Managing Quality

CHAPTER 6

CHAPTER OUTLINE

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Alaska Air lines

Alaska Air lines

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- *Managing Quality*
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- Inventory Management
- Scheduling
- Maintenance

GLOBAL COMPANY PROFILE
Arnold Palmer Hospital

Managing Quality Provides a Competitive Advantage at Arnold Palmer Hospital

Since 1989, Arnold Palmer Hospital, named after its famous golfing benefactor, has touched the lives of over 7 million children and women and their families. Its patients come not only from its Orlando location but from all 50 states and around the world. More than 12,000 babies are delivered every year at Arnold Palmer, and its huge neonatal intensive care unit boasts one of the highest survival rates in the U.S.

Every hospital professes quality health care, but at Arnold Palmer quality is the mantra—practiced in a fashion like the Ritz-Carlton practices it in the hotel industry. The hospital typically scores in the top 10% of national benchmark studies in terms of patient satisfaction. And its managers follow patient questionnaire results daily. If anything is amiss, corrective action takes place immediately.

Virtually every quality management technique we present in this chapter is employed at Arnold Palmer Hospital:

- *Continuous improvement:* The hospital constantly seeks new ways to lower infection rates, readmission rates, deaths, costs, and hospital stay times.

Courtesy Arnold Palmer Medical Center

The lobby of Arnold Palmer Hospital, with its 20-foot-high Genie, is clearly intended as a warm and friendly place for children.

Courtesy Arnold Palmer Medical Center

The Storkboard is a visible chart of the status of each baby about to be delivered, so all nurses and doctors are kept up to date at a glance.

Courtesy Arnold Palmer Medical Center

This PYXIS inventory station gives nurses quick access to medicines and supplies needed in their departments. When the nurse removes an item for patient use, the item is automatically billed to that account, and usage is noted at the main supply area.

The hospital has redesigned its neonatal rooms. In the old system, there were 16 neonatal beds in an often noisy and large room. The new rooms are semiprivate, with a quiet simulated-night atmosphere. These rooms have proven to help babies develop and improve more quickly.

Courtesy Arnold Palmer Medical Center

- *Employee empowerment:* When employees see a problem, they are trained to take care of it; staff are empowered to give gifts to patients displeased with some aspect of service.
- *Benchmarking:* The hospital belongs to a 2,000-member organization that monitors standards in many areas and provides monthly feedback to the hospital.

Courtesy Arnold Palmer Medical Center

When Arnold Palmer Hospital began planning for a new 11-story hospital across the street from its existing building, it decided on a circular pod design, creating a patient-centered environment. Rooms use warm colors, have pull-down Murphy beds for family members, 14-foot ceilings, and natural lighting with oversized windows. The pod concept also means there is a nursing station within a few feet of each 10-bed pod, saving much wasted walking time by nurses to reach the patient. The Video Case Study in Chapter 9 examines this layout in detail.

- *Just-in-time:* Supplies are delivered to Arnold Palmer on a JIT basis. This keeps inventory costs low and keeps quality problems from hiding.
- *Tools such as Pareto charts and flowcharts:* These tools monitor processes and help the staff graphically spot problem areas and suggest ways they can be improved.

From their first day of orientation, employees from janitors to nurses learn that the patient comes first. Staff standing in hallways will never be heard discussing their personal lives or commenting on confidential issues of health care. This culture of quality at Arnold Palmer Hospital makes a hospital visit, often traumatic to children and their parents, a warmer and more comforting experience.

LEARNING OBJECTIVES

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Quality and Strategy

VIDEO 6.1
The Culture of Quality at Arnold Palmer Hospital

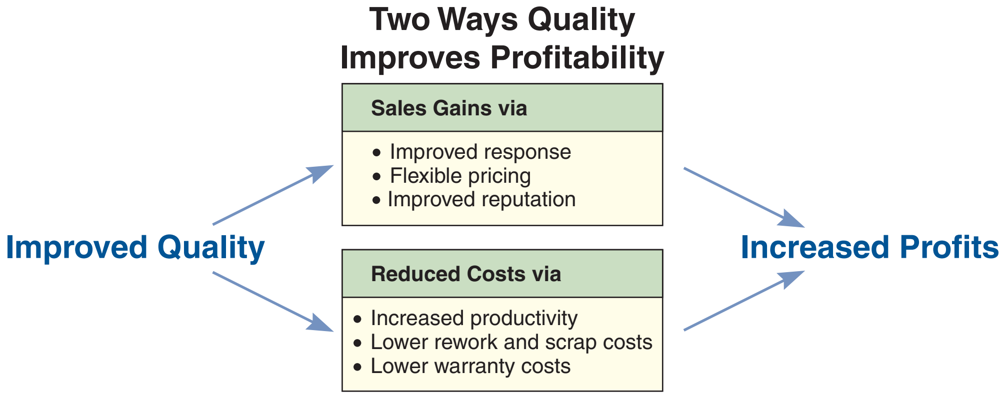
As Arnold Palmer Hospital and many other organizations have found, quality is a wonderful tonic for improving operations. Managing quality helps build successful strategies of *differentiation*, *low cost*, and *response*. For instance, defining customer quality expectations has helped Bose Corp. successfully *differentiate* its stereo speakers as among the best in the world. Nucor has learned to produce quality steel at *low cost* by developing efficient processes that produce consistent quality. And Dell Computers rapidly *responds* to customer orders because quality systems, with little rework, have allowed it to achieve rapid throughput in its plants. Indeed, quality may be the key success factor for these firms, just as it is at Arnold Palmer Hospital.

STUDENT TIP
High-quality products and services are the most profitable.

As Figure 6.1 suggests, improvements in quality help firms increase sales and reduce costs, both of which can increase profitability. Increases in sales often occur as firms speed response, increase or lower selling prices, and improve their reputation for quality products. Similarly, improved quality allows costs to drop as firms increase productivity and lower rework, scrap, and warranty costs. One study found that companies with the highest quality were five times as productive (as measured by units produced per labor-hour) as companies with the poorest quality. Indeed, when the implications of an organization's long-term costs and the potential for increased sales are considered, total costs may well be at a minimum when 100% of the goods or services are perfect and defect free.

Quality, or the lack of quality, affects the entire organization from supplier to customer and from product design to maintenance. Perhaps more important, *building* an organization that can achieve quality is a demanding task. Figure 6.2 lays out the flow of activities for an organization to use to achieve total quality management (TQM). A successful quality strategy begins with an organizational culture that fosters quality, followed by an understanding of the principles of quality, and then engaging employees in the necessary activities to implement quality. When these things are done well, the organization typically satisfies its customers and obtains a competitive advantage. The ultimate goal is to win customers. Because quality causes so many other good things to happen, it is a great place to start.

Figure **6.1**
Ways Quality Improves Profitability



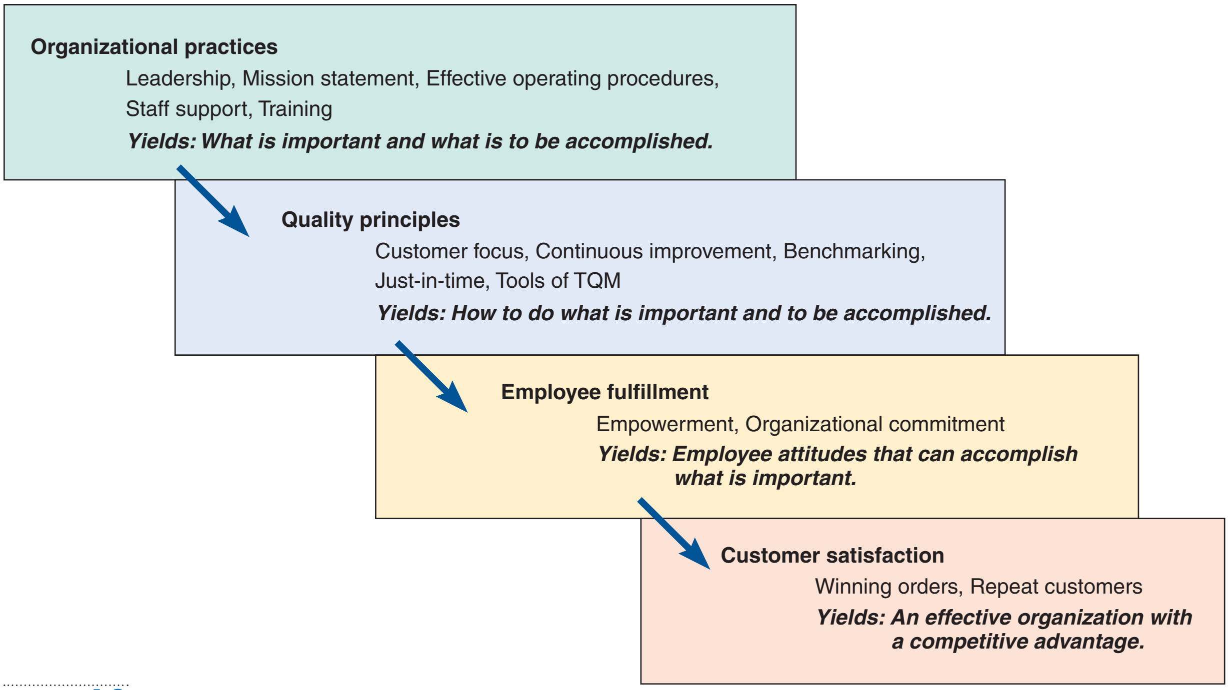


Figure **6.2**

The Flow of Activities Necessary to Achieve Total Quality Management

Defining Quality

The operations manager's objective is to build a total quality management system that identifies and satisfies customer needs. Total quality management takes care of the customer. Consequently, we accept the definition of **quality** as adopted by the American Society for Quality (ASQ; **www.asq.org**): "The totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs."

Quality
The ability of a product or service to meet customer needs.

Others, however, believe that definitions of quality fall into several categories. Some definitions are *user based*. They propose that quality "lies in the eyes of the beholder." Marketing people like this approach and so do customers. To them, higher quality means better performance, nicer features, and other (sometimes costly) improvements. To production managers, quality is *manufacturing based*. They believe that quality means conforming to standards and "making it right the first time." Yet a third approach is *product based*, which views quality as a precise and measurable variable. In this view, for example, really good ice cream has high butterfat levels.

LO 6.1 *Define* quality and TQM

This text develops approaches and techniques to address all three categories of quality. The characteristics that connote quality must first be identified through research (a user-based approach to quality). These characteristics are then translated into specific product attributes (a product-based approach to quality). Then, the manufacturing process is organized to ensure that products are made precisely to specifications (a manufacturing-based approach to quality). A process that ignores any one of these steps will not result in a quality product.

STUDENT TIP
To create a quality good or service, operations managers need to know what the customer expects.

Implications of Quality

In addition to being a critical element in operations, quality has other implications. Here are three other reasons why quality is important:

1. *Company reputation:* An organization can expect its reputation for quality—be it good or bad—to follow it. Quality will show up in perceptions about the firm's new products, employment practices, and supplier relations. Self-promotion is not a substitute for quality products.

2. *Product liability:* The courts increasingly hold organizations that design, produce, or distribute faulty products or services liable for damages or injuries resulting from their use. Legislation such as the Consumer Product Safety Act sets and enforces product standards by banning products that do not reach those standards. Impure foods that cause illness, nightgowns that burn, tires that fall apart, or auto fuel tanks that explode on impact can all lead to huge legal expenses, large settlements or losses, and terrible publicity.
3. *Global implications:* In this technological age, quality is an international, as well as OM, concern. For both a company and a country to compete effectively in the global economy, products must meet global quality, design, and price expectations. Inferior products harm a firm's profitability and a nation's balance of payments.

Malcolm Baldrige National Quality Award

The global implications of quality are so important that the U.S. has established the *Malcolm Baldrige National Quality Award* for quality achievement. The award is named for former Secretary of Commerce Malcolm Baldrige. Winners include such firms as Motorola, Milliken, Xerox, FedEx, Ritz-Carlton Hotels, AT&T, Cadillac, and Texas Instruments. (For details about the Baldrige Award and its 1,000-point scoring system, visit **www.nist.gov/baldrige/**.)

The Japanese have a similar award, the Deming Prize, named after an American, Dr. W. Edwards Deming.

ISO 9000 International Quality Standards

ISO 9000

A set of quality standards developed by the International Organization for Standardization (ISO).

