater variety (a feature of lean production), and realize a competitive advantage. Another disadvantage is that a manufacturer may freeze (standardize) a design prematurely and, once frozen, it may find compelling reasons to resist modification. A familiar example of this is the keyboard arrangement of typewriters and computer keyboards. Studies have demonstrated that another arrangement of keys would be more efficient, but the cost of replacing all of the equipment in existence and retraining millions of typists and word processors would not be worth the benefit.

Obviously, designers must consider important issues related to standardization when making choices. The major advantages and disadvantages of standardization are summarized in Table 4–1.

DESIGNING FOR MASS CUSTOMIZATION

Companies like standardization because it enables them to produce high volumes of relatively low-cost products, albeit products with little variety. Customers, on the other hand, typically prefer more variety, although they like the low cost. The question for producers is how to resolve these issues without (1) losing the benefits of standardization and (2) incurring a host of problems that are often liked to variety. These include increasing the resources needed to achieve design variety; increasing variety in the production process, which would add to the skills necessary to produce products, causing a decrease in productivity; creating an additional inventory burden during and after production, by having to carry replacement parts for the increased variety of parts; and adding to the difficulty of diagnosing and repairing failed products. The answer, at least for some companies, is **mass customization,** a strategy of producing standardized goods or services, but incorporating some degree of customization in the final product or service. Several tactics make this possible. One is *delayed differentiation,* and another is *modular design.*

mass customization Producing basically standardized goods, but incorporation some degree of customization.

delayed differentiation Producing, but not quite completing, a product or service until customer preferences are known.

Delayed differentiation is a *postponement* tactic: the process of producing, but not quite completing, a product or service, postponing completion until customer preferences or specifications are known. There are a number of variations of this. In the case of goods, almost-finished units might be held in inventory until customer orders are received, at which time customized features are incorporated, according to customer requests. For example, furniture makers can produce dining room sets, but not apply stain, allowing customers a choice of stains. Once the choice is made, the stain can be applied in a relatively short time, thus eliminating a long wait for customers, giving the seller a competitive advantage. Similarly, various e-mail or Internet services can be delivered to customers as standardized packages, which can then be modified according to the customer's preferences. The result of delayed differentiation is a product or service with customized features that can be quickly produced, appealings the customers' desire to for variety and speed of delivery, and yet one that for the most part is standardized, enabling the producer to realize the benefits of standardized production. This technique is not new. Manufacturers of men's clothing, for example, produce suits with pants that have legs that are unfinished, allowing customers to tailor choices as to the exact length and whether to have cuffs or no cuffs. What is new is the extent to which business organizations are finding ways to incorporate this concept into a broad range of products and services.

Modular design is a form of standardization. Modules represent groupings of component parts into subassemblies, usually to the point where the individual parts lose their separate identity. One familiar example of modular design is computers which have modular parts that can be replaced if they become defective. By arranging modules in different configurations, different computer capabilities can be obtained. For mass customization, modular design enables producers to quickly assemble modules to achieve a customized configuration for an individual customer, avoiding the long customer wait that would occur if individual parts had to be assembled. Modular design is also found in the construction industry. One firm in Rochester, New York, makes prefabricated motel rooms complete with wiring, plumbing, and even room decorations in its factory and then moves the complete rooms by rail to the construction site where they are integrated into the structure.

modular design A form of standardization in which component parts are grouped into modules that are easily replaced or interchanged.

One advantage of modular design of equipment compared with nonmodular design is that failures are often easier to diagnose and remedy because there are fewer pieces to investigate. Similar advantages are found in ease of repair and replacement; the faulty module is conveniently removed and replaced with a good one. The manufacture and assembly of modules generally involves simplifications: fewer parts are involved, so purchasing and inventory control become more routine, fabrication and assembly operations become more standardized, and training costs often are relatively low.

The main disadvantages of modular design stem from the decrease in variety: the number of possible configurations of modules is much less than the number of possible configurations based on individual components. Another disadvantage that is sometimes encountered is the inability to disassemble a module in order to replace a faulty part; the entire module must be scrapped—usually at a higher cost.

RELIABILITY

Reliability is a measure of the ability of a product, a part, a service, or an entire system to perform its intended function under a prescribed set of conditions. The importance of reliability is underscored by its use by prospective buyers in comparing alternatives and by sellers as one determinant of price. Reliability also can have an impact on repeat sales, reflect on the product's image, and, if it is too low, create legal implications.

reliability The ability of a product, part, or system to perform its intended function under a prescribed set of conditions.

The term **failure** is used to describe a situation in which an item does not perform as intended. This includes not only instances in which the item does not function at all, but also instances in which the item's performance is substandard or it functions in a way not intended. For example, a smoke alarm might fail to respond to the presence of smoke (not operate at all), it might sound an alarm that is too faint to provide an adequate warning (substandard performance), or it might sound an alarm even though no smoke is present (unintended response).

failure Situation in which a product, part, or system does not perform as intended.

Reliabilities are always specified with respect to certain conditions, called **normal operating conditions.** These can include load, temperature, and humidity ranges as well as operating procedures and maintenance schedules. Failure of users to heed these conditions often results in premature failure of parts or complete systems. For example, using a passenger car to tow heavy loads will cause excess wear and tear on the drive train; driving over potholes or curbs often results in untimely tire failure; and using a calculator to drive nails might have a marked impact on its usefulness for performing mathematical operations.

normal operating conditions The set of conditions under which an item's reliability is specified.

Improving Reliability.

Reliability can be improved in a number of ways, some of which are listed in Table 4–2.

Because overall system reliability is a function of the reliability of individual components, improvements in their reliability can increase system reliability. Unfortunately, inadequate production or assembly procedures can negate even the best of designs, and this

TABLE 4–2

Potential ways to improve reliability

1. Improve component design.
2. Improve production and/or assembly techniques.
3. Improve testing.
4. Use backups.
5. Improve preventive maintenance procedures.
6. Improve user education.
7. Improve system design.

is often a source of failures. System reliability can be increased by the use of backup components. Failures in actual use can often be reduced by upgrading user education and refining maintenance recommendations or procedures. Finally, it may be possible to increase the overall reliability of the system by simplifying the system (thereby reducing the number of components that could cause the system to fail) or altering component relationships (e.g., increasing the reliability of interfaces).

A fundamental question concerning improving reliability is: How much reliability is needed? Obviously, the reliability that is needed for a light bulb isn't in the same category as the reliability that is needed for an airplane. So the answer to the question depends on the potential benefits of improvements and on the cost of those improvements. Generally speaking, reliability improvements become increasingly costly. Thus, although benefits initially may increase at a much faster rate than costs, the opposite eventually becomes true. The optimal level of reliability is the point where the incremental benefit received equals the incremental cost of obtaining it. In the short term, this trade-off is made in the context of relatively fixed parameters (e.g., costs). However, in the longer term, efforts to improve reliability and reduce costs will lead to higher optimal levels of reliability.

ROBUST DESIGN

robust design Design that results in products or services that can function over a broad range of conditions.

Some products or services will function as designed only within a narrow range of conditions, while others will perform as designed over a much broader range of conditions. The latter have **robust design.** Consider a pair of fine leather boots—obviously not made for trekking through mud or snow. Now consider a pair of heavy rubber boots—just the thing for mud or snow. The rubber boots have a design that is more *robust* than the fine leather boots.

The more robust a product or service, the less likely it will fail due to a change in the environment in which it is used or in which it is performed. Hence, the more designers can build robustness into the product or service, the better it should hold up, resulting in a higher level of customer satisfaction.

A similar argument can be made for robust design as it pertains to the production process. Environmental factors can have a negative effect on the quality of a product or service. The more resistant a design is to those influences, the less likely is a negative effect. For example, many products go through a heating process: food products, ceramics, steel, petroleum products, and pharmaceutical products. Furnaces often do not heat uniformly; heat may vary either by position in an oven or over an extended period of production. One approach to this problem might be to develop a superior oven; another might be to design a system that moves the product during heating to achieve uniformity. A robust-design approach would develop a product that is unaffected by minor variations in temperature during processing.

Taguchi's Approach. Japanese engineer Genichi Taguchi's approach is based on the robust design. His premise is that it is often easier to design a product that is insensitive to environmental factors, either in manufacturing or in use, than to control the environmental factors.

The central feature of Taguchi's approach—and the feature used most often by U.S. companies—is *parameter design.* This involves determining the specification settings for both the product and the process that will result in robust design in terms of manufacturing variations, product deterioration, and conditions during use.

The Taguchi approach modifies the conventional statistical methods of experimental design. Consider this example. Suppose a company will use 12 chemicals in a new product it intends to produce. There are two suppliers for these chemicals, but the chemical concentrations vary slightly between the two suppliers. Classical design of experiments would require $2^{12} = 4{,}096$ test runs to determine which combination of chemicals would be optimum. Taguchi's approach would involve only testing a portion of the possible combinations. Relying on experts to identify the variables that would be most likely to affect important performance, the number of combinations would be dramatically reduced, perhaps to, say, 32. Identifying the best combination in the smaller sample might be a near-optimal combination instead of the optimal combination. The value of this approach is its ability to achieve major advances in product or process design fairly quickly, using a relatively small number of experiments.

Critics charge that Taguchi's methods are inefficient and incorrect, and often lead to nonoptimal solutions. Nonetheless, his methods are widely used and have been credited with helping to achieve major improvements in U.S. products and manufacturing processes.

Designing for Manufacturing

In the section, you will learn about design techniques that have greater applicability for the design of products than the design of services. Even so, you will see that they do have some relevance for service design. The topics include concurrent engineering, computer-assisted design, designing for assembly and disassembly, and the use of components for similar products.

CONCURRENT ENGINEERING

To achieve a smoother transition from product design to production, and to decrease product development time, many companies are using *simultaneous development,* or concurrent engineering. In its narrowest sense, **concurrent engineering** means bringing design and manufacturing engineering people together early in the design phase to simultaneously develop the product and the processes for creating the product. More recently, this concept has been enlarged to include manufacturing personnel (e.g., materials specialists) and marketing and purchasing personnel in loosely integrated, cross-functional teams. In addition, the views of suppliers and customers are frequently sought. The purpose, of course, is to achieve product designs that reflect customer wants as well as manufacturing capabilities.

concurrent engineering Bringing engineering design and manufacturing personnel together early in the design phase.

Vol. 3, Tape 1, Seg. 1
Caterpillar

Vol. 6, Seg. 1
TriState Industries

Traditionally, designers developed a new product without any input from manufacturing, and then turned over the design to manufacturing, which would then have to develop a process for making the new product. This "over-the-wall" approach created tremendous challenges for manufacturing, generating numerous conflicts and greatly increasing the time needed to successfully produce a new product. It also contributed to the "us versus them" mentality.

For these and similar reasons, the simultaneous development approach has great appeal. Among the key advantages of this approach are the following:

1. Manufacturing personnel are able to identify production capabilities and capacities. Very often, they have some latitude in design in terms of selecting suitable materials and processes. Knowledge of production capabilities can help in the selection process. In addition, cost and quality considerations can be greatly influenced by design, and conflicts during production can be greatly reduced.
2. Early opportunities for design or procurement of critical tooling, some of which might have long lead times. This can result in a major shortening of the product development process, which could be a key competitive advantage.

3. Early consideration of the technical feasibility of a particular design or a portion of a design. Again, this can avoid serious problems during production.
4. The emphasis can be on *problem* resolution instead of *conflict* resolution.

However, a number of potential difficulties exist in this codevelopment approach. Two key ones are the following:

1. Longstanding existing boundaries between design and manufacturing can be difficult to overcome. Simply bringing a group of people together and thinking that they will be able to work together effectively is probably naive.
2. There must be extra communication and flexibility if the process is to work, and these can be difficult to achieve.

Hence, managers should plan to devote special attention if this approach is to work.

COMPUTER-AIDED DESIGN (CAD)

computer-aided design (CAD) Product design using computer graphics.