The move toward global supply chains has placed so much emphasis on quality that the world has united around a single quality standard, **ISO 9000**. ISO 9000 is *the* quality standard with international recognition. Its focus is to enhance success through eight quality management principles: (1) top management leadership, (2) customer satisfaction, (3) continual improvement, (4) involvement of people, (5) process analysis, (6) use of data-driven decision making, (7) a systems approach to management, and (8) mutually beneficial supplier relationships.

LO 6.2 *Describe* the ISO international quality standards

The ISO standard encourages establishment of quality management procedures, detailed documentation, work instructions, and recordkeeping. Like the Baldrige Awards, the assessment includes self-appraisal and problem identification. Unlike the Baldrige, ISO certified organizations must be reaudited every three years.

The latest modification of the standard, ISO 9001: 2015, follows a structure that makes it more compatible with other management systems. This version gives greater emphasis to risk-based thinking, attempting to prevent undesirable outcomes.

STUDENT TIP

International quality standards grow in prominence every year. See **www.iso.ch**.

Over one million certifications have been awarded to firms in 206 countries, including about 30,000 in the U.S. To do business globally, it is critical for a firm to be certified and listed in the ISO directory.

Cost of Quality (COQ)

Cost of quality (COQ)

The cost of doing things wrong—that is, the price of nonconformance.

Four major categories of costs are associated with quality. Called the **cost of quality (COQ)**, they are:

- *Prevention costs:* costs associated with reducing the potential for defective parts or services (e.g., training, quality improvement programs).
- *Appraisal costs:* costs related to evaluating products, processes, parts, and services (e.g., testing, labs, inspectors).
- *Internal failure costs:* costs that result from production of defective parts or services before delivery to customers (e.g., rework, scrap, downtime).
- *External failure costs:* costs that occur after delivery of defective parts or services (e.g., rework, returned goods, liabilities, lost goodwill, costs to society).

TABLE 6.1 Leaders in the Field of Quality Management

LEADER	PHILOSOPHY/CONTRIBUTION
W. Edwards Deming	Deming insisted management accept responsibility for building good systems. The employee cannot produce products that on average exceed the quality of what the process is capable of producing. His 14 points for implementing quality improvement are presented in this chapter.
Joseph M. Juran	A pioneer in teaching the Japanese how to improve quality, Juran believed strongly in top-management commitment, support, and involvement in the quality effort. He was also a believer in teams that continually seek to raise quality standards. Juran varies from Deming somewhat in focusing on the customer and defining quality as fitness for use, not necessarily the written specifications.
Armand Feigenbaum	His 1961 book *Total Quality Control* laid out 40 steps to quality improvement processes. He viewed quality not as a set of tools but as a total field that integrated the processes of a company. His work in how people learn from each other's successes led to the field of cross-functional teamwork.
Philip B. Crosby	*Quality Is Free* was Crosby's attention-getting book published in 1979. Crosby believed that in the traditional trade-off between the cost of improving quality and the cost of poor quality, the cost of poor quality is understated. The cost of poor quality should include all of the things that are involved in not doing the job right the first time. Crosby coined the term *zero defects* and stated, "There is absolutely no reason for having errors or defects in any product or service."

Source: Based on *Quality Is Free* by Philip B. Crosby (New York, McGraw-Hill, 1979) p. 58.

The first three costs can be reasonably estimated, but external costs are very hard to quantify. When GE had to recall 3.1 million dishwashers (because of a defective switch alleged to have started seven fires), the cost of repairs exceeded the value of all the machines. This leads to the belief by many experts that the cost of poor quality is consistently underestimated.

Observers of quality management believe that, on balance, the cost of quality products is only a fraction of the benefits. They think the real losers are organizations that fail to work aggressively at quality. For instance, Philip Crosby stated that quality is free. "What costs money are the unquality things—all the actions that involve not doing it right the first time."[1]

Takumi is a Japanese character that symbolizes a broader dimension than quality, a deeper process than education, and a more perfect method than persistence.

Leaders in Quality Besides Crosby there are several other giants in the field of quality management, including Deming, Feigenbaum, and Juran. Table 6.1 summarizes their philosophies and contributions.

Ethics and Quality Management

For operations managers, one of the most important jobs is to deliver healthy, safe, and quality products and services to customers. The development of poor-quality products, because of inadequate design and production processes, not only results in higher production costs but also leads to injuries, lawsuits, and increased government regulation.

If a firm believes that it has introduced a questionable product, ethical conduct must dictate the responsible action. This may be a worldwide recall, as conducted by both Johnson & Johnson (for Tylenol) and Perrier (for sparkling water), when each of these products was found to be contaminated. A manufacturer must accept responsibility for any poor-quality product released to the public.

There are many stakeholders involved in the production and marketing of poor-quality products, including stockholders, employees, customers, suppliers, distributors, and creditors. As a matter of ethics, management must ask if any of these stakeholders are being wronged. Every company needs to develop core values that become day-to-day guidelines for everyone from the CEO to production-line employees.

Total Quality Management

Total quality management (TQM) refers to a quality emphasis that encompasses the entire organization, from supplier to customer. TQM stresses a commitment by management to have a continuing companywide drive toward excellence in all aspects of products and services that are

Total quality management (TQM)
Management of an entire organization so that it excels in all aspects of products and services that are important to the customer.

TABLE 6.2 Deming's 14 Points for Implementing Quality Improvement

1.	Create consistency of purpose.
2.	Lead to promote change.
3.	Build quality into the product; stop depending on inspections to catch problems.
4.	Build long-term relationships based on performance instead of awarding business on the basis of price.
5.	Continuously improve product, quality, and service.
6.	Start training.
7.	Emphasize leadership.
8.	Drive out fear.
9.	Break down barriers between departments.
10.	Stop haranguing workers.
11.	Support, help, and improve.
12.	Remove barriers to pride in work.
13.	Institute a vigorous program of education and self-improvement.
14.	Put everybody in the company to work on the transformation.

Source: Deming, W. Edwards. *Out of the Crisis*, pp. 23–24, © 2000 W. Edwards Deming Institute, published by The MIT Press. Reprinted by permission.

important to the customer. Each of the 10 decisions made by operations managers deals with some aspect of identifying and meeting customer expectations. Meeting those expectations requires an emphasis on TQM if a firm is to compete as a leader in world markets.

STUDENT TIP Here are 7 concepts that make up the heart of an effective TQM program.

Quality expert W. Edwards Deming used 14 points (see Table 6.2) to indicate how he implemented TQM. We develop these into seven concepts for an effective TQM program: (1) continuous improvement, (2) Six Sigma, (3) employee empowerment, (4) benchmarking, (5) just-in-time (JIT), (6) Taguchi concepts, and (7) knowledge of TQM tools.

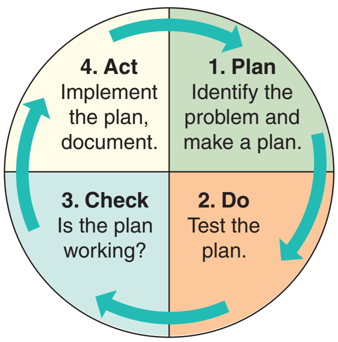
Continuous Improvement

Total quality management requires a never-ending process of continuous improvement that covers people, equipment, suppliers, materials, and procedures. The basis of the philosophy is that every aspect of an operation can be improved. The end goal is perfection, which is never achieved but always sought.

PDCA A continuous improvement model of plan, do, check. act.

Plan-Do-Check-Act Walter Shewhart, another pioneer in quality management, developed a circular model known as **PDCA** (plan, do, check, act) as his version of continuous improvement. Deming later took this concept to Japan during his work there after World War II. The PDCA cycle (also called a Deming circle or a Shewhart circle) is shown in Figure 6.3 as a circle to stress the continuous nature of the improvement process.

Figure 6.3
PDCA Cycle



The Japanese use the word *kaizen* to describe this ongoing process of unending improvement—the setting and achieving of ever-higher goals. In the U.S., *TQM* and *zero defects* are also used to describe continuous improvement efforts. But whether it's PDCA, kaizen, TQM, or zero defects, the operations manager is a key player in building a work culture that endorses continuous improvement.

Six Sigma

The term **Six Sigma**, popularized by Motorola, Honeywell, and General Electric, has two meanings in TQM. In a *statistical* sense, it describes a process, product, or service with an extremely high capability (99.9997% accuracy). For example, if 1 million passengers pass through the St. Louis Airport with checked baggage each month, a Six Sigma program for baggage handling will result in only 3.4 passengers with misplaced luggage. The more common *three-sigma* program (which we address in the supplement to this chapter) would result in 2,700 passengers with misplaced bags every month. See Figure 6.4.

Six Sigma
A program to save time, improve quality, and lower costs.

The second TQM definition of Six Sigma is a *program* designed to reduce defects to help lower costs, save time, and improve customer satisfaction. Six Sigma is a comprehensive system—a strategy, a discipline, and a set of tools—for achieving and sustaining business success:

LO 6.3 *Explain* Six Sigma

- It is a *strategy* because it focuses on total customer satisfaction.
- It is a *discipline* because it follows the formal Six Sigma Improvement Model known as **DMAIC**. This five-step process improvement model (1) ***Defines*** the project's purpose, scope, and outputs and then identifies the required process information, keeping in mind the customer's definition of quality; (2) ***Measures*** the process and collects data; (3) ***Analyzes*** the data, ensuring repeatability (the results can be duplicated) and reproducibility (others get the same result); (4) ***Improves***, by modifying or redesigning, existing processes and procedures; and (5) ***Controls*** the new process to make sure performance levels are maintained.
- It is a *set of seven tools* that we introduce shortly in this chapter: check sheets, scatter diagrams, cause-and-effect diagrams, Pareto charts, flowcharts, histograms, and statistical process control.

Motorola developed Six Sigma in the 1980s, in response to customer complaints about its products and in response to stiff competition. The company first set a goal of reducing defects by 90%. Within one year, it had achieved such impressive results—through benchmarking competitors, soliciting new ideas from employees, changing reward plans, adding training, and revamping critical processes—that it documented the procedures into what it called Six Sigma. Although the concept was rooted in manufacturing, GE later expanded Six Sigma into services, including human resources, sales, customer services, and financial/credit services. The concept of wiping out defects turns out to be the same in both manufacturing and services.

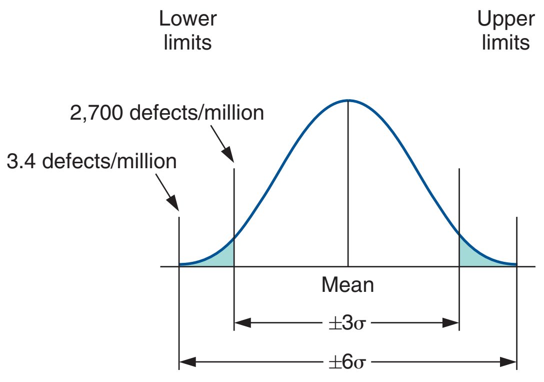


Figure **6.4**

Defects per Million for $\pm 3\sigma$ vs. $\pm 6\sigma$

STUDENT TIP
Recall that $\pm 3\sigma$ provides 99.73% accuracy, while $\pm 6\sigma$ is 99.9997%.

Implementing Six Sigma Implementing Six Sigma is a big commitment. Indeed, successful Six Sigma programs in every firm, from GE to Motorola to DuPont to Texas Instruments, require a major time commitment, especially from top management. These leaders have to formulate the plan, communicate their buy-in and the firm's objectives, and take a visible role in setting the example for others.

Successful Six Sigma projects are clearly related to the strategic direction of a company. It is a management-directed, team-based, and expert-led approach.[2]

Employee Empowerment

Employee empowerment
Enlarging employee jobs so that the added responsibility and authority is moved to the lowest level possible in the organization.

Employee empowerment means involving employees in every step of the production process. Consistently, research suggests that some 85% of quality problems have to do with materials and processes, not with employee performance. Therefore, the task is to design equipment and processes that produce the desired quality. This is best done with a high degree of involvement by those who understand the shortcomings of the system. Those dealing with the system on a daily basis understand it better than anyone else. One study indicated that TQM programs that delegate responsibility for quality to shop-floor employees tend to be twice as likely to succeed as those implemented with "top-down" directives.[3]

When nonconformance occurs, the worker is seldom at fault. Either the product was designed wrong, the process that makes the product was designed wrong, or the employee was improperly trained. Although the employee may be able to help solve the problem, the employee rarely causes it.