Computers are increasingly used for product design. **Computer-aided design (CAD)** uses computer graphics for product design. The designer can modify an existing design or create a new one on a CRT by means of a light pen, a keyboard, a joystick, or a similar device. Once the design is entered into the computer, the designer can maneuver it on the screen: It can be rotated to provide the designer with different perspectives, it can be split apart to give the designer a view of the inside, and a portion of it can be enlarged for

Computer aided design (CAD) is used to design components and products to exact measurement and detail. This firehead sprinkler was designed to exact specifications and then manufactured at the Thompson Factory in Atlanta, Georgia.

closer examination. The designer can obtain a printed version of the completed design and file it electronically, making it accessible to people in the firm who need this information (e.g., marketing).

A growing number of products are being designed in this way, including transformers, automobile parts, aircraft parts, integrated circuits, and electric motors.

A major benefit of CAD is the increased productivity of designers. No longer is it necessary to laboriously prepare mechanical drawings of products or parts and revise them repeatedly to correct errors or incorporate revisions. A rough estimate is that CAD increases the productivity of designers from 3 to 10 times. A second major benefit of CAD is the creation of a database for manufacturing that can supply needed information on product geometry and dimensions, tolerances, material specifications, and so on. It should be noted, however, that CAD needs this database to function and that this entails a considerable amount of effort.

Some CAD systems allow the designer to perform engineering and cost analyses on proposed designs. For instance, the computer can determine the weight and volume of a part and do stress analysis as well. When there are a number of alternative designs, the computer can quickly go through the possibilities and identify the best one, given the designer's criteria.

PRODUCTION REQUIREMENTS

As noted earlier in the chapter, designers must take into account *production capabilities*. Design needs to clearly understand the capabilities of production (e.g., equipment, skills, types of materials, schedules, technologies, special abilities). This will help in choosing designs that match capabilities. When opportunities and capabilities do not match, management must consider the potential for expanding or changing capabilities to take advantage of those opportunities.

Forecasts of future demand can be very useful, supplying information on the timing and volume of demand, and information on demands for new products and services.

Manufacturability is a key concern for manufactured goods: Ease of fabrication and/or assembly is important for cost, productivity, and quality. With services, ease of providing the service, cost, productivity, and quality are of great concern.

The term **design for manufacturing (DFM)** is used to indicate the designing of products that are compatible with an organization's capabilities. A related concept in manufacturing is **design for assembly (DFA).** A good design must take into account not only how a product will be fabricated, but also how it will be assembled. Design for assembly focuses on reducing the number of parts in an assembly, as well as on the assembly methods and sequence that will be employed.

design for manufacturing (DFM) Designers take into account the organization's capabilities when designing a product.

design for assembly (DFA) Design focuses on reducing the number of parts in a product and on assembly methods and sequence.

RECYCLING

Recycling is sometimes an important consideration for designers. **Recycling** means recovering materials for future use. This applies not only to manufactured parts, but also to materials used during production, such as lubricants and solvents. Reclaimed metal or plastic parts may be melted down and used to make different products.

recycling Recovering materials for other uses.

Companies recycle for a variety of reasons, including:

1. Cost savings.
2. Environment concerns.
3. Environmental regulations.

An interesting note: Companies that want to do business in the European Economic Community must show that a specified proportion of their products are recyclable.

The pressure to recycle has given rise to the term **design for recycling (DFR),** referring to product design that takes into account the ability to disassemble a used product to recover the recyclable parts.

design for recycling (DFR) Design facilitates the recovery of materials and components in used products for reuse.

NEWSCLIP

More Cars Come with a Shade of Green—Recycled Materials

www.ford.com
www.gm.com
www.chryslercorp.com

Detroit's Big Three automakers, doing their best to build cars that don't fall apart, have a new goal: building cars that are easy to take apart.

The reason: Easy-to-remove parts are easy to recycle.

Car companies are putting the ability to recycle parts on the same level as safety, fuel economy, and costs when they design new vehicles.

For example, the Oldsmobile Aurora . . . uses scrap metal in its radiator mounting, and the bumper beams contain recycled copper and aluminum. Chrysler Corp. uses recycled tires for the splash guards on its midsize sedans.

Car parts have been recycled for years. But the auto industry only recently began to build cars with the idea of using recycled material. About 75 percent of new cars contain recycled material, mostly iron or steel used in the body.

Auto dismantlers usually buy a vehicle and remove all the parts that still work, such as seats, engines and headlights. The vehicle then goes to a shredder where it is reduced to small fragments and a huge magnet separates out the metal parts.

The challenge for auto companies is to find ways to separate the more than 20,000 different grades of plastic found in cars. About 24 percent of shredded material, known as "fluff," contains plastic, fluids, rubber, glass and other material. Most "fluff" can't be recycled.

Ford, GM and Chrysler have jointly formed the Vehicle Recycling Partnership in hopes of improving the technology to recover plastics and other material found in "fluff." Suppliers of material and the recycling industry are included in the partnership.

Manufacturers aren't suddenly becoming Friends of the Earth. "All of the recycling programs undertaken by Ford have been cost-effective," says Susan Day, vehicle recycling coordinator.

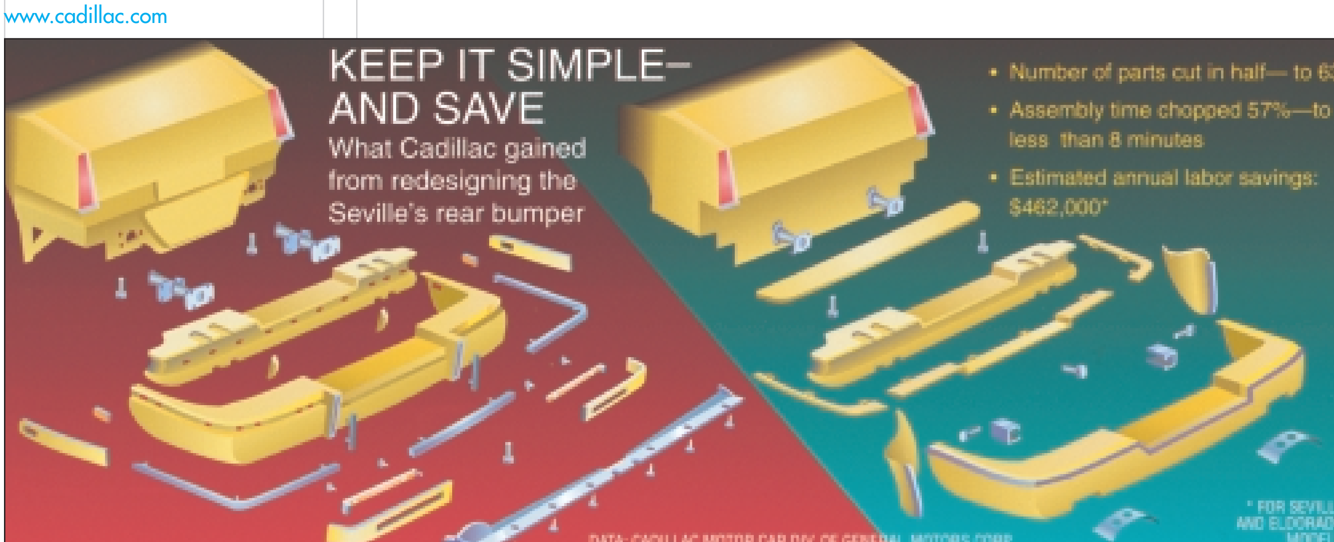
Source: *Rochester Democrat and Chronicle,* February 20, 1994, p. 11.

remanufacturing Refurbishing used products by replacing wornout or defective components.

www.cadillac.com

REMANUFACTURING

An emerging concept in manufacturing is the remanufacturing of products. **Remanufacturing** refers to refurbishing used products by replacing wornout or defective components, and reselling the products. This can be done by the original manufacturer, or another company. Among the products that have remanufactured components are automobiles, printers, copiers, cameras, computers, and telephones.



By redesigning the Seville's rear bumper, Cadillac cut the number of parts, thus reducing assembly time and labor costs. The new design also leads to high quality as there are few parts and steps that might be defective.

There are a number of important reasons for doing this. One is that a remanufactured product can be sold for about 50 percent of the cost of a new product. Another is that the process requires mostly unskilled and semiskilled workers. And in the global market, European lawmakers are increasingly requiring manufacturers to take back used products, because this means fewer products end up in landfills and there is less depletion of natural resources such as raw materials and fuel.

Designing products so that they can be more easily taken apart has given rise to yet another design consideration: **Design for disassembly (DFD)** includes using fewer parts and less material, and using snap-fits where possible instead of screws or nuts and bolts.

design for disassembly (DFD) Design so that used products can be easily taken apart.

The reading "Making It (Almost) New Again" gives examples of what some companies are doing.

READING

Making It (Almost) New Again

Phil Ebersole

www.kodak.com

Tired: *Landfills.*
Wired: *Recycling.*
Inspired: *Remanufacturing.*

The symbol of 20th century industry was the assembly line. The symbol of 21st century industry may be the disassembly line.

Xerox Corp. and Eastman Kodak Co. design products to make them not only easy to put together, but easy to take apart.

That's because so many parts and components from their old products are refurbished and put into new ones.

Xerox and Kodak, along with Caterpillar Inc. are the leaders in a movement called remanufacturing, said Robert T. Lund, a professor of manufacturing engineering at Boston University and author of a 1996 study of the subject.

"The driving force behind remanufacturing is thrift," Lund said. "A remanufactured product can be sold for 45 to 60 percent of the cost of a new one. You have something enormously more valuable than if you ground it up as raw material."

But in a few years, remanufacturing may be more than just a good idea. European countries are developing rules to make manufacturers take back their products instead of allowing them to wind up in landfills. Europe's rules could set the standard for the world, just as California auto emissions laws set the standard for the U.S. auto industry.

The 15-nation European Union is considering a rule that would require 85 percent of a car by weight to be recycled or remanufactured by the year 2002. This would increase to 95 percent by 2015.

This goes beyond what's done now. Currently about 75 percent of the average U.S. car is recycled or remanufactured. About all the metal in a car is reused, but little plastic and other materials.

Fixing up used equipment for resale is nothing new, but Xerox and Kodak take remanufacturing to the point of breaking down the distinction between new and used.

Almost all their new copiers and single-use cameras contain remanufactured parts. Virgin and remanufactured components go through the same production lines and meet the same tests.

If you could find an all-virgin product, they say, you couldn't tell the difference between it and one that was 95 percent remanufactured.

It's a process that goes beyond recycling, because companies conserve not only raw materials, but the energy, labor and ingenuity that went into making the components.

Lund said there are 73,000 companies in 61 industries, ranging from computer chips to locomotives, who do remanufacturing. They have 480,000 employees and do $53 billion worth of business.

Rochester Institute of Technology is a leader in this movement. It operates a remanufacturing laboratory at its Center for Integrated Manufacturing Studies and publishes a quarterly called *Remanufacturing Today.*

Remanufacturing isn't easy:

- Although companies ultimately may save money, the initial costs are higher. Remanufacturing is labor-intensive. Each remanufactured component is different, so the process can't be automated.
- Remanufacturers have to overcome a reputation for low quality. "People think remanufacturing is like repair, but it isn't," said Nabil Nasr, an RIT professor of manufacturing engineering.

- Designing products for remanufacturing makes it easier for other companies to refurbish your used products and sell them in competition with you.

For example, Kodak, along with Fuji Photo Film Co. and Konica Corp., battles "reloaders"—companies that sell poorly remade cameras under their own names with cheap Chinese film and used lenses and batteries, said David M. Snook, manager of worldwide recycling for Kodak single-use cameras.

The better Kodak designs its cameras for remanufacturing, the easier Kodak makes it for reloaders.

Remanufacturing is mainly carried on by small and mid-sized companies. Few large U.S. producers remanufacture their own products to the degree Xerox and Kodak do.

Some big companies still try to discourage remanufacturing, Lund said. They regard remanufactured products as competition for their virgin products. Others, like the Big 3 automakers, sanction or subcontract remanufacturing, but do little themselves.

Richard O. Carville, manager of design and manufacturing engineering for Xerox's print cartridge business unit, said he encountered skepticism in 1990 when he proposed remanufacturing print cartridges, the part of the copier that registers and prints the xerographic image.

After the first six months, the unit made a profit. It was able to cut prices as a result of the cost savings it had achieved.

One big challenge has been persuading customers to return the print cartridges, Carville said.

The first leaflets on cartridge return were ineffective. Now, when a customer opens the print engine package, the first thing he or she sees is a prepaid United Parcel Service or Canada Post mailer, shaped like an airplane.

"Environmental partnership" cartridges are sold at a discount if the customer promises to return them. "It's not a rebate," Carville said. "It's a prebate."

Xerox has a 60 percent return rate for cartridges. For comparison, Kodak has a 74 percent return rate for its Fun Saver cameras, which, Snook says, compares favorably to recycled aluminum cans.

The print cartridges are sent, at Xerox's expense, to centers in Nogales, Ariz., and Utica, NY, where the cartridges are dismantled, cleaned and inspected. Rejected parts are ground up as raw material. The rest are refurbished and shipped to Webster, NY, for remanufacturing.

All plastics in Xerox copiers are impregnated with a flame-retardant material. Carville's unit worked with Underwriters Laboratories in 1992 and 1993 to get an approval process for remanufactured plastic materials. Currently Xerox plastic is approved for up to five reuses.

Carville said his unit doesn't want to franchise remanufacturers. Xerox wants to control the process so as to guarantee quality.

But from the standpoint of the customer, you can get a remanufactured product quicker and cheaper from an outside company, said James D. Condon, president of Photikon Corp. of Fairport.

His company, originally a broker in copier or printer parts, started making photoreceptor belts in 1989 and now remanufactures entire printer cartridges.

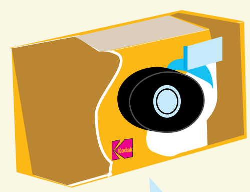
Unlike Xerox, Photikon is a true remanufacturer. Its products are completely remade, not a blend of remade and virgin parts like Xerox's. For this reason, Photikon's products can be made cheaper than Xerox's, Condon said.

NOT A THROWAWAY

Kodak's Fun Saver shows remanufacturing in action.

Step 1
Buy Kodak Fun Saver Camera loaded with Kodak Gold Film. Take pictures and drop off the entire camera to a photofinisher.

Step 2
Photofinisher ships the used camera back to Kodak's sites at Elmgrove, Guadalajara, Mexico and Chalon, France. Kodak gives incentives and premiums to encourage returns.



Step 3
Kodak and its subcontractors take the camera apart and inspect the parts. Worn out parts are ground up and used as raw material. Usable parts are refurbished for use in new cameras. 86 percent of the cameras by weight are recycled or refurbished.

Step 4
New Kodak Fun Saver cameras are made from virgin and refurbished parts, with new lenses and fresh film.

Photikon has worked on products remade up to 25 times, although not by Photikon every time.

The demand for remanufactured products is booming, Condon said. Photikon's 19 employees have been working overtime for the past three months, and he expects to hire 10 more in the next year.

Xerox remanufacturers about 1 million parts and 150,000 office machines each year. Kodak collects 50 million single-use cameras each year from 20 countries for remanufacturing, as well as reworking products ranging from microfilm machines to photographic film base.

Both companies use subcontractors extensively. Snook said that during the peak season, Outsource Enterprises of Rochester gets as many as 6 million single-use cameras in a week to be inspected, disassembled and sorted.

The most logical company to remanufacture a product is the original manufacturer, said Gordon H. McNeil, president of Magnetic Technologies Corp. of Pittsford, NY, which makes subsystems for Xerox and other companies. And looking at the used parts provides useful information in making new parts, he said.

He said about 35 percent of Magnetic Tech's output is remanufactured products, and this could grow to more than half in a few years.

Source: "Making It New Again and Again." Phil Ebersole, *Rochester Democrat and Chronicle,* July 14, 1997, p. E1. Used with permission.

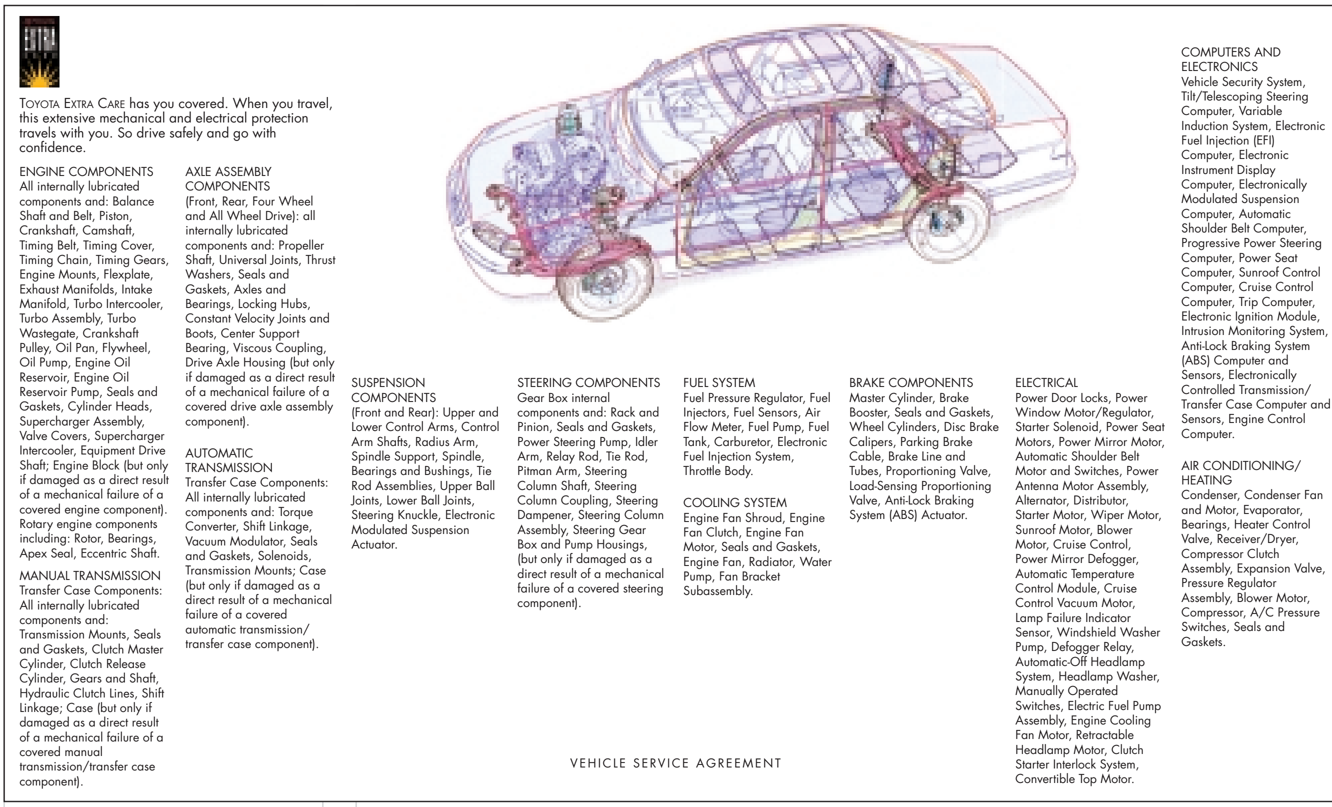
COMPONENT COMMONALITY

Companies often have multiple products or services to offer customers. Typically, these products or services have a high degree of similarity of features and components. This is particularly true of *product families,* but it is also true of many services. Companies can realize significant benefits when a part can be used in multiple products. For example, car manufacturers employ this tactic by using internal components such as water pumps, engines, and transmissions on several automobile nameplates. In addition to the saving in design time, companies reap benefits through standard training for assembly and installation, increased opportunities for savings by buying in bulk from suppliers, and commonality of parts for repair, which reduces the inventory dealers and auto parts stores must carry. Similar benefits accrue in services. For example, in automobile repair, component commonality means less training is needed because the variety of jobs is reduced. The same applies to appliance repair, where commonality and *substitutability* of parts are typical. Multiple-use forms in financial and medical services is another example. Computer software often comprises a number of modules that are commonly used for similar applications, thereby saving the time and cost to write the code for major portions of the software.

Designing for Services

As noted, some of the discussion on product design also applies to service design.

In certain cases, product design and service design go hand in hand. This stems from the fact that goods and services often exist in combination. For example, getting an oil change for your car involves a service (draining the old oil and putting in new oil) and a good (the new oil). Likewise, having new carpeting installed involves a service (the installation) and a good (the carpet). In some cases, what a customer receives is essentially a *pure* service, as in getting a haircut or your lawn mowed. However, the vast majority of cases involve some combination of goods and services. The proportion of service might be relatively low, as is the case in manufacturing, where the emphasis is on the production of goods. But even in manufacturing, there are services such as machine repair, employee training, safety inspections, and so on. Because goods and services are so intertwined, managers must be knowledgeable about both in order to be able to manage effectively. However, there are some key differences between manufacturing and service that warrant special consideration for service design. This section outlines these key differences, gives an overview of product design, and provides a brief list of guidelines for service design.



Toyota's Extra Care service contract protects the vehicle owner against costly mechanical and electrical repairs. This illustration uses design blueprint information to highlight covered parts and systems.

www.toyota.com

DIFFERENCES BETWEEN SERVICE DESIGN AND PRODUCT DESIGN

1. Products are generally tangible; services are generally intangible. Consequently, service design often focuses more on intangible factors (e.g., peace of mind, ambiance) than does product design.
2. In many instances services are created and delivered at the same time (e.g., a haircut, a car wash). In such instances there is less latitude in finding and correcting errors *before* the customer has a chance to discover them. Consequently, training, process design, and customer relations are particularly important.
3. Services cannot be inventoried. This poses restrictions on flexibility and makes capacity design very important.
4. Services are highly visible to consumers and must be designed with that in mind; this adds an extra dimension to process design, one that usually is not present in product design.
5. Some services have low barriers to entry and exit. This places additional pressures on service design to be innovative and cost-effective.
6. Location is often important to service design, with convenience as a major factor. Hence, design of services and choice of location are often closely linked.

Let's consider some of these differences in more detail. One is the need to consider the degree of customer contact in service design. That can range from no contact to high contact. When there is little or no contact, service design can be very much like product design. However, the greater the degree of customer contact, the greater the difference between service and product design, and the more complex service design becomes. The element of

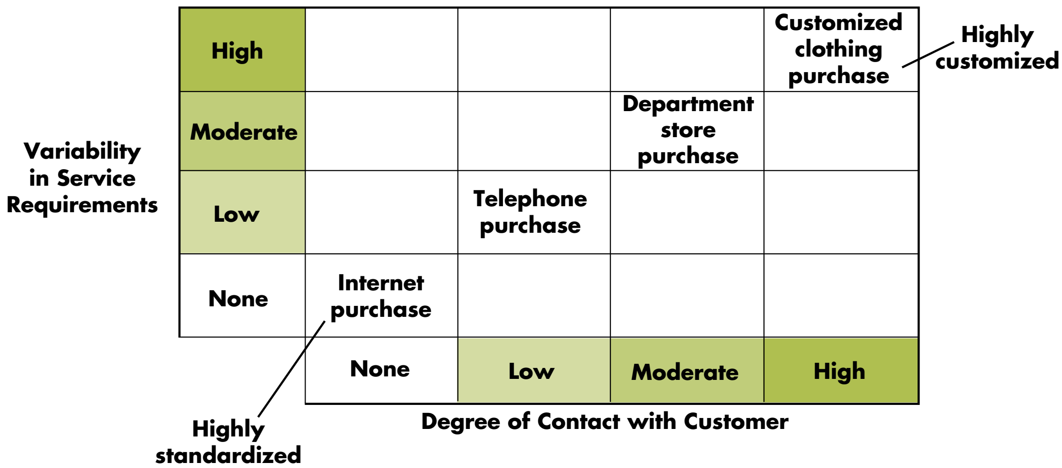


FIGURE 4–3

Service variability and customer contact influence service design

customer contact means that service design must incorporate *process* design; when there is customer contact, the process *is* the service. Although it is desirable to consider the manufacturability of a product when designing products, the product and the process are nonetheless separate entities. The following example of service design illustrates the inseparable nature of the service/process connection when customers are a part of the system. If a refrigerator manufacturer changes the procedure it uses for assembling a refrigerator, that change will be transparent to the person who purchases the refrigerator. Conversely, if the bus company makes changes to the bus schedule, or the bus routes, those changes will not be transparent to the riders. Obviously, this service redesign could not be done realistically without considering the *process* for delivering the service.