Techniques for building employee empowerment include (1) building communication networks that include employees; (2) developing open, supportive supervisors; (3) moving responsibility from both managers and staff to production employees; (4) building high-morale organizations; and (5) creating such formal organization structures as teams and quality circles.

Quality circle
A group of employees meeting regularly with a facilitator to solve work-related problems in their work area.

Teams can be built to address a variety of issues. One popular focus of teams is quality. Such teams are often known as quality circles. A **quality circle** is a group of employees who meet regularly to solve work-related problems. The members receive training in group planning, problem solving, and statistical quality control. They generally meet once a week (usually after work but sometimes on company time). Although the members are not rewarded financially, they do receive recognition from the firm. A specially trained team member, called the *facilitator*, usually helps train the members and keeps the meetings running smoothly. Teams with a quality focus have proven to be a cost-effective way to increase productivity as well as quality.

Benchmarking

Benchmarking
Selecting a demonstrated standard of performance that represents the very best performance for a process or an activity.

Benchmarking is another ingredient in an organization's TQM program. **Benchmarking** involves selecting a demonstrated standard of products, services, costs, or practices that represent

Workers at this TRW airbag manufacturing plant in Marshall, Illinois, are their own inspectors. Empowerment is an essential part of TQM. This man is checking the quality of a crash sensor he built.

TRW Automotive/General Manley Ford

TABLE 6.3 Best Practices for Resolving Customer Complaints

BEST PRACTICE	JUSTIFICATION
Make it easy for clients to complain.	It is free market research.
Respond quickly to complaints.	It adds customers and loyalty.
Resolve complaints on the first contact.	It reduces cost.
Use computers to manage complaints.	Discover trends, share them, and align your services.
Recruit the best for customer service jobs.	It should be part of formal training and career advancement.

Source: Based on Canadian Government Guide on Complaint Mechanism.

the very best performance for processes or activities very similar to your own. The idea is to develop a target at which to shoot and then to develop a standard or benchmark against which to compare your performance. The steps for developing benchmarks are:

1. Determine what to benchmark.
2. Form a benchmark team.
3. Identify benchmarking partners.
4. Collect and analyze benchmarking information.
5. Take action to match or exceed the benchmark.

LO 6.4 *Explain* how benchmarking is used in TQM

Typical performance measures used in benchmarking include percentage of defects, cost per unit or per order, processing time per unit, service response time, return on investment, customer satisfaction rates, and customer retention rates.

In the ideal situation, you find one or more similar organizations that are leaders in the particular areas you want to study. Then you compare yourself (benchmark yourself) against them. The company need not be in your industry. Indeed, to establish world-class standards, it may be best to look outside your industry. If one industry has learned how to compete via rapid product development while yours has not, it does no good to study your industry.

This is exactly what Xerox and Mercedes-Benz did when they went to L.L. Bean for order-filling and warehousing benchmarks. Xerox noticed that L.L. Bean was able to "pick" orders three times faster. After benchmarking, Xerox was immediately able to pare warehouse costs by 10%. Mercedes-Benz observed that L.L. Bean warehouse employees used flowcharts to spot wasted motions. The auto giant followed suit and now relies more on problem solving at the worker level.

Benchmarks often take the form of "best practices" found in other firms or in other divisions. Table 6.3 illustrates best practices for resolving customer complaints.

Likewise, Britain's Great Ormond Street Hospital benchmarked the Ferrari Racing Team's pit stops to improve one aspect of medical care. (See the *OM in Action* box "A Hospital Benchmarks Against the Ferrari Racing Team?")

Internal Benchmarking When an organization is large enough to have many divisions or business units, a natural approach is the internal benchmark. Data are usually much more accessible than from outside firms. Typically, one internal unit has superior performance worth learning from.

Xerox's almost religious belief in benchmarking has paid off not only by looking outward to L.L. Bean but by examining the operations of its various country divisions. For example, Xerox Europe, a $6 billion subsidiary of Xerox Corp., formed teams to see how better sales could result through internal benchmarking. Somehow, France sold five times as many color copiers as did other divisions in Europe. By copying France's approach, namely, better sales training and use of dealer channels to supplement direct sales, Norway increased sales by 152%, Holland by 300%, and Switzerland by 328%!

Benchmarks can and should be established in a variety of areas. Total quality management requires no less.

OM in Action — A Hospital Benchmarks Against the Ferrari Racing Team?

After surgeons successfully completed a 6-hour operation to fix a hole in a 3-year-old boy's heart, Dr. Angus McEwan supervised one of the most dangerous phases of the procedure: the boy's transfer from surgery to the intensive care unit.

Thousands of such "handoffs" occur in hospitals every day, and devastating mistakes can happen during them. In fact, at least 35% of preventable hospital mishaps take place because of handoff problems. Risks come from many sources: using temporary nursing staff, frequent shift changes for interns, surgeons working in larger teams, and an ever-growing tangle of wires and tubes connected to patients.

Using an unlikely benchmark, Britain's largest children's hospital turned to Italy's Formula One Ferrari racing team for help in revamping patient handoff techniques. Armed with videos and slides, the racing team described how they analyze pit crew performance. It also explained how its system for recording errors stressed the small ones that go unnoticed in pit-stop handoffs.

To move forward, Ferrari invited a team of doctors to attend practice sessions at the British Grand Prix in order to get closer looks at pit stops. Ferrari's technical director, Nigel Stepney, then watched a video of a hospital handoff. Stepney was not impressed. "In fact, he was amazed at how clumsy, chaotic, and informal the process appeared," said one hospital official. At that meeting, Stepney described how each Ferrari crew member is required to do a specific job, in a specific sequence, and in silence.

Oliver Multhaup/AP Images

The hospital handoff, in contrast, had several conversations going on at once, while different members of its team disconnected or reconnected patient equipment, but in no particular order.

Results of the benchmarking process: handoff errors fell over 40%, with a bonus of faster handoff time.

Sources: The Wall Street Journal (December 3, 2007) and (November 14, 2006).

Just-in-Time (JIT)

The philosophy behind just-in-time (JIT) is one of continuing improvement and enforced problem solving. JIT systems are designed to produce or deliver goods just as they are needed. JIT is related to quality in three ways:

- *JIT cuts the cost of quality:* This occurs because scrap, rework, inventory investment, and damage costs are directly related to inventory on hand. Because there is less inventory on hand with JIT, costs are lower. In addition, inventory hides bad quality, whereas JIT immediately *exposes* bad quality.
- *JIT improves quality:* As JIT shrinks lead time, it keeps evidence of errors fresh and limits the number of potential sources of error. JIT creates, in effect, an early warning system for quality problems, both within the firm and with vendors.
- *Better quality means less inventory and a better, easier-to-employ JIT system:* Often the purpose of keeping inventory is to protect against poor production performance resulting from unreliable quality. If consistent quality exists, JIT allows firms to reduce all the costs associated with inventory.

Taguchi Concepts

Most quality problems are the result of poor product and process design. Genichi Taguchi has provided us with three concepts aimed at improving both product and process quality: *quality robustness*, *target-oriented quality,* and the *quality loss function*.

Quality robust
Products that are consistently built to meet customer needs despite adverse conditions in the production process.

Quality robust products are products that can be produced uniformly and consistently in adverse manufacturing and environmental conditions. Taguchi's idea is to remove the *effects* of adverse conditions instead of removing the causes. Taguchi suggests that removing the effects

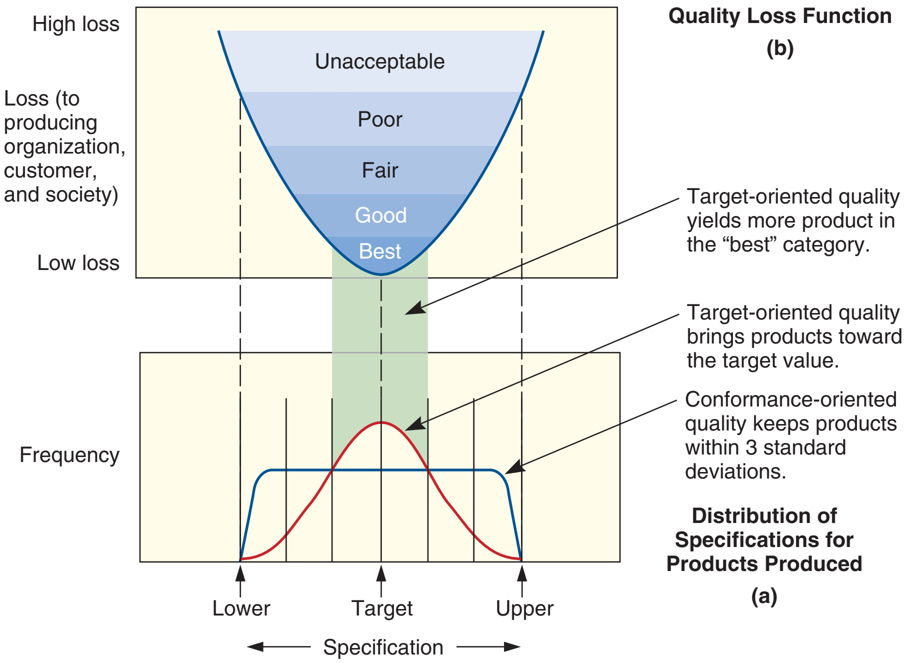


Figure **6.5**

(a) Distribution of Products Produced and (b) Quality Loss Function

Taguchi aims for the target because products produced near the upper and lower acceptable specifications result in a higher quality loss.

is often cheaper than removing the causes and more effective in producing a robust product. In this way, small variations in materials and process do not destroy product quality.

A study found that U.S. consumers preferred Sony TVs made in Japan to Sony TVs made in the U.S., even though both factories used the exact same designs and specifications. The difference in approaches to quality generated the difference in consumer preferences. In particular, the U.S. factory was *conformance-oriented*, accepting all components that were produced within specification limits. On the other hand, the Japanese factory strove to produce as many components as close to the actual target as possible (see Figure 6.5(a)).

LO 6.5 *Explain* quality robust products and Taguchi concepts

This suggests that even though components made close to the boundaries of the specification limits may technically be acceptable, they may still create problems. For example, TV screens produced near their diameter's lower spec limit may provide a loose fit with screen frames produced near their upper spec limit, and vice versa. This implies that a final product containing many parts produced near their specification boundaries may contain numerous loose and tight fits, which could cause assembly, performance, or aesthetic concerns. Customers may be dissatisfied, resulting in possible returns, service work, or decreased future demand.

Taguchi introduced the concept of **target-oriented quality** as a philosophy of continuous improvement to bring the product exactly on target. As a measure, Taguchi's **quality loss function (QLF)** attempts to estimate the cost of deviating from the target value. Even though the item is produced within specification limits, the variation in quality can be expected to increase costs as the item output moves away from its target value. (These quality-related costs are estimates of the average cost over many such units produced.)