OVERVIEW OF SERVICE DESIGN

Service design begins with the choice of a service strategy, which determines the nature and focus of the service, and the target market. This requires an assessment by top management of the potential market and profitability (or need, in the case of a nonprofit organization) of a particular service, and an assessment of the organization's ability to provide the service. Once decisions on the focus of the service and the target market have been made, the customer requirements and expectations of the target market must be determined.

Two key issues in service design are the degree of variation in service requirements, and the degree of customer contact and customer involvement in the delivery system. These have an impact on the degree to which service can be standardized or must be customized. The lower the degree of customer contact and service requirement variability, the more standardized the service can be. Service design with no contact and little or no processing variability is very much like product design. Conversely, high variability and high customer contact generally mean the service must be highly customized. These concepts are illustrated in Figure 4–3.

A related consideration in service design is the opportunity for selling: The greater the degree of customer contact, the greater the opportunities for selling.

DESIGN GUIDELINES

A number of simple but highly effective rules are often used to guide the development of service systems. The key rules are the following:

1. Have a single, unifying theme, such as convenience or speed. This will help personnel to work together rather than at cross-purposes.
2. Make sure the system has the capability to handle any expected variability in service requirements.

Vol. 2, Tape 1, Seg. 1
First National Bank of Chicago

3. Include design features and checks to ensure that service will be reliable and will provide consistently high quality.
4. Design the system to be user-friendly. This is especially true for self-service systems.

Quality Function Deployment

quality function deployment (QFD) An approach that integrates the "voice of the customer" into the product development process.

Vol. 1, Tape 1, Seg. 2
Zytec, Motorola, Hewlett-Packard

Quality function deployment (QFD) is a structured approach for integrating the "voice of the customer" into the product or service development process. The purpose is to ensure that customer requirements are factored into every aspect of the process. Listening to and understanding the customer is the central feature of QFD. Requirements often take the form of a general statement such as, "It should be easy to adjust the cutting height of the lawn mower." Once the requirements are known, they must be translated into technical terms related to the product or service. For example, a statement about changing the height of the lawn mower may relate to the mechanism used to accomplish that, its position, instructions for use, tightness of the spring that controls the mechanism, or materials needed. For manufacturing purposes, these must be related to the materials, dimensions, and equipment used for processing.

The structure of QFD is based on a set of matrices. The main matrix relates customer requirements (what) and their corresponding technical requirements (how). This concept is illustrated in Figure 4–4.

FIGURE 4–4

An example of the house of quality. The main QFD Matrix.
Source: Ernst and Young Consulting Group, *Total Quality* (Homewood, Ill.: Dow-Jones Irwin, 1991), p. 121. Reprinted by permission.

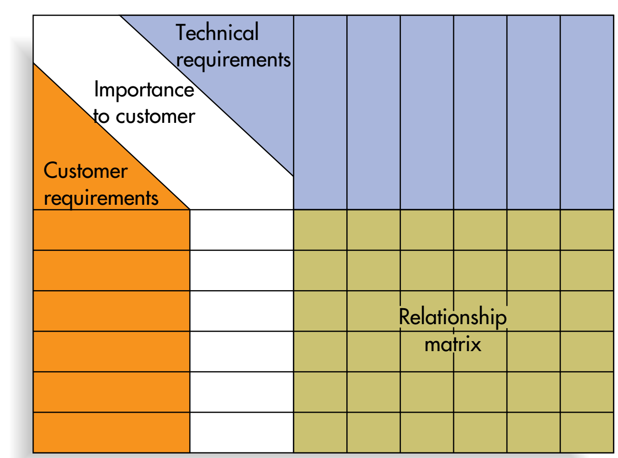


FIGURE 4–5

The house of quality

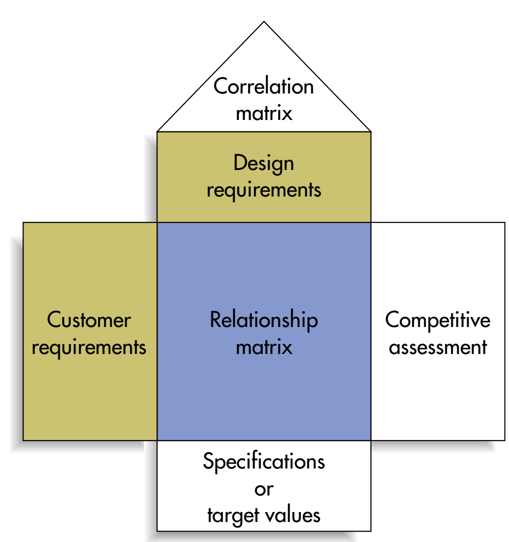


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Figure 4-5 appears before its text reference on next page (but on same spread).
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Additional features are usually added to the basic matrix to broaden the scope of analysis. Typical additional features include importance weightings and competitive evaluations. A correlational matrix is usually constructed for technical requirements; this can reveal conflicting technical requirements. With these additional features, the set of matrices has the form illustrated in Figure 4–5. It is often referred to as the *house of quality* because of its houselike appearance.

An analysis using this format is shown in Figure 4–6. The data relate to a commercial printer (customer) and the company that supplies the paper. At first glance, the display appears complex. It contains a considerable amount of information for product and process planning. Therefore, let's break it up into separate parts and consider them one at a time. To start, a key part is the list of customer requirements on the left side of the figure. Next,

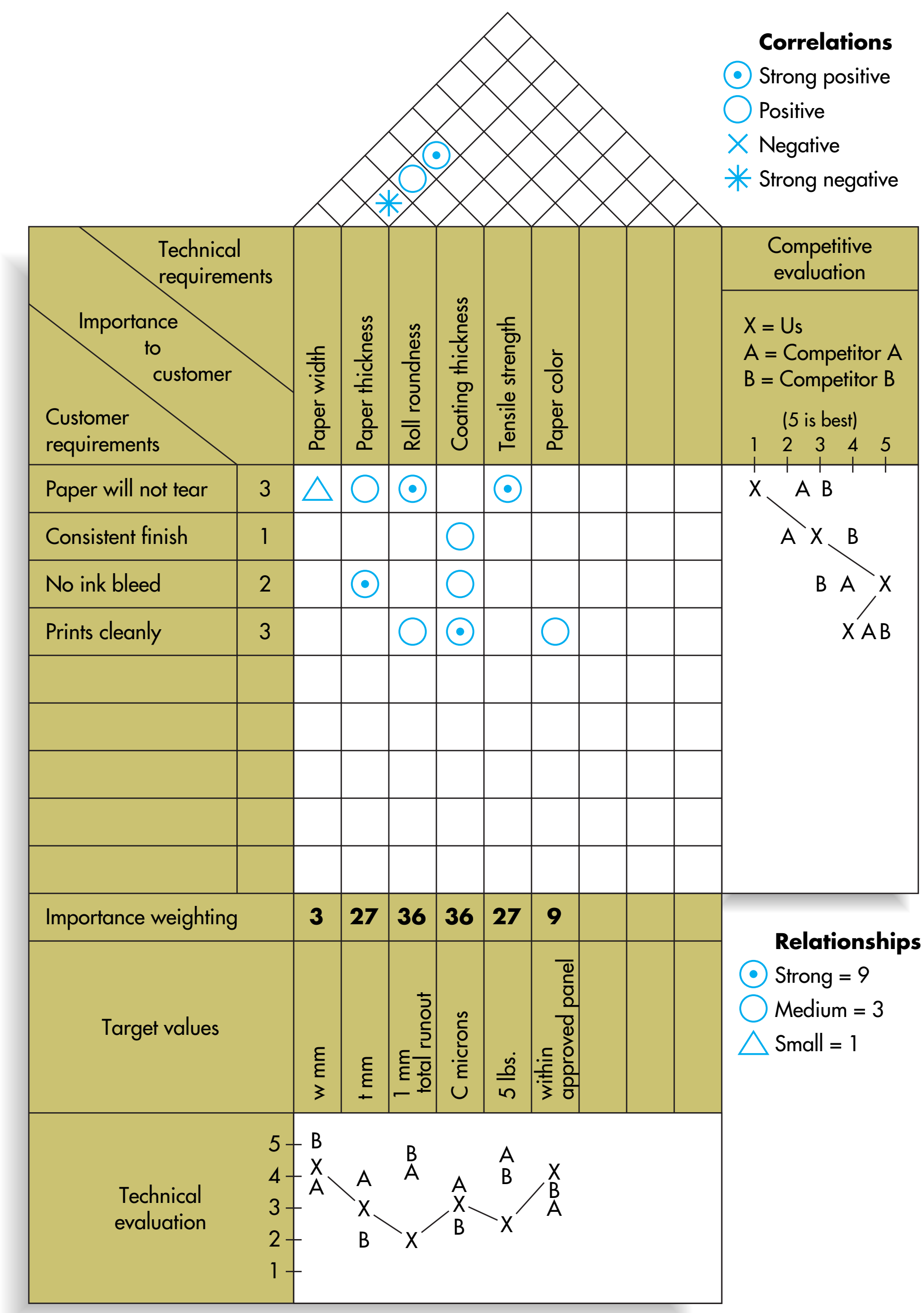

FIGURE 4–6

An example of the house of quality

note the technical requirements, listed vertically near the top. The key relationships and their degree of importance, are shown in the center of the figure. The circle with a dot inside indicates the strongest positive relationship; that is, it denotes the most important technical requirements for satisfying customer requirements. Now look at the "importance to customer" numbers that are shown next to each customer requirement (3 is the most important). Designers will take into account the importance values and the strength of correlation in determining where to focus the greatest effort.

Next, consider the correlation matrix at the top of the "house." Of special interest is the strong negative correlation between "paper thickness" and "roll roundness." Designers will have to find some way to overcome that or make a trade-off decision.

On the right side of the figure is a competitive evaluation comparing the supplier's performance on the customer requirements with each of the two key competitors (A and B). For example, the supplier (X) is worst on the first customer requirement and best on the third customer requirement. The line connects the X performances. Ideally, design will cause all of the Xs to be in the highest positions.

Across the bottom of Figure 4–6 are importance weightings, target values, and technical evaluations. The technical evaluations can be interpreted in a manner similar to that of the competitive evaluations (note the line connecting the Xs). The target values typically contain technical specifications, which we will not discuss. The importance weightings are the sums of values assigned to the relationships (see the lower right-hand key for relationship weights). The 3 in the first column is the product of the importance to the customer, 3, and the small (Δ) weight, 1. The importance weightings and target evaluations help designers focus on desired results. In this example, the first technical requirement has the lowest importance weighting, while the next four technical requirements all have relatively high importance weightings.

NEWSBITE

A QFD Snapshot

How a pencilmaker sharpened up its product by listening to "the voice of the customer" through quality function deployment.

Devised by Japan's Professor Yoji Akao, QFD has been winning adherents since it was transplanted to the U.S. in the late 1980s. In this example of how it works, Writesharp Inc. is imaginary, but the technique in the accompanying diagram is real.

First, Writesharp's customers were surveyed to determine what they value in a pencil and how they rate the leading brands. Each wish list item was correlated with a pencil's functional characteristics (see FUNCTIONAL CHARACTERISTICS matrix). "Reverse engineering"—tearing down a competitors' product to see what makes it tick—produced the competitive benchmark measurements for the various functions.

An analysis of the plots quickly revealed that the improvement with the biggest potential was a better-quality lead (see CUSTOMER SATISFACTION/CUSTOMER DEMANDS matrix). An interdepartmental team was assigned the task of evaluating new lead formulations that would last longer and generate less dust. Another team ran tests to determine whether substituting cedar for oak in the wood casing would improve shape quality, or hexagonality, and thus reduce the pencil's tendency to roll down slanted desktops.

Japanese Professor Yoji devised the system and coined the phrase "quality function deployment." The QFD matrix combines benchmarking, customer demands, a product's characteristics, and customer satisfaction to measure and improve product quality.

Functional characteristics
△ Strong correlation ○ Some correlation □ Possible correlation

Customer satisfaction
Scale: 1 to 5 (5 = best)

		Pencil length (inches)	Time between sharpenings (written lines)	Lead dust (particles per line)	Hexagonality	Importance rating (5 = highest)	Writesharp (now)	Competitor X (now)	Competitor Y (now)	Writesharp (target)
Customer demands	Easy to hold	○			○	3	4	3	3	4
	Does not smear		○	△		4	5	4	5	5
	Point lasts	□	△	○		5	4	5	3	5
	Does not roll	□			△	2	3	3	3	4
Benchmarks	Writesharp (now)	5	56	10	70%					
	Competitor X (now)	5	84	12	80%					
	Competitor Y (now)	4	41	10	60%					
	Writesharp (target)	5.5	100	6	80%					

	Writesharp (now)	Competitor X (now)	Competitor Y (now)	Writesharp (target)
Market price	15¢	18¢	14¢	16¢
Market share	16%	12%	32%	20%
Profit	2¢	3¢	2¢	4¢

The lead-formulation team organized its work with a similar matrix chart, segmented to show the functional contributions of the ingredients in pencil lead. This revealed that the binder, or glue, used in forming the lead was the key variable. Tests found a polymer that dramatically reduced dusting by retaining more moisture and also wore down more slowly. While this binder was more expensive, better production controls—going slightly beyond the performance of Competitor Y—promised to reduce waste enough to trim total per-pencil manufacturing costs by 1¢.

Changing the wood, meanwhile, yielded only marginal enhancements. So the company decided to upgrade the process controls used for cutting the wood and match the quality of Competitor X (see BENCHMARKS matrix).

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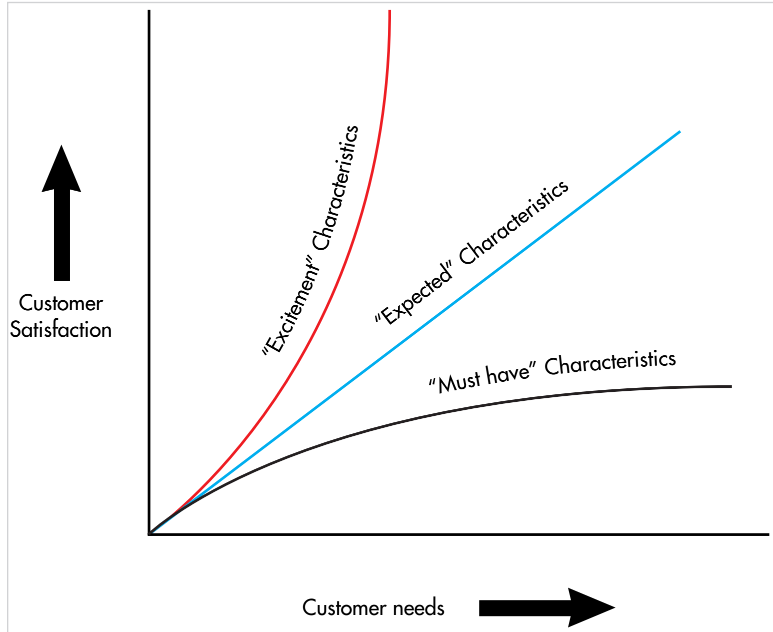
THE KANO MODEL

The *Kano model* can be an interesting way to conceptualize design characteristics in terms of customer satisfaction. It is illustrated in Figure 4–7. It describes relationships between customer needs and customer satisfaction for three categories of design characteristics: "must have" characteristics, "expected" characteristics, and "excitement" characteristics.

The "must have" characteristics are those which yield a basic level of satisfaction, but do not have the potential for increasing customer satisfaction beyond a certain level. For instance, increasing the length of refrigerator cords beyond a reasonable length will not increase customer satisfaction. Neither will making flour whiter, or producing chewing gum that keeps its flavor (while being chewed) for four weeks. In contrast, the "expected" characteristics in a design will yield a steady increase in customer satisfaction. For example, increasing the life of a tire, or the life of a roof, will yield additional customer

FIGURE 4-7

The Kano Model



satisfaction. And the longer the life of a tire or a roof, the higher the level of customer satisfaction. However, the greatest yield comes from "excitement" characteristics, perhaps evoking a "wow" from customers. These characteristics generate a disproportionate increase in customer satisfaction.

A possible design strategy would be to identify the design characteristics in each category for a particular product or service in order to incorporate the "must have" characteristics, and then conduct a cost-benefit analysis of characteristics in the other two categories to achieve desired results. This may not be as easy as it seems, especially in the case of the "excitement" characteristics, because those are often the most difficult to identify. In fact, customers may not be able to articulate them. Consequently, it may be necessary to turn to other alternatives (e.g., trial and error) to attempt to identify them.

Operations Strategy

Product and service design is a fertile area for achieving competitive advantage and/or increasing customer satisfaction. Potential sources of such benefits include:

1. Shortening the time to market. Many Japanese companies have been able to greatly reduce the time needed to get new or improved products to the market, giving them a competitive advantage.
2. Packaging products and ancillary services to increase sales. Examples include selling PCs at a reduced cost with a two-year Internet access sign-up agreement, extended warrantees on products, companies offering installation and service, and companies offering training with computer software.
3. Increasing emphasis on component commonality.
4. Using multiple-use platforms. Auto manufacturers use the same platform (basic chassis, say) for several nameplates (e.g., Jaguar S type, Lincoln LS, and Ford Thunderbird have shared the same platform). There are two basic computer platforms, PC and Mac, with many variations of computers using a particular platform.

5. Implementing tactics that will achieve the benefits of high volume while satisfying customer needs for variety, such as mass customization.
6. Continually monitoring products and services for small improvements rather than the "big bang" approach. Often the "little" things can have a positive, long-lasting effect on consumer attitudes and buying behavior.

Summary

Product and service design is a key factor in satisfying the customer. To be successful in product and service design, organizations must be continually aware of what customers want, what the competition is doing, what government regulations are, and what new technologies are available.

The design process involves motivation, ideas for improvement, organizational capabilities, and forecasting. In addition to product life cycles, legal, environmental, and ethical considerations influence design choices. What degree of standardization designers should incorporate into designs is also an important consideration. Key objectives for designers are to achieve a product or service design that will meet or exceed customer expectations, that is within cost or budget, and that takes into account the capabilities of operations. Although product design and service design are similar in some respects, a number of key differences exist between products and services that influence the way they are designed.

Successful design often incorporates many of these basic principles: Determine what customers want as a starting point; minimize the number of parts needed to manufacture an item or the number of steps to provide a service; simplify assembly or service, standardize as much as possible; and make the design robust. Trade-off decisions are common in design, and they involve such things as development time and cost, product or service cost, special features/performance, and product or service complexity.

Research and development efforts can play a significant role in product and process innovations, although these are sometimes so costly that only large companies or governments can afford to underwrite them.

Reliability of a product or service is often a key dimension in the eyes of the customer. Measuring and improving reliability are important aspects of product and service design, although other areas of the organization also have an influence on reliability.

Quality function deployment is one approach for getting customer input for product or service design.

Key Terms

computer-aided design (CAD), 000
concurrent engineering, 000
delayed differentiation, 000
design for assembly (DFA), 000
design for disassembly (DFD), 000
design for manufacturing (DFM), 000
design for operations, 152
design for recycling (DFR), 000
failure, 000
life cycle, 000
manufacturability, 000
mass customization, 000
modular design, 000
normal operating conditions, 000
product liability, 000
quality function deployment (QFD), 000
recycling, 000
reliability, 000
remanufacturing, 000
research and development (R&D), 000
reverse engineering, 000
robust design, 000
standardization, 000
Uniform Commercial Code, 000

Discussion and Review Questions

1. What are some of the factors that cause organizations to redesign their products or services?
2. Contrast applied research and basic research.
3. What is CAD? Describe some of the ways a product designer can use it.
4. Name some of the main advantages and disadvantages of standardization.
5. What is modular design? What are its main advantages and disadvantages?

6. Explain the term *design for manufacturing* and briefly explain why it is important.
7. What are some of the competitive advantages of concurrent engineering?
8. Explain the term *remanufacturing*.
9. What is meant by the term *life cycle?* Why would this be a consideration in product or service design?
10. Why is R&D a key factor in productivity improvement? Name some ways R&D contributes to productivity improvements.
11. What is *mass customization?*
12. Name two factors that could make service design much different from product design.
13. Explain the term *robust design.*
14. Explain what *quality function deployment* is and how it can be useful.

Memo Writing Exercises

1. At a recent presentation, your company's CEO stated the company's intent to expand into the service sector. Currently, your company is devoted exclusively to manufacturing. Of particular interest to your supervisor, Tom Henry, were the following statements: "In all likelihood, we will use some of our own product designers for service design. They know our products and, besides, product design and service design are pretty much the same." Henry has asked you to look into this proposal. Write Tom a half-page memo indicating the circumstances under which this proposal might work and those under which it might not.
2. Suppose you have just received a memo questioning the merits of remanufacturing, a proposed new approach to be used by your company. The writer, Mary Barkley, a group leader in another department, is skeptical. Write a half-page memo to her on the benefits of remanufacturing.
3. Suppose you have been hired as a consultant for a supermarket chain to advise on a plan to prepare ahead of time and cook complete "package" meals to be sold as convenience items for customers. The menu will vary from day to day, but a typical menu might look like this:

♣♣♣♣♣	♣♣♣♣♣	♣♣♣♣♣
Roast leg of lamb	Filet mignon	Fried chicken
Rosemary potatoes	Pan roast potatoes	Mashed potatoes
Garden peas	Garden salad	Fruit salad
Roll, butter	French bread, butter	Biscuit, honey

Write a one-page memo to Brad Marlow, Manager of Special Services, proposing the use of delayed differentiation for this concept. Explain how it would work and outline the potential benefits as well as the potential disadvantages of your idea.

Problems

1. Prepare a table similar to Figure 4–3. Then place each of these banking transactions in the appropriate cell of the table:
   a. Make a cash withdrawal from an automatic teller machine (ATM).
   b. Make a savings deposit using a teller.
   c. Direct deposit by employer.
   d. Open a savings account.
   e. Apply for a home equity loan.
2. Prepare a table similar to Figure 4–3. Then place each of these post office transactions in the appropriate cell of the table:
   a. Buy stamps from a machine.
   b. Buy stamps from a postal clerk.
   c. Mail a package that involves checking first class and express rates.
   d. File a complaint.
3. List the steps involved in getting gasoline into your car for full service and for self service. Assume that paying cash is the only means of payment. For each list, identify the potential trouble points and indicate a likely problem.
4. Construct a list of steps for making a cash withdrawal from an automatic teller machine (ATM). Assume that the process begins at the ATM with your bank card in hand. Then identify the

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potential failure points (i.e., where problems might arise in the process). For each failure point, state one potential problem.