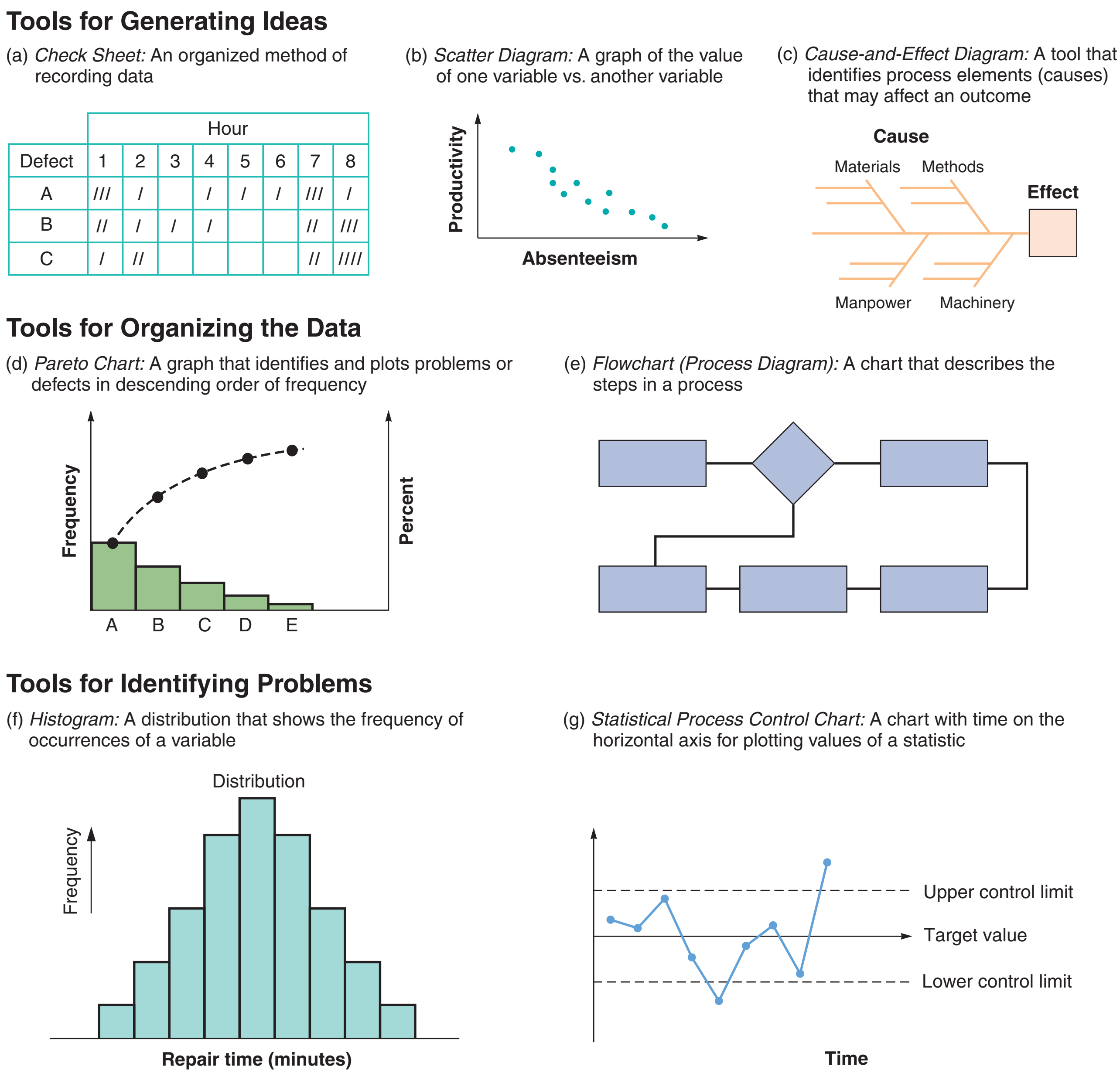
Target-oriented quality
A philosophy of continuous improvement to bring a product exactly on target.

Quality loss function (QLF)
A mathematical function that identifies all costs connected with poor quality and shows how these costs increase as output moves away from the target value.

The QLF is an excellent way to estimate quality costs of different processes. A process that produces closer to the actual target value may be more expensive, but it may yield a more valuable product. The QLF is the tool that helps the manager determine if this added cost is worthwhile. The QLF takes the general form of a simple quadratic equation (see Figure 6.5(b)).

Knowledge of TQM Tools

To empower employees and implement TQM as a continuing effort, everyone in the organization must be trained in the techniques of TQM. In the following section, we focus on some of the diverse and expanding tools that are used in the TQM crusade.



	Hour							
Defect	1	2	3	4	5	6	7	8
A	///	/		/	/	/	///	/
B	//	/	/	/			//	///
C	/	//					//	////

Figure 6.6

Seven Tools of TQM

STUDENT TIP These tools will prove useful in many of your courses and throughout your career.

Tools of TQM

Seven tools that are particularly helpful in the TQM effort are shown in Figure 6.6. We will now introduce these tools.

LO 6.6 *Use* the seven tools of TQM

Check Sheets

A check sheet is any kind of a form that is designed for recording data. In many cases, the recording is done so the patterns are easily seen while the data are being taken [see Figure 6.6(a)]. Check sheets help analysts find the facts or patterns that may aid subsequent analysis. An example might be a drawing that shows a tally of the areas where defects are occurring or a check sheet showing the type of customer complaints.

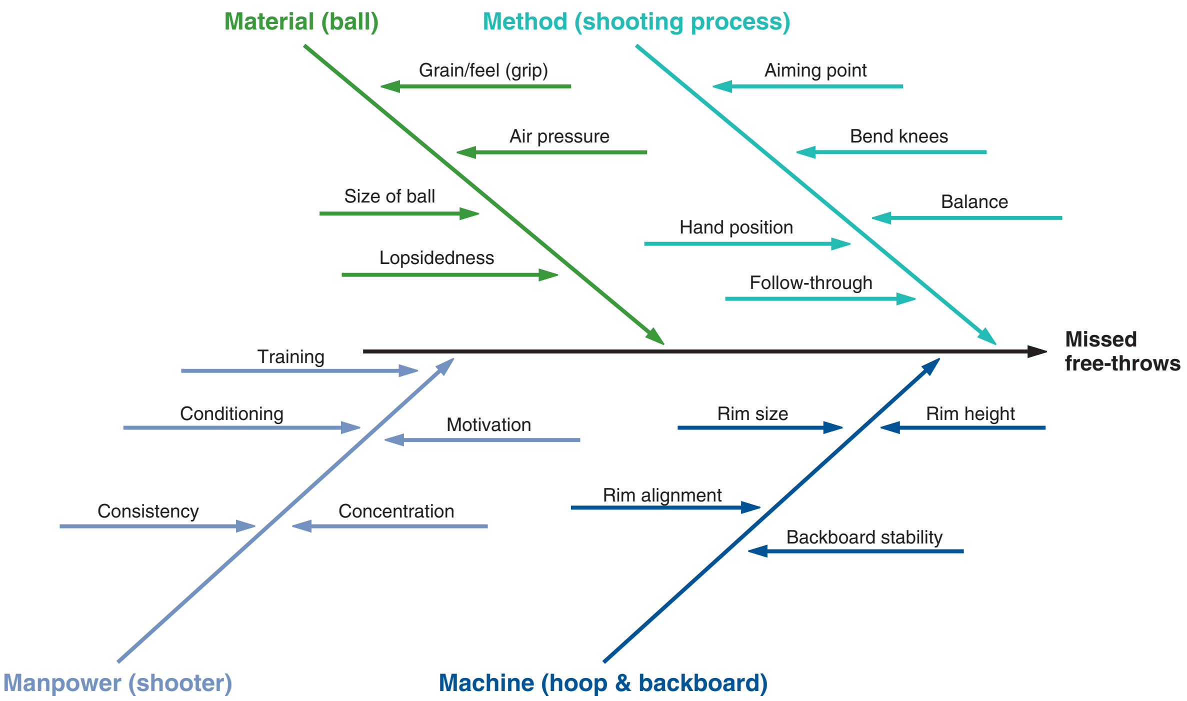


Figure **6.7**

Fish-Bone Chart (or Cause-and-Effect Diagram) for Problems with Missed Free-Throws

Source: Adapted from MoreSteam.com, 2007.

Scatter Diagrams

Scatter diagrams show the relationship between two measurements. An example is the positive relationship between length of a service call and the number of trips a repair person makes back to the truck for parts. Another example might be a plot of productivity and absenteeism, as shown in Figure 6.6(b). If the two items are closely related, the data points will form a tight band. If a random pattern results, the items are unrelated.

Cause-and-Effect Diagrams

Another tool for identifying quality issues and inspection points is the **cause-and-effect diagram**, also known as an **Ishikawa diagram** or a **fish-bone chart**. Figure 6.7 illustrates a chart (note the shape resembling the bones of a fish) for a basketball quality control problem—missed free-throws. Each "bone" represents a possible source of error.

Cause-and-effect diagram
A schematic technique used to discover possible locations of quality problems.

The operations manager starts with four categories: material, machinery/equipment, manpower, and methods. These four *M*s are the "causes." They provide a good checklist for initial analysis. Individual causes associated with each category are tied in as separate bones along that branch, often through a brainstorming process. For example, the method branch in Figure 6.7 has problems caused by hand position, follow-through, aiming point, bent knees, and balance. When a fish-bone chart is systematically developed, possible quality problems and inspection points are highlighted.

Pareto Charts

Pareto charts are a method of organizing errors, problems, or defects to help focus on problem-solving efforts. They are based on the work of Vilfredo Pareto, a 19th-century economist. Joseph M. Juran popularized Pareto's work when he suggested that 80% of a firm's problems are a result of only 20% of the causes.

Pareto charts
A graphic way of classifying problems by their level of importance, often referred to as the 80–20 rule.

Example 1 indicates that of the five types of complaints identified, the vast majority were of one type—poor room service.

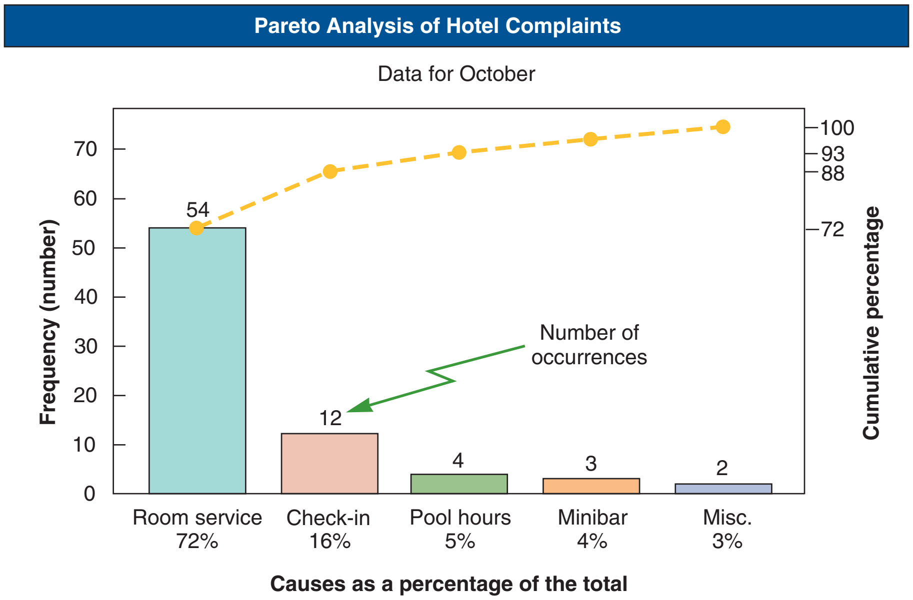
Example 1

A PARETO CHART AT THE HARD ROCK HOTEL

The Hard Rock Hotel in Bali has just collected the data from 75 complaint calls to the general manager during the month of October. The manager wants to prepare an analysis of the complaints. The data provided are room service, 54; check-in delays, 12; hours the pool is open, 4; minibar prices, 3; and miscellaneous, 2.

APPROACH ▶ A Pareto chart is an excellent choice for this analysis.

SOLUTION ▶ The Pareto chart shown below indicates that 72% of the calls were the result of one cause: room service. The majority of complaints will be eliminated when this one cause is corrected.



INSIGHT ▶ This visual means of summarizing data is very helpful—particularly with large amounts of data, as in the Southwestern University case study at the end of this chapter. We can immediately spot the top problems and prepare a plan to address them.

LEARNING EXERCISE ▶ Hard Rock's bar manager decides to do a similar analysis on complaints she has collected over the past year: too expensive, 22; weak drinks, 15; slow service, 65; short hours, 8; unfriendly bartender, 12. Prepare a Pareto chart. [Answer: slow service, 53%; expensive, 18%; drinks, 12%; bartender, 10%; hours, 7%.]

RELATED PROBLEMS ▶ 6.1, 6.3, 6.7b, 6.12, 6.13, 6.16c, 6.17b

ACTIVE MODEL 6.1 This example is further illustrated in Active Model 6.1 in MyOMLab.

Pareto analysis indicates which problems may yield the greatest payoff. Pacific Bell discovered this when it tried to find a way to reduce damage to buried phone cable, the number-one cause of phone outages. Pareto analysis showed that 41% of cable damage was caused by construction work. Armed with this information, Pacific Bell was able to devise a plan to reduce cable cuts by 24% in one year, saving $6 million.

Likewise, Japan's Ricoh Corp., a copier maker, used the Pareto principle to tackle the "callback" problem. Callbacks meant the job was not done right the first time and that a second visit, at Ricoh's expense, was needed. Identifying and retraining only the 11% of the customer engineers with the most callbacks resulted in a 19% drop in return visits.

Flowcharts

Flowcharts
Block diagrams that graphically describe a process or system.

Flowcharts graphically present a process or system using annotated boxes and interconnected lines [see Figure 6.6(e)]. They are a simple but great tool for trying to make sense of a process or explain a process. Example 2 uses a flowchart to show the process of completing an MRI at a hospital.