5. *a.* Refer to Figure 4–6. What two technical requirements have the highest impact on the customer requirement that the paper not tear?
   b. The following table presents technical requirements and customer requirements for the output of a laser printer. First, decide if any of the technical requirements relate to each customer requirement. Decide which technical requirement, if any, has the greatest impact on that customer requirement.

	TECHNICAL REQUIREMENTS		
Customer Requirements	**Type of Paper**	**Internal Paper Feed**	**Print Element**
Paper doesn't wrinkle			
Prints clearly			
Easy to use			

6. Prepare a table similar to that shown in Problem 5b for cookies sold in a bakery. List what you believe are the three most important customer requirements (not including cost) and the three most relevant technical requirements (not including sanitary conditions). Next, indicate by a checkmark which customer requirements and which technical requirements are related.

	TECHNICAL REQUIREMENTS		
Customer Require-ments	**Ingre-dients**	**Han-dling**	**Prepa-ration**
Taste			
Appear-ance			
Texture/consistency			

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Internet Sites

www.onlineethics.org has a long list of codes of ethics for various professional engineering and scientific societies.

SUPPLEMENT TO CHAPTER 4

Reliability

SUPPLEMENT OUTLINE

LEARNING OBJECTIVES

After completing this supplement, you should be able to

1. Define reliability.
2. Perform simple reliability computations.
3. Explain the purpose of redundancy in a system.

Introduction

Reliability is a measure of the ability of a product, service, part, or system to perform its intended function under a prescribed set of conditions. In effect, reliability is a *probability.*

Suppose that an item has a reliability of .90. This means that it has a 90 percent probability of functioning as intended. The probability it will fail is $1 - .90 = .10$, or 10 percent. Hence, it is expected that, on the average, 1 of every 10 such items will fail or, equivalently, that the item will fail, on the average, once in every 10 trials. Similarly, a reliability of .985 implies 15 failures per 1,000 parts or trials.

reliability The ability of a product, part, or system to perform its intended function under a prescribed set of conditions.

Quantifying Reliability

Engineers and designers have a number of techniques at their disposal for assessing the reliability. A discussion of those techniques is not within the scope of this text. Instead, let us turn to the issue of quantifying overall product or system reliability. Probability is used in two ways.

1. The probability that the product or system will function when activated.
2. The probability that the product or system will function for a given length of time.

The first of these focuses on *one point in time* and is often used when a system must operate for one time or a relatively few number of times. The second of these focuses on the *length of service.* The distinction will become more apparent as each of these approaches is described in more detail.

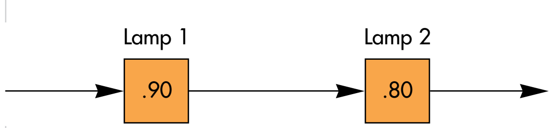
The probability that a system or a product will operate as planned is an important concept in system and product design. Determining that probability when the product or system consists of a number of *independent* components requires the use of the rules of probability for independent events. **Independent events** have no relation to the occurrence or nonoccurrence of each other. What follows are three examples illustrating the use of probability rules to determine whether a given system will operate successfully.

independent events Events whose occurrence or nonoccurrence do not influence each other.

Rule 1. If two or more events are independent and "success" is defined as the probability that all of the events occur, then the probability of success is equal to the product of the probabilities of the events.

Example. Suppose a room has two lamps, but to have adequate light both lamps must work (success) when turned on. One lamp has a probability of working of .90, and the other has a probability of working of .80. The probability that both will work is $.90 \times .80 = .72$. Note that the order of multiplication is unimportant: $.80 \times .90 = .72$. Also note that if the room had three lamps, three probabilities would have been multiplied.

This system can be represented by the following diagram:



Even though the individual components of a system might have high reliabilities, the system as a whole can have considerably less reliability because all components that are in series (as are the ones in the preceding example) must function. As the number of components in a series increases, the system reliability decreases. For example, a system that has eight components in a series, each with a reliability of .99, has a reliability of only $.99^8 = .923$.

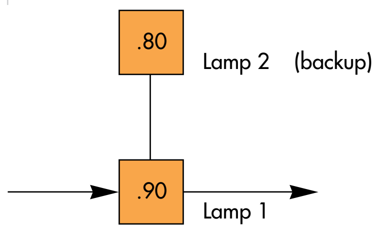
Obviously, many products and systems have a large number of component parts that must all operate, and some way to increase overall reliability is needed. One approach is to use **redundancy** in the design. This involves providing backup parts for some items.

redundancy The use of backup components to increase reliability.

Rule 2. If two events are independent and "success" is defined as the probability that *at least one* of the events will occur, the probability of success is equal to the probability of either one plus 1.00 minus that probability multiplied by the other probability.

Example. There are two lamps in a room. When turned on, one has a probability of working of .90 and the other has a probability of working of .80. Only a single lamp is needed to light for success. If one fails to light when turned on, the other lamp is turned on. Hence, one of the lamps is a backup in case the other one fails. Either lamp can be treated as the backup; the probability of success will be the same. The probability of success is .90 + (1 − .90) × .80 = .98. If the .80 light is first, the computation would be .80 + (1 − .80) × .90 = .98.

This system can be represented by the following diagram.

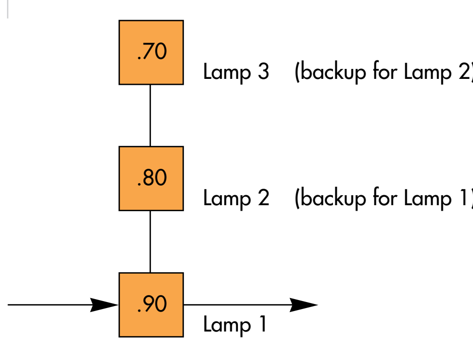


Rule 3. If three events are involved and success is defined as the probability that at least one of them occurs, the probability of success is equal to the probability of the first one (any of the events), plus the product of 1.00 minus that probability and the probability of the second event (any of the remaining events), plus the product of 1.00 minus each of the first two probabilities and the probability of the third event, and so on. This rule can be expanded to cover more than three events.

Example. Three lamps have probabilities of .90, .80, and .70 of lighting when turned on. Only one lighted lamp is needed for success; hence, two of the lamps are considered to be backups. The probability of success is:

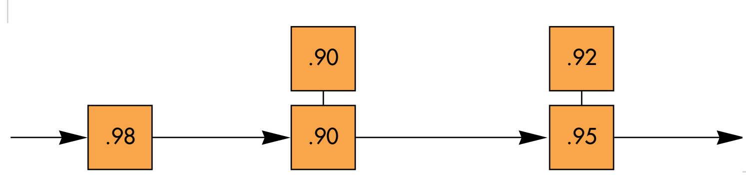
[#1 operates]	[#1 fails	and	#2 operates]	[#1 fails	and	#2 fails	and	#3 operates]	
.90	+ (1 − .90)	×	.80	+ (1.00 − .90)	×	(1.00 − .80)	×	.70	= .994

This system can be represented by the following diagram:



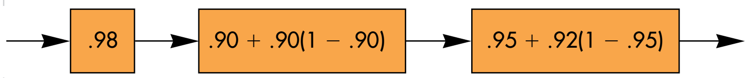
Example 1

Determine the reliability of the system shown below.



Solution

The system can be reduced to a series of three components:



The system reliability is, then, the product of these:

$.98 \times .99 \times .996 = .966$

The second way of looking at reliability considers the incorporation of a time dimension: Probabilities are determined relative to a specified length of time. This approach is commonly used in product warranties, which pertain to a given period of time after purchase of a product.

A typical profile of product failure rate over time is illustrated in Figure 4S−1. Because of its shape, it is sometimes referred to as a bathtub curve. Frequently, a number of products fail shortly after they are put into service, not because they wear out, but because they are defective to begin with. The rate of failures decreases rapidly once the truly defective items are weeded out. During the second phase, there are fewer failures because most of the defective items have been eliminated, and it is too soon to encounter items that fail because they have worn out. In some cases, this phase covers a relatively long period of time. In the third phase, failures occur because the products are worn out, and the failure rate increases.

Information on the distribution and length of each phase requires the collection of historical data and analysis of those data. It often turns out that the **mean time between failures (MTBF)** in the infant mortality phase can be modeled by a negative exponential distribution, such as that depicted in Figure 4S−2. Equipment failures as well as product failures may occur in this pattern. In such cases, the exponential distribution can be used

mean time between failures (MTBF) The average length of time between failures of a product or component.

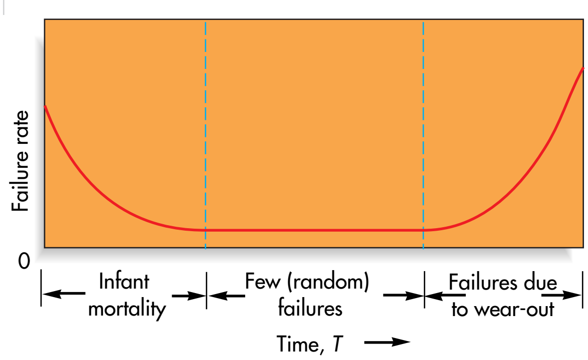


FIGURE 4S-1

Failure rate is a function of time

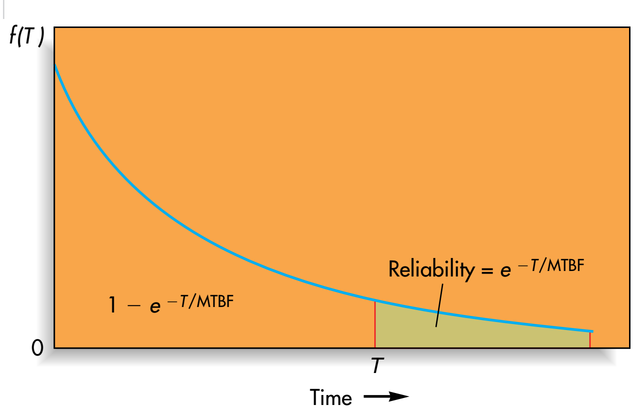


FIGURE 4S-2

An exponential distribution

to determine various probabilities of interest. The probability that equipment or a product put into service at time 0 will fail *before* some specified time, *T*, is equal to the area under the curve between 0 and *T*. Reliability is specified as the probability that a product will last *at least until* time *T*; reliability is equal to the area under the curve *beyond T*. (Note that the total area under the curve in each phase is treated as 100 percent for computational purposes.) Observe that as the specified length of service increases, the area under the curve to the right of that point (i.e., the reliability) decreases.

Determining values for the area under a curve to the right of a given point, *T*, becomes a relatively simple matter using a table of exponential values. An exponential distribution is completely described using a single parameter, the distribution mean, which reliability engineers often refer to as the mean time between failures. Using the symbol *T* to represent length of service, the probability that failure will not occur before time *T* (i.e., the area in the right tail) is easily determined:

$$P(\text{no failure before } T) = e^{-T/\text{MTBF}}$$

where

e = Natural logarithm, 2.7183 . . .

T = Length of service before failure

MTBF = Mean time between failures

The probability that failure will occur before time *T* is 1.00 minus that amount:

$$P(\text{failure before } T) = 1 - e^{-T/\text{MTBF}}$$

Selected values of $e^{-T/\text{MTBF}}$ are listed in Table 4S−1.