Example 2

A FLOWCHART FOR HOSPITAL MRI SERVICE

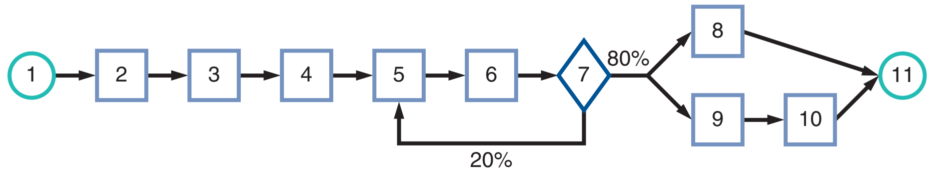
Arnold Palmer Hospital has undertaken a series of process improvement initiatives. One of these is to make the MRI service efficient for patient, doctor, and hospital. The first step, the administrator believes, is to develop a flowchart for this process.

APPROACH ▶ A process improvement staffer observed a number of patients and followed them (and information flow) from start to end. Here are the 11 steps:

1. Physician schedules MRI after examining patient (START).
2. Patient taken from the examination room to the MRI lab with test order and copy of medical records.
3. Patient signs in, completes required paperwork.
4. Patient is prepped by technician for scan.
5. Technician carries out the MRI scan.
6. Technician inspects film for clarity.
7. If MRI not satisfactory (20% of time), Steps 5 and 6 are repeated.
8. Patient taken back to hospital room.
9. MRI is read by radiologist and report is prepared.
10. MRI and report are transferred electronically to physician.
11. Patient and physician discuss report (END).

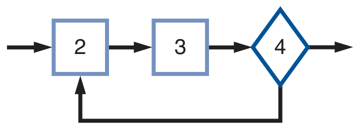
SOLUTION ▶ Here is the flowchart:

STUDENT TIP Flowcharting any process is an excellent way to understand and then try to improve that process.



INSIGHT ▶ With the flowchart in hand, the hospital can analyze each step and identify value-added activities and activities that can be improved or eliminated.

LEARNING EXERCISE ▶ A new procedure requires that if the patient's blood pressure is over 200/120 when being prepped for the MRI, she is taken back to her room for 2 hours and the process returns to Step 2. How does the flowchart change? Answer:



RELATED PROBLEMS ▶ 6.6, 6.15

Histograms

Histograms show the range of values of a measurement and the frequency with which each value occurs [see Figure 6.6(f)]. They show the most frequently occurring readings as well as the variations in the measurements. Descriptive statistics, such as the average and standard deviation, may be calculated to describe the distribution. However, the data should always be plotted so the shape of the distribution can be "seen." A visual presentation of the distribution may also provide insight into the cause of the variation.

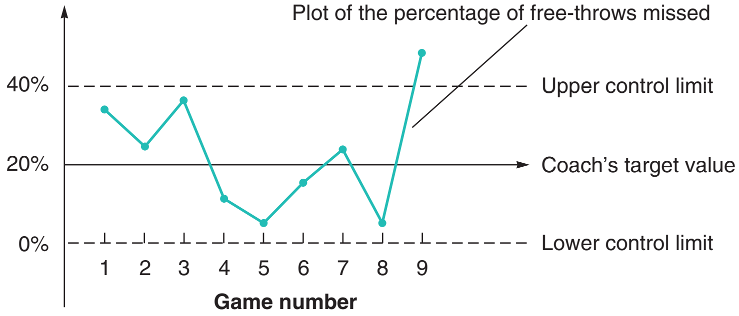
Statistical Process Control (SPC)

Statistical process control (SPC) monitors standards, makes measurements, and takes corrective action as a product or service is being produced. Samples of process outputs are examined; if they are within acceptable limits, the process is permitted to continue. If they fall outside certain specific ranges, the process is stopped and, typically, the assignable cause located and removed.

Statistical process control (SPC)
A process used to monitor standards, make measurements, and take corrective action as a product or service is being produced.

Figure 6.8

Control Chart for Percentage of Free-throws Missed by the Orlando Magic in Their First Nine Games of the New Season



McClatchy/Tribune Content Agency LLC/Alamy

Control charts
Graphic presentations of process data over time, with predetermined control limits.

Control charts are graphic presentations of data over time that show upper and lower limits for the process we want to control [see Figure 6.6(g)]. Control charts are constructed in such a way that new data can be quickly compared with past performance data. We take samples of the process output and plot the average of each of these samples on a chart that has the limits on it. The upper and lower limits in a control chart can be in units of temperature, pressure, weight, length, and so on.

Figure 6.8 shows the plot of sample averages in a control chart. When the samples fall within the upper and lower control limits and no discernible pattern is present, the process is said to be in control with only natural variation present. Otherwise, the process is out of control or out of adjustment.

The supplement to this chapter details how control charts of different types are developed. It also deals with the statistical foundation underlying the use of this important tool.

The Role of Inspection

Inspection
A means of ensuring that an operation is producing at the quality level expected.

To make sure a system is producing as expected, control of the process is needed. The best processes have little variation from the standard expected. In fact, if variation were completely eliminated, there would be no need for inspection because there would be no defects. The operations manager's challenge is to build such systems. However, inspection must often be performed to ensure that processes are performing to standard. This **inspection** can involve measurement, tasting, touching, weighing, or testing of the product (sometimes even destroying it when doing so). Its goal is to detect a bad process immediately. Inspection does not correct deficiencies in the system or defects in the products, nor does it change a product or increase its value. Inspection only finds deficiencies and defects. Moreover, inspections are expensive and do not add value to the product.

Inspection should be thought of as a vehicle for improving the system. Operations managers need to know critical points in the system: (1) *when to inspect* and (2) *where to inspect*.

When and Where to Inspect

Deciding when and where to inspect depends on the type of process and the value added at each stage. Inspections can take place at any of the following points:

1. At your supplier's plant while the supplier is producing.
2. At your facility upon receipt of goods from your supplier.
3. Before costly or irreversible processes.
4. During the step-by-step production process.
5. When production or service is complete.
6. Before delivery to your customer.
7. At the point of customer contact.

Matthias Schrader/dpa picture alliance archive/Alamy

Good methods analysis and the proper tools can result in poka-yokes that improve both quality and speed. Here, two poka-yokes are demonstrated. First, the aluminum scoop automatically positions the french fries vertically, and second, the properly sized container ensures that the portion served is correct. McDonald's thrives by bringing rigor and consistency to the restaurant business.

The seven tools of TQM discussed in the previous section aid in this "when and where to inspect" decision. However, inspection is not a substitute for a robust product produced by well-trained employees in a good process. In one well-known experiment conducted by an independent research firm, 100 defective pieces were added to a "perfect" lot of items and then subjected to 100% inspection. The inspectors found only 68 of the defective pieces in their first inspection. It took another three passes by the inspectors to find the next 30 defects. The last two defects were never found. So the bottom line is that there is variability in the inspection process. In addition, inspectors are only human: They become bored, they become tired, and the inspection equipment itself has variability. Even with 100% inspection, inspectors cannot guarantee perfection. Therefore, good processes, employee empowerment, and source control are a better solution than trying to find defects by inspection. You cannot inspect quality into the product.

STUDENT TIP
One of our themes of quality is that "quality cannot be inspected into a product."

For example, at Velcro Industries, as in many other organizations, quality was viewed by machine operators as the job of "those quality people." Inspections were based on random sampling, and if a part showed up bad, it was thrown out. The company decided to pay more attention to the system (operators, machine repair and design, measurement methods, communications, and responsibilities) and to invest more money in training. Over time as defects declined, Velcro was able to pull half its quality control people out of the process.

Source Inspection

The best inspection can be thought of as no inspection at all; this "inspection" is always done at the source—it is just doing the job properly with the operator ensuring that this is so. This may be called **source inspection** (or source control) and is consistent with the concept of employee empowerment, where individual employees self-check their own work. The idea is that each supplier, process, and employee *treats the next step in the process as the customer*, ensuring perfect product to the next "customer." This inspection may be assisted by the use of checklists and controls such as a fail-safe device called a *poka-yoke*, a name borrowed from the Japanese.

Source inspection
Controlling or monitoring at the point of production or purchase—at the source.

A **poka-yoke** is a foolproof device or technique that ensures production of good units every time. These special devices avoid errors and provide quick feedback of problems. A simple example of a poka-yoke device is the diesel gas pump nozzle that will not fit into the "unleaded" gas tank opening on your car. In McDonald's, the french fry scoop and standard-size container used to measure the correct quantity are poka-yokes. Similarly, in a hospital, the prepackaged surgical coverings that contain exactly the items needed for a medical procedure are poka-yokes.

Poka-yoke
Literally translated, "mistake proofing"; it has come to mean a device or technique that ensures the production of a good unit every time.

Checklists are a type of poka-yoke to help ensure consistency and completeness in carrying out a task. A basic example is a to-do list. This tool may take the form of preflight checklists used by airplane pilots, surgical safety checklists used by doctors, or software quality assurance lists used by programmers. The *OM in Action* box "Safe Patients, Smart Hospitals" illustrates the important role checklists have in hospital quality.

Checklist
A type of poka-yoke that lists the steps needed to ensure consistency and completeness in a task.

The idea of source inspection, poka-yokes, and checklists is to guarantee 100% good product or service at each step of a process.

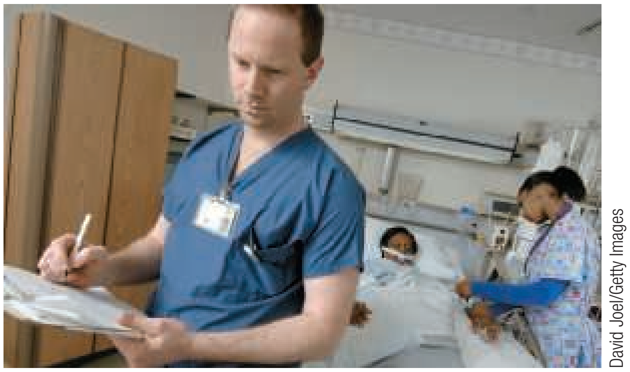
OM in Action Safe Patients, Smart Hospitals

Simple and avoidable errors are made in hospitals each day, causing patients to die. Inspired by two tragic medical mistakes—his father's misdiagnosed cancer and sloppiness that killed an 18-month-old child at Johns Hopkins—Dr. Peter Pronovost has made it his mission, often swimming upstream against the medical culture, to improve patient safety and prevent deaths.

He began by developing a basic 5-step checklist to reduce catheter infections. Inserted into veins in the groin, neck, or chest to administer fluids and medicines, catheters can save lives. But every year, 80,000 Americans get infections from *central venous catheters* (or lines), and over 30,000 of these patients die. Pronovost's checklist has dropped infection rates at hospitals that use it down to zero, saving thousands of lives and tens of millions of dollars.

His steps for doctors and nurses are simple: (1) wash your hands; (2) use sterile gloves, masks, and drapes; (3) use antiseptic on the area being opened for the catheter; (4) avoid veins in the arms and legs; and (5) take the catheter out as soon as possible. He also created a special cart, where all supplies needed are stored.

Dr. Provonost believes that many hospital errors are due to lack of standardization, poor communications, and a noncollaborative culture that is "antiquated and toxic." He points out that checklists in the airline industry are a science, and *every* crew member works as part of the safety team. Provonost's book has shown that one person, with small changes, can make a huge difference.



David Joel/Getty Images

Sources: Safe Patients, Smart Hospitals (Penguin Publishers, 2011); and *The Wall Street Journal* (December 13, 2014).

Service Industry Inspection

VIDEO 6.2
Quality Counts at Alaska Airlines

In *service*-oriented organizations, inspection points can be assigned at a wide range of locations, as illustrated in Table 6.4. Again, the operations manager must decide where inspections are justified and may find the seven tools of TQM useful when making these judgments.

TABLE 6.4 Examples of Inspection in Services

ORGANIZATION	WHAT IS INSPECTED	STANDARD
Alaska Airlines	Last bag on carousel	Less than 20 minutes after arrival at the gate
	Airplane door opened	Less than 2 minutes after arrival at the gate
Jones Law Offices	Receptionist performance	Phone answered by the second ring
	Billing	Accurate, timely, and correct format
	Attorney	Promptness in returning calls
Hard Rock Hotel	Reception desk	Use customer's name
	Doorman	Greet guest in less than 30 seconds
	Room	All lights working, spotless bathroom
	Minibar	Restocked and charges accurately posted to bill
Arnold Palmer Hospital	Billing	Accurate, timely, and correct format
	Pharmacy	Prescription accuracy, inventory accuracy
	Lab	Audit for lab-test accuracy
	Nurses	Charts immediately updated
	Admissions	Data entered correctly and completely
Olive Garden Restaurant	Busboy	Serves water and bread within one minute
	Busboy	Clears all entrèe items and crumbs prior to dessert
	Waiter	Knows and suggests specials, desserts
Nordstrom Department Store	Display areas	Attractive, well organized, stocked, good lighting
	Stockrooms	Rotation of goods, organized, clean
	Salesclerks	Neat, courteous, very knowledgeable

Inspection of Attributes versus Variables

When inspections take place, quality characteristics may be measured as either *attributes* or *variables*. **Attribute inspection** classifies items as being either good or defective. It does not address the *degree* of failure. For example, the lightbulb burns or it does not. **Variable inspection** measures such dimensions as weight, speed, size, or strength to see if an item falls within an acceptable range. If a piece of electrical wire is supposed to be 0.01 inch in diameter, a micrometer can be used to see if the product is close enough to pass inspection.

Knowing whether attributes or variables are being inspected helps us decide which statistical quality control approach to take, as we will see in the supplement to this chapter.

Attribute inspection
An inspection that classifies items as being either good or defective.

Variable inspection
Classifications of inspected items as falling on a continuum scale, such as dimension or strength.

TQM in Services

The personal component of services is more difficult to measure than the quality of the tangible component. Generally, the user of a service, like the user of a good, has features in mind that form a basis for comparison among alternatives. Lack of any one feature may eliminate the service from further consideration. Quality also may be perceived as a bundle of attributes in which many lesser characteristics are superior to those of competitors. This approach to product comparison differs little between goods and services. However, what is very different about the selection of services is the poor definition of the (1) *intangible differences between products* and (2) *the intangible expectations customers have of those products*. Indeed, the intangible attributes may not be defined at all. They are often unspoken images in the purchaser's mind. This is why all of those marketing issues such as advertising, image, and promotion can make a difference.

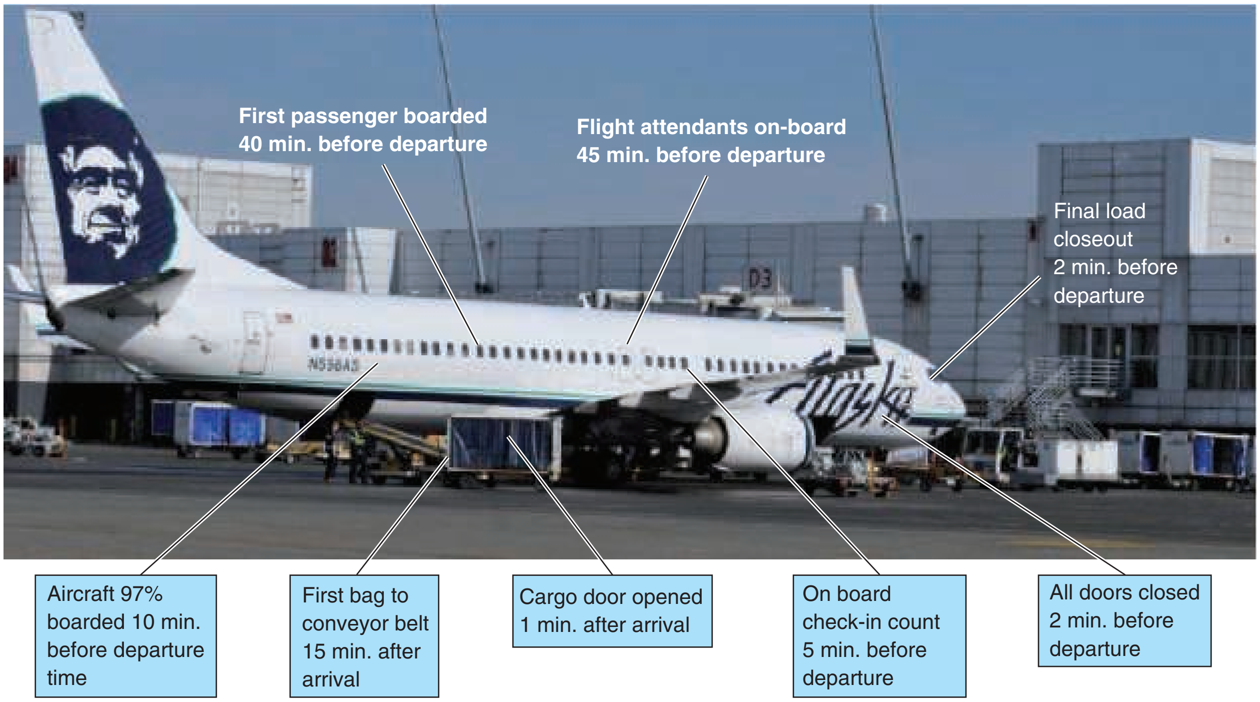
The operations manager plays a significant role in addressing several major aspects of service quality. First, the *tangible component of many services is important*. How well the service is designed and produced does make a difference. This might be how accurate, clear, and complete your checkout bill at the hotel is, how warm the food is at Taco Bell, or how well your car runs after you pick it up at the repair shop.

Second, another aspect of service and service quality is the process. Notice in Table 6.5 that 9 out of 10 of the determinants of service quality are related to *the service process*. Such things as reliability and courtesy are part of the process. An operations manager can

TABLE 6.5 Determinants of Service Quality

Reliability involves consistency of performance and dependability. It means that the firm performs the service right the first time and that the firm honors its promises.
Responsiveness concerns the willingness or readiness of employees to provide service. It involves timeliness of service.
Competence means possession of the required skills and knowledge to perform the service.
Access involves approachability and ease of contact.
Courtesy involves politeness, respect, consideration, and friendliness of contact personnel (including receptionists, telephone operators, etc.).
Communication means keeping customers informed in language they can understand and listening to them. It may mean that the company has to adjust its language for different consumers—increasing the level of sophistication with a well-educated customer and speaking simply and plainly with a novice.
Credibility involves trustworthiness, believability, and honesty. It involves having the customer's best interests at heart.
Security is the freedom from danger, risk, or doubt.
Understanding/knowing the customer involves making the effort to understand the customer's needs.
Tangibles include the physical evidence of the service.

Sources: Adapted from A. Parasuranam, Valarie A. Zeithaml, and Leonard L. Berry, "A Conceptual Model of Service Quality and Its Implications for Future Research," *Journal of Marketing* (1985): 49. Copyright © 1985 by the American Marketing Association. Reprinted with permission.



Like many service organizations, Alaska Airlines sets quality standards in areas such as courtesy, appearance, and time. Shown here are some of Alaska Airlines 50 quality checkpoints, based on a timeline for each departure.

design processes that have these attributes and can ensure their quality through the TQM techniques discussed in this chapter. (See the Alaska Airlines photo.)

Third, the operations manager should realize that the customer's expectations are the standard against which the service is judged. Customers' perceptions of service quality result from a comparison of their "before-service expectations" with their "actual-service experience." In other words, service quality is judged on the basis of whether it meets expectations. *The manager may be able to influence both the quality of the service and the expectation*. Don't promise more than you can deliver.

Fourth, the manager must expect exceptions. There is a standard quality level at which the regular service is delivered, such as the bank teller's handling of a transaction. However, there are "exceptions" or "problems" initiated by the customer or by less-than-optimal operating conditions (e.g., the computer "crashed"). This implies that the quality control system must recognize and *have a set of alternative plans for less-than-optimal operating conditions*.

Service recovery
Training and empowering frontline workers to solve a problem immediately.

Well-run companies have **service recovery** strategies. This means they train and empower frontline employees to immediately solve a problem. For instance, staff at Marriott Hotels are drilled in the **LEARN** routine—Listen, Empathize, Apologize, React, Notify—with the final step ensuring that the complaint is fed back into the system. And at the Ritz-Carlton, staff members are trained not to say merely "sorry" but "please accept my apology." The Ritz gives them a budget for reimbursing upset guests. Similarly, employees at Alaska Airlines are empowered to soothe irritated travelers by drawing from a "toolkit" of options at their disposal.

SERVQUAL
A popular measurement scale for service quality that compares service expectations with service performance.

Managers of service firms may find **SERVQUAL** useful when evaluating performance. SERVQUAL is a widely used instrument that provides direct comparisons between customer service expectations and the actual service provided. SERVQUAL focuses on the *gaps* between the customer service expectations and the service provided on 10 service quality determinants. The most common version of the scale collapses the 10 service quality determinants shown in Table 6.5 into five factors for measurement: reliability, assurance, tangibles, empathy, and responsiveness.

Designing the product, managing the service process, matching customer expectations to the product, and preparing for the exceptions are keys to quality services. The *OM in Action* box "Richey International's Spies" provides another glimpse of how OM managers improve quality in services.

VIDEO 6.3
TQM at Ritz-Carlton Hotels

OM in Action Richey International's Spies

How do luxury hotels maintain quality? They inspect. But when the product is one-on-one service, largely dependent on personal behavior, how do you inspect? You hire spies!

Richey International is the spy. Preferred Hotels and Resorts Worldwide and Intercontinental Hotels have both hired Richey to do quality evaluations via spying. Richey employees posing as customers perform the inspections. However, even then management must have established what the customer expects and specific services that yield customer satisfaction. Only then do managers know where and how to inspect. Aggressive training and objective inspections reinforce behavior that will meet those customer expectations.

The hotels use Richey's undercover inspectors to ensure performance to exacting standards. The hotels do not know when the evaluators will arrive. Nor what aliases they will use. Over 50 different standards are evaluated before the inspectors even check in at a luxury hotel. Over the next 24 hours, using checklists, tape recordings, and photos, written reports are prepared. The reports include evaluation of standards such as:

- Does the doorman greet each guest in less than 30 seconds?
- Does the front-desk clerk use the guest's name during check-in?
- Are the bathroom tub and shower spotlessly clean?
- How many minutes does it take to get coffee after the guest sits down for breakfast?
- Did the waiter make eye contact?
- Were minibar charges posted correctly on the bill?

Established standards, aggressive training, and inspections are part of the TQM effort at these hotels. Quality does not happen by accident.

Sources: Hotelier (Feb. 6, 2010); *Hotel and Motel Management* (August 2002); and *The Wall Street Journal* (May 12, 1999).

Summary

Quality is a term that means different things to different people. We define quality as "the totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs." Defining quality expectations is critical to effective and efficient operations.

Quality requires building a total quality management (TQM) environment because quality cannot be inspected into a product. The chapter also addresses seven TQM *concepts*: continuous improvement, Six Sigma, employee empowerment, benchmarking, just-in-time, Taguchi concepts, and knowledge of TQM tools. The seven TQM *tools* introduced in this chapter are check sheets, scatter diagrams, cause-and-effect diagrams, Pareto charts, flowcharts, histograms, and statistical process control (SPC).

Key Terms

Quality (p. 217)
ISO 9000 (p. 218)
Cost of quality (COQ) (p. 218)
Total quality management (TQM) (p. 219)
PDCA (p. 220)
Six Sigma (p. 221)
Employee empowerment (p. 222)
Quality circle (p. 222)
Benchmarking (p. 222)
Quality robust (p. 224)
Target-oriented quality (p. 225)
Quality loss function (QLF) (p. 225)
Cause-and-effect diagram, Ishikawa diagram, or fish-bone chart (p. 227)
Pareto charts (p. 227)
Flowcharts (p. 228)
Statistical process control (SPC) (p. 229)
Control charts (p. 230)
Inspection (p. 230)
Source inspection (p. 231)
Poka-yoke (p. 231)
Checklist (p. 231)
Attribute inspection (p. 233)
Variable inspection (p. 233)
Service recovery (p. 234)
SERVQUAL (p. 234)

Ethical Dilemma

A lawsuit a few years ago made headlines worldwide when a McDonald's drive-through customer spilled a cup of scalding hot coffee on herself. Claiming the coffee was too hot to be safely consumed in a car, the badly burned 80-year-old woman won $2.9 million in court. (The judge later reduced the award to $640,000.) McDonald's claimed the product was served to the correct specifications and was of proper quality. Further, the cup read "Caution—Contents May Be Hot." McDonald's coffee, at 180°, is substantially hotter (by corporate rule) than typical restaurant coffee, despite hundreds of coffee-scalding complaints in the past 10 years. Similar court cases, incidentally, resulted in smaller verdicts, but again in favor of the plaintiffs. For example, Motor City Bagel Shop was sued for a spilled cup of coffee by a drive-through patron, and Starbucks by a customer who spilled coffee on her own ankle.