TABLE 4S–1

Values of $e^{-T/MTBF}$

T/MTBF	$e^{-T/MTBF}$	T/MTBF	$e^{-T/MTBF}$	T/MTBF	$e^{-T/MTBF}$
0.10	.9048	2.60	.0743	5.10	.0061
0.20	.8187	2.70	.0672	5.20	.0055
0.30	.7408	2.80	.0608	5.30	.0050
0.40	.6703	2.90	.0550	5.40	.0045
0.50	.6065	3.00	.0498	5.50	.0041
0.60	.5488	3.10	.0450	5.60	.0037
0.70	.4966	3.20	.0408	5.70	.0033
0.80	.4493	3.30	.0369	5.80	.0030
0.90	.4066	3.40	.0334	5.90	.0027
1.00	.3679	3.50	.0302	6.00	.0025
1.10	.3329	3.60	.0273	6.10	.0022
1.20	.3012	3.70	.0247	6.20	.0020
1.30	.2725	3.80	.0224	6.30	.0018
1.40	.2466	3.90	.0202	6.40	.0017
1.50	.2231	4.00	.0183	6.50	.0015
1.60	.2019	4.10	.0166	6.60	.0014
1.70	.1827	4.20	.0150	6.70	.0012
1.80	.1653	4.30	.0136	6.80	.0011
1.90	.1496	4.40	.0123	6.90	.0010
2.00	.1353	4.50	.0111	7.00	.0009
2.10	.1255	4.60	.0101		
2.20	.1108	4.70	.0091		
2.30	.1003	4.80	.0082		
2.40	.0907	4.90	.0074		
2.50	.0821	5.00	.0067		

Example 2

By means of extensive testing, a manufacturer has determined that its Super Sucker Vacuum Cleaner models have an expected life that is exponential with a mean of four years. Find the probability that one of these cleaners will have a life that ends:

a. After the initial four years of service.

b. Before four years of service are completed.

c. Not before six years of service.

Solution

MTBF = 4 years

a. $T = 4$ years:

$$T/\text{MTBF} = \frac{4 \text{ years}}{4 \text{ years}} = 1.0$$

From Table 4S−1, $e^{-1.0} = .3679$.

b. The probability of failure before $T = 4$ years is $1 - e^{-1}$, or $1 - .3679 = .6321$.

c. $T = 6$ years:

$$T/\text{MTBF} = \frac{6 \text{ years}}{4 \text{ years}} = 1.50$$

From Table 4S−1, $e^{-1.5} = .2231$.

Product failure due to wear-out can sometimes be modeled by a normal distribution. Obtaining probabilities involves the use of a table (refer to Appendix Table B). The table provides areas under a normal curve from (essentially) the left end of the curve to a specified point z, where z is a *standardized* value computed using the formula

$$z = \frac{T - \text{Mean wear-out time}}{\text{Standard deviation of wear-out time}}$$

Thus, to work with the normal distribution, it is necessary to know the mean of the distribution and its standard deviation. A normal distribution is illustrated in Figure 4S–3. Appendix Table B contains normal probabilities (i.e., the area that lies to the left of z). To obtain a probability that service life will not exceed some value T, compute z and refer to the table. To find the reliability for time T, subtract this probability from 100 percent. To obtain the value of T that will provide a given probability, locate the nearest probability under the curve *to the left* in Table B. Then use the corresponding z in the preceding formula and solve for T.

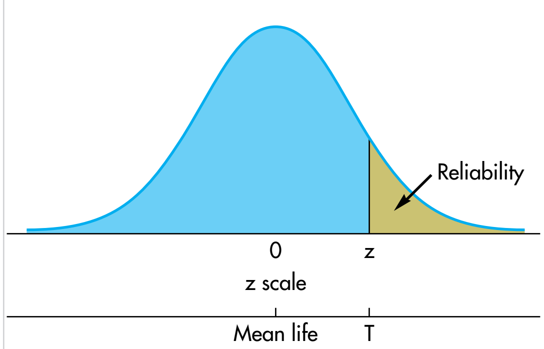


FIGURE 4S–3

A normal curve

Example 3

The mean life of a certain ball bearing can be modeled using a normal distribution with a mean of six years and a standard deviation of one year. Determine each of the following:

a. The probability that a ball bearing will wear out *before* seven years of service.

b. The probability that a ball bearing will wear out *after* seven years of service (i.e., find its reliability).

c. The service life that will provide a wear-out probability of 10 percent.

Solution

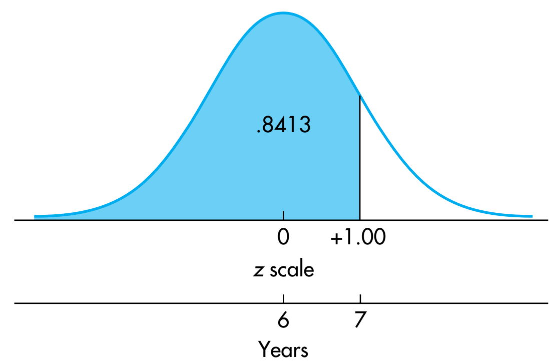
Wear-out life mean = 6 years

Wear-out life standard deviation = 1 year

Wear-out life is normally distributed

a. Compute z and use it to obtain the probability directly from Appendix Table B (see diagram).

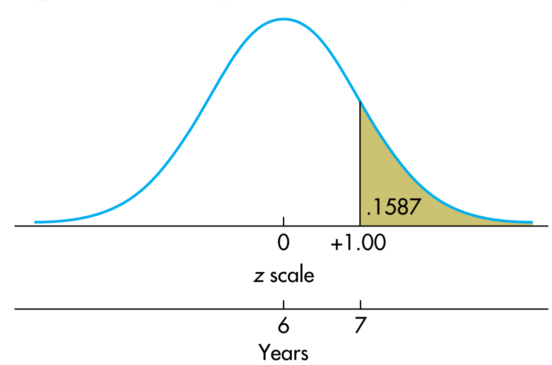
$$z = \frac{7-6}{1} = +1.00$$



Thus, $P(T < 7) = .8413$.

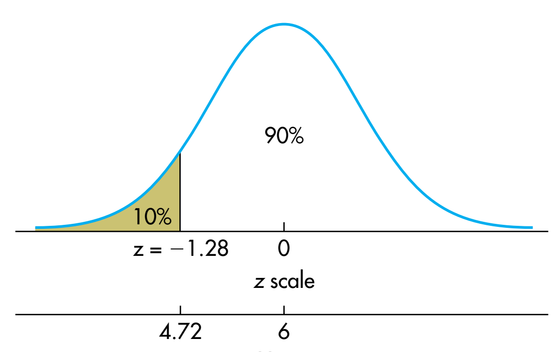
b. Subtract the probability determined in part *a* from 100 percent (see diagram).

$$1.00 - .8413 = .1587$$



c. Use the normal table and find the value of z that corresponds to an area under the curve of 10% (see diagram).

$$z = -1.28 = \frac{T-6}{1}$$



Solving for T, we find $T = 4.72$ years.

Availability

A related measure of importance to customers, and hence to designers, is **availability.** It measures the fraction of time a piece of equipment is expected to be operational (as opposed to being down for repairs). Availability can range from zero (never available) to 1.00 (always available). Companies that can offer equipment with a high availability factor have a competitive advantage over companies that offer equipment with lower availability values. Availability is a function of both the mean time between failures and the mean time to repair. The availability factor can be computed using the following formula:

availability The fraction of time a piece of equipment is expected to be available for operation.

$$Availability = \frac{MTBF}{MTBF + MTR}$$

where

MTBF = Mean time between failures

MTR = Mean time to repair

Example 4

A copier is expected to be able to operate for 200 hours between repairs, and the mean repair time is expected to be two hours. Determine the availability of the copier.

Solution

MTBF = 200 hours, and MTR = 2 hours

$$Availability = \frac{MTBF}{MTBF + MTR} = \frac{200}{200 + 2} = .99$$

Two implications for design are revealed by the availability formula. One is that availability increases as the mean time between failures increases. The other is that availability also increases as the mean repair time decreases. It would seem obvious that designers would want to design products that have a long time between failures. However, some design options enhance repairability, which can be incorporated into the product. Laser printers, for example, are designed with print cartridges that can easily be replaced.

Key Terms

Solved Problems

Problem 1

A product design engineer must decide if a redundant component is cost-justified in a certain system. The system in question has a critical component with a probability of .98 of operating. System failure would involve a cost of $20,000. For a cost of $100, a switch could be added that would automatically transfer the system to the backup component in the event of a failure. Should the backup be added if the backup probability is also .98?

Solution

Because no probability is given for the switch, we will assume its probability of operating when needed is 100 percent. The expected cost of failure (i.e., without the backup) is $20,000 (1 − .98) = $400.

With the backup, the probability of *not* failing would be:

$$.98 + .02(.98) = .9996$$

Hence, the probability of failure would be 1 − .9996 = .0004. The expected cost of failure with the backup would be the added cost of the backup plus the failure cost:

$$\$100 + \$20{,}000(.0004) = \$108$$

Because this is less than the cost without the backup, it appears that adding the backup is definitely cost justifiable.

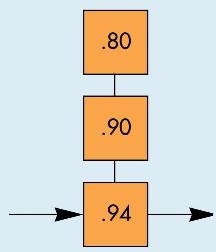
Problem 2

Due to the extreme cost of interrupting production, a firm has two standby machines available in case a particular machine breaks down. The machine in use has a reliability of .94, and the backups have reliabilities of .90 and .80. In the event of a failure, either backup can be pressed into service. If one fails, the other backup can be used. Compute the system reliability.

Solution

$R1 = .94, \quad R2 = .90, \quad \text{and} \quad R3 = .80$

The system can be depicted in this way:



$$R_{\text{system}} = R_1 + R_2(1 - R_1) + R_3(1 - R_2)(1 - R_1)$$
$$= .94 + .90(1 - .94) + .80(1 - .90)(1 - .94) = .9988$$

Problem 3

A hospital has three *independent* fire alarm systems, with reliabilities of .95, .97, and .99. In the event of a fire, what is the probability that a warning would be given?

Solution

A warning would *not* be given if all three alarms failed. The probability that at least one alarm would operate is $1 - P(\text{none operate})$:

$$P(\text{none operate}) = (1 - .95)(1 - .97)(1 - .99) = .000015$$
$$P(\text{warning}) = 1 - .000015 = .999985$$

Problem 4

A weather satellite has an expected life of 10 years from the time it is placed into earth orbit. Determine its probability of no wear-out before each of the following lengths of service. (Assume the exponential distribution is appropriate.)

a. 5 years. *b.* 12 years. *c.* 20 years. *d.* 30 years.

Solution

MTBF = 10 years

Compute the ratio T/MTBF for T = 5, 12, 20, and 30, and obtain the values of $e^{-T/\text{MTBF}}$ from Table 4S−1. The solutions are summarized in the following table.

T	MTBF	T/MTBF	$e^{-T/\text{MTBF}}$
a. 5	10	0.50	.6065
b. 12	10	1.20	.3012
c. 20	10	2.00	.1353
d. 30	10	3.00	.0498

Problem 5

What is the probability that the satellite described in Solved Problem 4 will fail between 5 and 12 years after being placed into earth orbit?

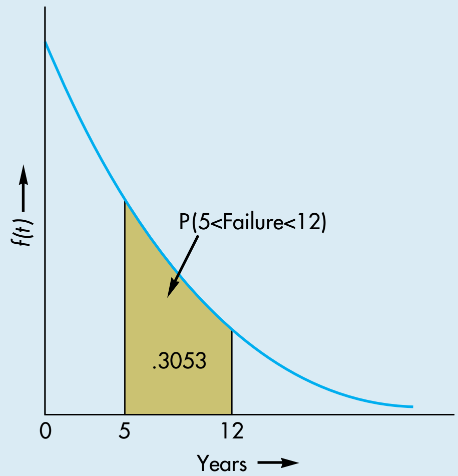
Solution

$$P(5 \text{ years} < \text{failure} < 12 \text{ years}) = P(\text{failure after 5 years}) - P(\text{failure after 12 years})$$

Using the probabilities shown in the previous solution, you obtain:

$$P(\text{failure after 5 years}) = .6065$$
$$-P(\text{failure after 12 years}) = \underline{.3012}$$
$$.3053$$

The corresponding area under the curve is illustrated as follows:



Problem 6

One line of radial tires produced by a large company has a wear-out life that can be modeled using a normal distribution with a mean of 25,000 miles and a standard deviation of 2,000 miles. Determine each of the following:

a. The percentage of tires that can be expected to wear out within ± 2,000 miles of the average (i.e., between 23,000 miles and 27,000 miles).