Are McDonald's, Motor City, and Starbucks at fault in situations such as these? How do quality and ethics enter into these cases?

Discussion Questions

1. Explain how improving quality can lead to reduced costs.
2. As an Internet exercise, determine the Baldrige Award criteria. See the Web site **www.nist.gov/baldrige/**.
3. Which 3 of Deming's 14 points do you think are most critical to the success of a TQM program? Why?
4. List the seven concepts that are necessary for an effective TQM program. How are these related to Deming's 14 points?
5. Name three of the important people associated with the quality concepts of this chapter. In each case, write a sentence about each one summarizing his primary contribution to the field of quality management.
6. What are seven tools of TQM?
7. How does fear in the workplace (and in the classroom) inhibit learning?
8. How can a university control the quality of its output (that is, its graduates)?
9. Philip Crosby said that quality is free. Why?
10. List the three concepts central to Taguchi's approach.
11. What is the purpose of using a Pareto chart for a given problem?
12. What are the four broad categories of "causes" to help initially structure an Ishikawa diagram or cause-and-effect diagram?
13. Of the several points where inspection may be necessary, which apply especially well to manufacturing?
14. What roles do operations managers play in addressing the major aspects of service quality?
15. Explain, in your own words, what is meant by *source inspection*.
16. What are 10 determinants of service quality?
17. Name several products that do not require high quality.
18. In this chapter, we have suggested that building quality into a process and its people is difficult. Inspections are also difficult. To indicate just how difficult inspections are, count the number of *E*s (both capital *E* and lowercase *e*) in the *OM in Action* box "Richey International's Spies" on page 235 (include the title but not the source note). How many did you find? If each student does this individually, you are very likely to find a distribution rather than a single number!

Solved Problems

Virtual Office Hours help is available in MyOMLab.

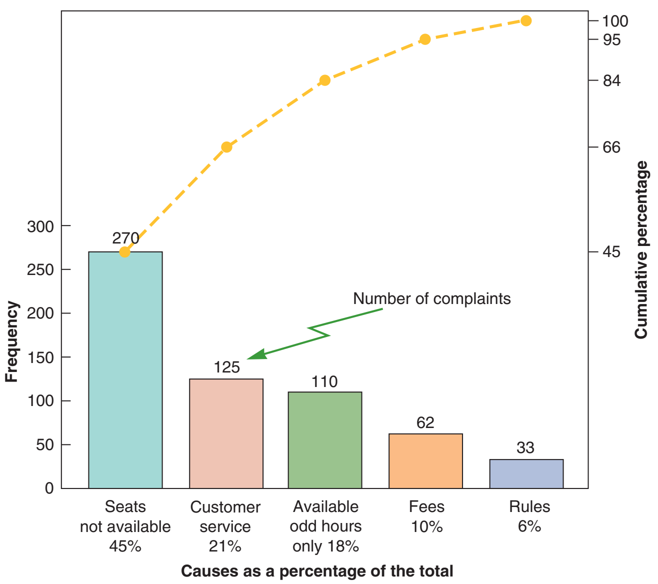
SOLVED PROBLEM 6.1

Northern Airlines's frequent flyer complaints about redeeming miles for free, discounted, and upgraded travel are summarized below, in five categories, from 600 letters received this year.

COMPLAINT	FREQUENCY
Could not get through to customer service to make requests	125
Seats not available on date requested	270
Had to pay fees to get "free" seats	62
Seats were available but only on flights at odd hours	110
Rules kept changing whenever customer called	33

Develop a Pareto chart for the data.

SOLUTION



Problems

Problems 6.1–6.20 relate to Tools of TQM

• **6.1** An avant-garde clothing manufacturer runs a series of high-profile, risqué ads on a billboard on Highway 101 and regularly collects protest calls from people who are offended by them. The company has no idea how many people in total see the ads, but it has been collecting statistics on the number of phone calls from irate viewers:

TYPE	DESCRIPTION	NUMBER OF COMPLAINTS
R	Offensive racially/ethnically	10
M	Demeaning to men	4
W	Demeaning to women	14
I	Ad is incomprehensible	6
O	Other	2

a) Depict this data with a Pareto chart. Also depict the cumulative complaint line.
b) What percent of the total complaints can be attributed to the most prevalent complaint?

• **6.2** Develop a scatter diagram for two variables of interest [say pages in the newspaper by day of the week; see the example in Figure 6.6(b)].

• **6.3** Develop a Pareto chart of the following causes of poor grades on an exam:

REASON FOR POOR GRADE	FREQUENCY
Insufficient time to complete	15
Late arrival to exam	7
Difficulty understanding material	25
Insufficient preparation time	2
Studied wrong material	2
Distractions in exam room	9
Calculator batteries died during exam	1
Forgot exam was scheduled	3
Felt ill during exam	4

• **6.4** Develop a histogram of the time it took for you or your friends to receive six recent orders at a fast-food restaurant.

•• **6.5** Kathleen McFadden's restaurant in Boston has recorded the following data for eight recent customers:

CUSTOMER NUMBER, i	MINUTES FROM TIME FOOD ORDERED UNTIL FOOD ARRIVED (y_i)	NO. OF TRIPS TO KITCHEN BY WAITRESS (x_i)
1	10.50	4
2	12.75	5
3	9.25	3
4	8.00	2
5	9.75	3
6	11.00	4
7	14.00	6
8	10.75	5

a) McFadden wants you to graph the eight points (x_i, y_i), $i = 1, 2, \ldots 8$. She has been concerned because customers have been waiting too long for their food, and this graph is intended to help her find possible causes of the problem.
b) This is an example of what type of graph?

•• **6.6** Develop a flowchart [as in Figure 6.6(e) and Example 2] showing all the steps involved in planning a party.

•• **6.7** Consider the types of poor driving habits that might occur at a traffic light. Make a list of the 10 you consider most likely to happen. Add the category of "other" to that list.

a) Compose a check sheet [like that in Figure 6.6(a)] to collect the frequency of occurrence of these habits. Using your check sheet, visit a busy traffic light intersection at four different times of the day, with two of these times being during high-traffic periods (rush hour, lunch hour). For 15 to 20 minutes each visit, observe the frequency with which the habits you listed occurred.
b) Construct a Pareto chart showing the relative frequency of occurrence of each habit.

•• **6.8** Draw a fish-bone chart detailing reasons why an airline customer might be dissatisfied.

•• **6.9** Consider the everyday task of getting to work on time or arriving at your first class on time in the morning. Draw a fish-bone chart showing reasons why you might arrive late in the morning.

•• **6.10** Construct a cause-and-effect diagram to reflect "student dissatisfied with university registration process." Use the "four *Ms*" or create your own organizing scheme. Include at least 12 causes.

•• **6.11** Draw a fish-bone chart depicting the reasons that might give rise to an incorrect fee statement at the time you go to pay for your registration at school.

••• **6.12** Mary Beth Marrs, the manager of an apartment complex, feels overwhelmed by the number of complaints she is receiving. Below is the check sheet she has kept for the past 12 weeks. Develop a Pareto chart using this information. What recommendations would you make?

WEEK	GROUNDS	PARKING/ DRIVES	POOL	TENANT ISSUES	ELECTRICAL/ PLUMBING
1	✓✓✓	✓✓	✓	✓✓✓	
2	✓	✓✓✓	✓✓	✓✓	✓
3	✓✓✓	✓✓✓	✓✓	✓	
4	✓	✓✓✓✓	✓	✓	✓✓
5	✓✓	✓✓✓	✓✓✓✓	✓✓	
6	✓	✓✓✓✓	✓✓		
7		✓✓✓	✓✓	✓✓	
8	✓	✓✓✓✓	✓✓	✓✓✓	✓
9	✓	✓✓	✓		
10	✓	✓✓✓✓	✓✓	✓✓	
11		✓✓✓	✓✓	✓	
12	✓✓	✓✓✓	✓✓✓	✓	

• **6.13** Use Pareto analysis to investigate the following data collected on a printed-circuit-board assembly line:

DEFECT	NUMBER OF DEFECT OCCURRENCES
Components not adhering	143
Excess adhesive	71
Misplaced transistors	601
Defective board dimension	146
Mounting holes improperly positioned	12
Circuitry problems on final test	90
Wrong component	212

a) Prepare a graph of the data.
b) What conclusions do you reach?

• • **6.14** A list of 16 issues that led to incorrect formulations in Tuncey Bayrak's jam manufacturing unit in New England is provided below:

List of Issues

1. Incorrect measurement	9. Variability in scale accuracy
2. Antiquated scales	10. Equipment in disrepair
3. Lack of clear instructions	11. Technician calculation off
4. Damaged raw material	12. Jars mislabeled
5. Operator misreads display	13. Temperature controls off
6. Inadequate cleanup	14. Incorrect weights
7. Incorrect maintenance	15. Priority miscommunication
8. Inadequate flow controls	16. Inadequate instructions

Create a fish-bone diagram and categorize each of these issues correctly, using the "four *M*s" method.

• • **6.15** Develop a flowchart for one of the following:
a) Filling up with gasoline at a self-serve station.
b) Determining your account balance and making a withdrawal at an ATM.
c) Getting a cone of yogurt or ice cream from an ice cream store.

• • • • **6.16** Boston Electric Generators has been getting many complaints from its major customer, Home Station, about the quality of its shipments of home generators. Daniel Shimshak, the plant manager, is alarmed that a customer is providing him with the only information the company has on shipment quality. He decides to collect information on defective shipments through a form he has asked his drivers to complete on arrival at customers' stores. The forms for the first 279 shipments have been turned in. They show the following over the past 8 weeks:

WEEK	NO. OF SHIP-MENTS	NO. OF SHIP-MENTS WITH DEFECTS	*REASON FOR DEFECTIVE SHIPMENT*			
			INCORRECT BILL OF LADING	INCORRECT TRUCK-LOAD	DAMAGED PRODUCT	TRUCKS LATE
1	23	5	2	2	1	
2	31	8	1	4	1	2
3	28	6	2	3	1	
4	37	11	4	4	1	2
5	35	10	3	4	2	1
6	40	14	5	6	3	
7	41	12	3	5	3	1
8	44	15	4	7	2	2

Even though Daniel increased his capacity by adding more workers to his normal contingent of 30, he knew that for many weeks he exceeded his regular output of 30 shipments per week. A review of his turnover over the past 8 weeks shows the following:

WEEK	NO. OF NEW HIRES	NO. OF TERMINATIONS	TOTAL NO. OF WORKERS
1	1	0	30
2	2	1	31
3	3	2	32
4	2	0	34
5	2	2	34
6	2	4	32
7	4	1	35
8	3	2	36

a) Develop a scatter diagram using total number of shipments and number of defective shipments. Does there appear to be any relationship?
b) Develop a scatter diagram using the variable "turnover" (number of new hires plus number of terminations) and the number of defective shipments. Does the diagram depict a relationship between the two variables?
c) Develop a Pareto chart for the type of defects that have occurred.
d) Draw a fish-bone chart showing the possible causes of the defective shipments.

• • • **6.17** A recent Gallup poll of 519 adults who flew in the past year found the following number of complaints about flying: cramped seats (45), cost (16), dislike or fear of flying (57), security measures (119), poor service (12), connecting flight problems (8), overcrowded planes (42), late planes/waits (57), food (7), lost luggage (7), and other (51).
a) What percentage of those surveyed found nothing they disliked?
b) Draw a Pareto chart summarizing these responses. Include the "no complaints" group.
c) Use the "four *M*s" method to create a fish-bone diagram for the 10 specific categories of dislikes (exclude "other" and "no complaints").
d) If you were managing an airline, what two or three specific issues would you tackle to improve customer service? Why?

Christophe Testi/Shutterstock

Problems **6.18–6.20** *are available in* MyOMLab.

Problem 6.21 (available in MyOMLab) relates to TQM in Services

CASE STUDIES

Southwestern University: (C)*

The popularity of Southwestern University's football program under its new coach Phil Flamm surged in each of the 5 years since his arrival at the Stephenville, Texas, college. (See Southwestern University: (A) in Chapter 3 and (B) in Chapter 4.) With a football stadium close to maxing out at 54,000 seats and a vocal coach pushing for a new stadium, SWU president Joel Wisner faced some difficult decisions. After a phenomenal upset victory over its archrival, the University of Texas, at the homecoming game in the fall, Dr. Wisner was not as happy as one would think. Instead of ecstatic alumni, students, and faculty, all Wisner heard were complaints. "The lines at the concession stands were too long"; "Parking was harder to find and farther away than in the old days" (that is, before the team won regularly); "Seats weren't comfortable"; "Traffic was backed up halfway to Dallas"; and on and on. "A college president just can't win," muttered Wisner to himself.