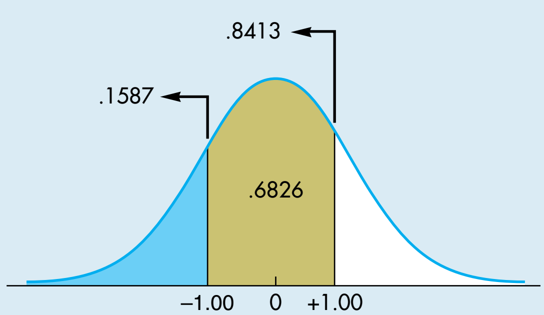
b. The percentage of tires that can be expected to fail between 26,000 miles and 29,000 miles.

Solution

Notes: (1) Miles are analogous to time and are handled in exactly the same way; (2) the term *percentage* refers to a probability.

a. The phrase "within ± 2,000 miles of the average" translates to within one standard deviation of the mean since the standard deviation equals 2,000 miles. Therefore the range of z is $z = -1.00$ to $z = +1.00$, and the area under the curve between those points is found as the difference between $P(z < +1.00)$ and $P(z < -1.00)$, using values obtained from Appendix Table B.

$$P(z < +1.00) = .8413$$
$$-P(z < -1.00) = .1587$$
$$P(-1.00 < z < +1.00) = .6826$$



b. Wear-out mean = 25,000 miles

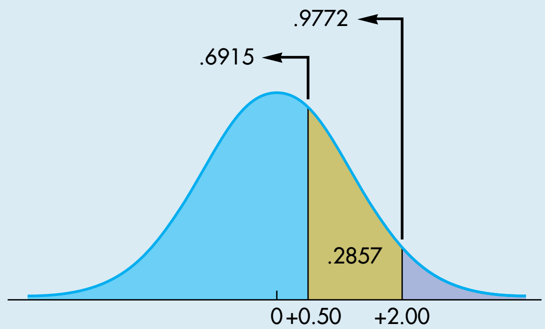
Wear-out standard deviation = 2,000 miles

$$P(26{,}000 < \text{Wear-out} < 29{,}000) = P(z_{29{,}000}) - P(z < z_{26{,}000})$$

$$z29{,}000 = \frac{29{,}000 - 25{,}000}{2{,}000} = +2.00 \rightarrow .9772$$

$$z26{,}000 = \frac{26{,}000 - 25{,}000}{2{,}000} = +.50 \rightarrow .6915$$

The difference is .9772 − .6915 = .2857, which is the expected percent of tires that will wear out between 26,000 miles and 29,000 miles.



Discussion and Review Questions

1. Define the term *reliability.*
2. Explain why a product or system might have an overall reliability that is low even though it is comprised of components that have fairly high reliabilities.
3. What is redundancy and how can it improve product design?

Problems

1. Consider the following system:

Determine the probability that the system will operate under each of these conditions:

a. .81
b. .9801
c. .9783

a. The system as shown.
b. Each system component has a backup with a probability of .90 and a switch that is 100 percent reliable.
c. Backups with .90 probability and a switch that is 99 percent reliable.

.9033

2. A product is composed of four parts. In order for the product to function properly in a given situation, each of the parts must function. Two of the parts each have a .96 probability of functioning, and two each have a probability of .99. What is the overall probability that the product will function properly?

.9726

3. A system consists of three identical components. In order for the system to perform as intended, all of the components must perform. Each has the same probability of performance. If the system is to have a .92 probability of performing, what is the minimum probability of performing needed by each of the individual components?

.93

4. A product engineer has developed the following equation for the cost of a system component: $C = (10P)^2$, where C is the cost in dollars and P is the probability that the component will operate as expected. The system is composed of two identical components, both of which must operate for the system to operate. The engineer can spend $173 for the two components. To the nearest two decimal places, what is the largest component probability that can be achieved?
5. The guidance system of a ship is controlled by a computer that has three major modules. In order for the computer to function properly, all three modules must function. Two of the modules have reliabilities of .97, and the other has a reliability of .99.

a. .9315
b. .9953
c. .994

a. What is the reliability of the computer?
b. A backup computer identical to the one being used will be installed to improve overall reliability. Assuming the new computer automatically functions if the main one fails, determine the resulting reliability.
c. If the backup computer must be activated by a switch in the event that the first computer fails, and the switch has a reliability of .98, what is the overall reliability of the system? (*Both* the switch and the backup computer must function in order for the backup to take over.)

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6. One of the industrial robots designed by a leading producer of servomechanisms has four major components. Components' reliabilities are .98, .95, .94, and .90. All of the components must function in order for the robot to operate effectively.
   a. Compute the reliability of the robot.
   b. Designers want to improve the reliability by adding a backup component. Due to space limitations, only one backup can be added. The backup for any component will have the same reliability as the unit for which it is the backup. Which component should get the backup in order to achieve the highest reliability?
   c. If one backup with a reliability of .92 can be added to any one of the main components, which component should get it to obtain the highest overall reliability?

   a. .7876
   b. 1st = .8034
   2nd = .8270
   3rd = .8349
   4th = .8664
   c. Add to component with .90 reliability.

7. A production line has three machines A, B, and C, with reliabilities of .99, .96, and .93, respectively. The machines are arranged so that if one breaks down, the others must shut down. Engineers are weighing two alternative designs for increasing the line's reliability. Plan 1 involves adding an identical backup *line,* and plan 2 involves providing a backup for each *machine.* In either case, three machines (A, B, and C) would be used with reliabilities equal to the original three.
   a. Which plan will provide the higher reliability?
   b. Explain why the two reliabilities are not the same.
   c. What other factors might enter into the decision of which plan to adopt?

   a. Plan 1: .9865
   Plan 2: .9934
   b. See IM.
   c. space, cost, etc.

8. Refer to the previous problem.
   a. Assume that the single switch used in plan 1 is 98 percent reliable, while reliabilities of the machines remain the same. Recalculate the reliability of plan 1. Compare the reliability of this plan with the reliability of the plan 1 calculated in solving the original problem. How much did reliability of plan 1 decrease as result of a 98 percent reliable switch?
   b. Assume that the three switches used in plan 2 are all 98 percent reliable, while reliabilities of the machines remain the same. Recalculate the reliability of plan 2. Compare the reliability of this plan with the reliability of the plan 2 calculated in solving the original problem. How much did reliability of plan 2 decrease?

   a. .0021
   b. .0022

9. A web server has five major components which must all function in order for it to operate as intended. Assuming that each component of the system has the same reliability, what is the minimum reliability each one must have in order for the overall system to have a reliability of .98?

   .996

10. Repeat Problem 9 under the condition that one of the components will have a backup with a reliability equal to that of any one of the other components.

    .995

11. Hoping to increase the chances of reaching a performance goal, the director of a research project has assigned three separate research teams the same task. The director estimates that the team probabilities are .9, .8, and .7 for successfully completing the task in the allotted time. Assuming that the teams work independently, what is the probability that the task will not be completed in time?

    .006

12. An electronic chess game has a useful life that is exponential with a mean of 30 months. Determine each of the following:
    a. The probability that any given unit will operate for at least: (1) 39 months, (2) 48 months, (3) 60 months.
    b. The probability that any given unit will fail sooner than: (1) 33 months, (2) 15 months, (3) 6 months.
    c. The length of service time after which the percentage of failed units will approximately equal: (1) 50 percent, (2) 85 percent, (3) 95 percent, (4) 99 percent.

    a. (1): .2725
    (2): .2019
    (3): .1353
    b. (1): .6671
    (2): .3935
    (3): .1813
    c. (1): 21 months
    (2): 57 months
    (3): 90 months
    (4): 138 months

13. A manufacturer of programmable calculators is attempting to determine a reasonable free-service period for a model it will introduce shortly. The manager of product testing has indicated that the calculators have an expected life of 30 months. Assume product life can be described by an exponential distribution.
    a. If service contracts are offered for the expected life of the calculator, what percentage of those sold would be expected to fail during the service period?
    b. What service period would result in a failure rate of approximately 10 percent?

    a. .6321
    b. 3 months

14. Lucky Lumen light bulbs have an expected life that is exponentially distributed with a mean of 5,000 hours. Determine the probability that one of these light bulbs will last

a. .3012
b. .1813
c. .5175

a. At least 6,000 hours.

b. No longer than 1,000 hours.

c. Between 1,000 hours and 6,000 hours.

a. .2231
b. .8647
c. .0878
d. .0302

15. Planetary Communications, Inc., intends to launch a satellite that will enhance reception of television programs in Alaska. According to its designers, the satellite will have an expected life of six years. Assume the exponential distribution applies. Determine the probability that it will function for each of the following time periods:

    a. More than 9 years.

    b. Less than 12 years.

    c. More than 9 years but less than 12 years.

    d. At least 21 years.

a. 22.66%
b. 44%
c. 38.3%

16. An office manager has received a report from a consultant that includes a section on equipment replacement. The report indicates that scanners have a service life that is normally distributed with a mean of 41 months and a standard deviation of 4 months. On the basis of this information, determine the percentage of scanners that can be expected to fail in the following time periods:

    a. Before 38 months of service.

    b. Between 40 and 45 months of service.

    c. Within −2 months of the mean life.

a. (1): $z = -2.00$
.9772
(2): $z = 0.00$
.5000
(3): $z = -3.00$
P = 13/10,000
= .0013
b. $z = -4.00$
nearly zero

17. A major television manufacturer has determined that its 19-inch color TV picture tubes have a mean service life that can be modeled by a normal distribution with a mean of six years and a standard deviation of one-half year.

    a. What probability can you assign to service lives of at least: (1) Five years? (2) Six years? (3) Seven and one-half years?

    b. If the manufacturer offers service contracts of four years on these picture tubes, what percentage can be expected to fail from wear-out during the service period?

a. $z = -2.055$
4.97 years
b. $z = -1.645$
5.18 years

18. Refer to Problem 17. What service period would achieve an expected wear-out rate of:

    a. 2 percent?

    b. 5 percent?

a. .930
b. .980

19. Determine the availability for each of these cases:

    a. MTBF = 40 days, average repair time = 3 days.

    b. MTBF = 300 hours, average repair time = 6 hours.

.962

20. A machine can operate for an average of 10 weeks before it needs to be overhauled, a process which takes two days. The machine is operated five days a week. Compute the availability of this machine. (Hint: all times must be in the same units.)

Machine A = .953
Machine B = .970

21. A manager must decide between two machines. The manager will take into account each machine's operating costs and initial costs, and its breakdown and repair times. Machine A has a projected average operating time of 142 hours and a projected average repair time of seven hours. Projected times for machine B are an average operating time of 65 hours and a repair time of two hours. What are the projected availabilities of each machine?

a. .9633
b. .9653

22. A designer estimates that she can (*a*) increase the average time between failures of a part by 5 percent at a cost of $450, or (*b*) reduce the average repair time by 10 percent at a cost of $200. Which option would be more cost-effective? Currently, the average time between failures is 100 hours and the average repair time is four hours.

23. Auto batteries have an average life of 2.4 years. Battery life is normally distributed with a mean of 2.7 years and a standard deviation of .3 year. The batteries are warranted to operate for a minimum of two years. If a battery fails within the warranty period, it will be replaced with a new battery at no charge. The company sells and installs the batteries. Also, the normal $5 installation charge will be waived.

    a. What percentage of batteries would you expect to fail before the warranty period expires?

    b. A competitor is offering a warranty of 30 months on its premium battery. The manager of this company is toying with the idea of using the same battery with a different exterior, labeling it as a premium battery, and offering a 30-month warranty on it. How much more would the company have to charge on its "premium" battery to offset the additional cost of replacing batteries?

    c. What other factors would you take into consideration besides the price of the battery?