At his staff meeting the following Monday, Wisner turned to his VP of administration, Leslie Gardner. "I wish you would take care of these football complaints, Leslie," he said. "See what the *real* problems are and let me know how you've resolved them." Gardner wasn't surprised at the request. "I've already got a handle on it, Joel," she replied. "We've been randomly surveying 50 fans per game for the past year to see what's on their minds. It's all part of my campuswide TQM effort. Let me tally things up and I'll get back to you in a week."

When she returned to her office, Gardner pulled out the file her assistant had compiled (see Table 6.6). "There's a lot of information here," she thought.

TABLE 6.6 Fan Satisfaction Survey Results ($N = 250$)

		OVERALL GRADE				
		A	B	C	D	F
Game Day	A. Parking	90	105	45	5	5
	B. Traffic	50	85	48	52	15
	C. Seating	45	30	115	35	25
	D. Entertainment	160	35	26	10	19
	E. Printed Program	66	34	98	22	30
Tickets	A. Pricing	105	104	16	15	10
	B. Season Ticket Plans	75	80	54	41	0
Concessions	A. Prices	16	116	58	58	2
	B. Selection of Foods	155	60	24	11	0
	C. Speed of Service	35	45	46	48	76
Respondents						
Alumnus	113					
Student	83					
Faculty/Staff	16					
None of the above	38					

Open-Ended Comments on Survey Cards:

Parking a mess Add a skybox Get better cheerleaders Double the parking attendants Everything is okay Too crowded Seats too narrow Great food Phil F. for President! I smelled drugs being smoked Stadium is ancient Seats are like rocks Not enough cops for traffic Game starts too late Hire more traffic cops Need new band Great!	More hot dog stands Seats are all metal Need skyboxes Seats stink Go SWU! Lines are awful Seats are uncomfortable I will pay more for better view Get a new stadium Student dress code needed I want cushioned seats Not enough police Students too rowdy Parking terrible Toilets weren't clean Not enough handicap spots in lot Well done, SWU	Put in bigger seats Friendly ushers Need better seats Expand parking lots Hate the bleacher seats Hot dogs cold $3 for a coffee? No way! Get some skyboxes Love the new uniforms Took an hour to park Coach is terrific More water fountains Better seats Seats not comfy Bigger parking lot I'm too old for bench seats Cold coffee served at game	My company will buy a skybox—build it! Programs overpriced Want softer seats Beat those Longhorns! I'll pay for a skybox Seats too small Band was terrific Love Phil Flamm Everything is great Build new stadium Move games to Dallas No complaints Dirty bathroom

Discussion Questions

1. Using at least two different quality tools, analyze the data and present your conclusions.
2. How could the survey have been more useful?
3. What is the next step?

*This integrated case study runs throughout the text. Other issues facing Southwestern's football stadium include: (A) Managing the renovation project (Chapter 3); (B) Forecasting game attendance (Chapter 4); (D) Break-even analysis of food services (Supplement 7 Web site); (E) Locating the new stadium (Chapter 8 Web site); (F) Inventory planning of football programs (Chapter 12 Web site); and (G) Scheduling of campus security officers/staff for game days (Chapter 13 Web site).

The Culture of Quality at Arnold Palmer Hospital

Video Case

Founded in 1989, Arnold Palmer Hospital is one of the largest hospitals for women and children in the U.S., with 431 beds in two facilities totaling 676,000 square feet. Located in downtown Orlando, Florida, and named after its famed golf benefactor, the hospital, with more than 2,000 employees, serves an 18-county area in central Florida and is the only Level 1 trauma center for children in that region. Arnold Palmer Hospital provides a broad range of medical services including neonatal and pediatric intensive care, pediatric oncology and cardiology, care for high-risk pregnancies, and maternal intensive care.

The Issue of Assessing Quality Health Care

Quality health care is a goal all hospitals profess, but Arnold Palmer Hospital has actually developed comprehensive and scientific means of asking customers to judge the quality of care they receive. Participating in a national benchmark comparison against other hospitals, Arnold Palmer Hospital consistently scores in the top 10% in overall patient satisfaction. Executive Director Kathy Swanson states, "Hospitals in this area will be distinguished largely on the basis of their customer satisfaction. We must have accurate information about how our patients and their families judge the quality of our care, so I follow the questionnaire results daily. The in-depth survey helps me and others on my team to gain quick knowledge from patient feedback." Arnold Palmer Hospital employees are empowered to provide gifts in value up to $200 to patients who find reason to complain about any hospital service such as food, courtesy, responsiveness, or cleanliness.

Swanson doesn't focus just on the customer surveys, which are mailed to patients one week after discharge, but also on a variety of internal measures. These measures usually start at the grassroots level, where the staff sees a problem and develops ways to track performance. The hospital's longstanding philosophy supports the concept that each patient is important and respected as a person. That patient has the right to comprehensive, compassionate family-centered health care provided by a knowledgeable physician-directed team.

Some of the measures Swanson carefully monitors for continuous improvement are morbidity, infection rates, readmission rates, costs per case, and length of stays. The tools she uses daily include Pareto charts, flowcharts, and process charts, in addition to benchmarking against hospitals both nationally and in the southeast region.

The result of all of these efforts has been a quality culture as manifested in Arnold Palmer's high ranking in patient satisfaction and one of the highest survival rates of critically ill babies.

Discussion Questions*

1. Why is it important for Arnold Palmer Hospital to get a patient's assessment of health care quality? Does the patient have the expertise to judge the health care she receives?
2. How would you build a culture of quality in an organization such as Arnold Palmer Hospital?
3. What techniques does Arnold Palmer Hospital practice in its drive for quality and continuous improvement?
4. Develop a fish-bone diagram illustrating the quality variables for a patient who just gave birth at Arnold Palmer Hospital (or any other hospital).

*You may wish to view the video that accompanies this case before answering these questions.

Quality Counts at Alaska Airlines

Video Case

Alaska Airlines, with nearly 100 destinations, including regular service to Alaska, Hawaii, Canada, and Mexico, is the seventh-largest U.S. carrier. Alaska Airlines has won the J.D. Power and Associates Award for highest customer satisfaction in the industry for eight years in a row while being the number one on-time airline for five years in a row.

Management's unwavering commitment to quality has driven much of the firm's success and generated an extremely loyal customer base. Executive V.P. Ben Minicucci exclaims, "We have rewritten our DNA." Building an organization that can achieve quality is a demanding task, and the management at Alaska Airlines accepted the challenge. This is a highly participative quality culture, reinforced by leadership training, constant process improvement, comprehensive metrics, and frequent review of those metrics. The usual training of flight crews and pilots is supplemented with

Alaska Air lines

ELEMENTS	WEIGHTING	PERFORMANCE	SCORE	BONUS POINTS	TOTAL	GRADE
Process Compliance	20		15		15	B
Staffing	15		15	5	20	A+
MAP Rate (for bags)	20		15		15	B
Delays	10		9		9	A
Time to Carousel (total weight = 10)			10		10	A
Percentage of flights scanned	2	98.7%				
Percentage of bags scanned	2	70.9%				
20 Minutes all bags dropped (% compliance)	4	92.5%				
Outliers (>25mins)	2	2				
Safety Compliance	15		15	5	20	A+
Quality Compliance	10		10		10	A
Total - 100%	**100**		**89**	**10**	**99**	**A+**

Time to Carousel

Points	2	1.5	1	0
Percentage of flights scanned	95%–100%	90%–94.9%	89.9%–85%	< 84.9%

Points	2	0
Percentage of bags scanned	60% or above	≤ 59.9%

Points	0	4
Last bag percent compliance	Below 89.9%	90%–100%

Points	0	1	1.5	2
Last Bag >25 min. (Outliers)	20	15	10	5

classroom training in areas such as Six Sigma. Over 200 managers have obtained Six Sigma Green Belt certification.

Alaska collects more than 100 quality and performance metrics every day. For example, the accompanying picture tells the crew that it has 6 minutes to close the door and back away from the gate to meet the "time to pushback" target. Operations personnel review each airport hub's performance scorecard daily and the overall operations scorecard weekly. As Director of System Operations Control, Wayne Newton proclaims, "If it is not measured, it is not managed." The focus is on identifying problem areas or trends, determining causes, and working on preventive measures.

Within the operations function there are numerous detailed input metrics for station operations (such as the percentage of time that hoses are free of twists, the ground power cord is stowed, and no vehicles are parked in prohibited zones). Management operates under the assumption that if all the detailed input metrics are acceptable, the major key performance indicators, such as Alaska's on-time performance and 20-minute luggage guarantee, will automatically score well.

The accompanying table displays a sample monthly scorecard for Alaska's ground crew provider in Seattle. The major evaluation categories include process compliance, staffing (degree that crew members are available when needed), MAP rate (minimum acceptable performance for mishandled bags), delays, time to carousel, safety compliance, and quality compliance. The quality compliance category alone tracks 64 detailed input metrics using approximately 30,000 monthly observations. Each of the major categories on the scorecard has an importance weight, and the provider is assigned a weighted average score at the end of each month. The contract with the supplier provides for up to a 3.7% bonus for outstanding performance and as much as a 5.0% penalty for poor performance. The provider's line workers receive a portion of the bonus when top scores are achieved.

As a company known for outstanding customer service, service recovery efforts represent a necessary area of emphasis. When things go wrong, employees mobilize to first communicate with, and in many cases compensate, affected customers. "It doesn't matter if it's not our fault," says Minicucci. Front-line workers are empowered with a "toolkit" of options to offer to inconvenienced customers, including the ability to provide up to 5,000 frequent flyer miles and/or vouchers for meals, hotels, luggage, and tickets. When an Alaska flight had to make an emergency landing in Eugene, Oregon, due to a malfunctioning oven, passengers were immediately texted with information about what happened and why, and they were told that a replacement plane would be arriving within one hour. Within that hour, an apology letter along with a $450 ticket voucher were already in the mail to each passenger's home. No customer complaints subsequently appeared on Twitter or Facebook. It's no wonder why Alaska's customers return again and again.

Discussion Questions*

1. What are some ways that Alaska can ensure that quality and performance metric standards are met when the company outsources its ground operations to a contract provider?
2. Identify several quality metrics, in addition to those identified earlier, that you think Alaska tracks or should be tracking.
3. Think about a previous problem that you had when flying, for example, a late flight, a missed connection, or lost luggage. How, if at all, did the airline respond? Did the airline adequately address your situation? If not, what else should they

have done? Did your experience affect your desire (positively or negative) to fly with that airline in the future?

4. See the accompanying table. The contractor received a perfect Time to Carousel score of 10 total points, even though its performance was not "perfect." How many total points would the contractor have received with the following performance scores: 93.2% of flights scanned, 63.5% of bags scanned, 89.6% of all bags dropped within 20 minutes, and 15 bags arriving longer than 25 minutes?

*You may wish to view the video that accompanies this case before addressing these questions.

Quality at the Ritz-Carlton Hotel Company

Video Case

Ritz-Carlton. The name alone evokes images of luxury and quality. As the first hotel company to win the Malcolm Baldrige National Quality Award, the Ritz treats quality as if it is the heartbeat of the company. This means a daily commitment to meeting customer expectations and making sure that each hotel is free of any deficiency.

In the hotel industry, quality can be hard to quantify. Guests do not purchase a product when they stay at the Ritz: They buy an experience. Thus, creating the right combination of elements to make the experience stand out is the challenge and goal of every employee, from maintenance to management.

Before applying for the Baldrige Award, company management undertook a rigorous self-examination of its operations in an attempt to measure and quantify quality. Nineteen processes were studied, including room service delivery, guest reservation and registration, message delivery, and breakfast service. This period of self-study included statistical measurement of process work flows and cycle times for areas ranging from room service delivery times and reservations to valet parking and housekeeping efficiency. The results were used to develop performance benchmarks against which future activity could be measured.

With specific, quantifiable targets in place, Ritz-Carlton managers and employees now focus on continuous improvement. The goal is 100% customer satisfaction: If a guest's experience does not meet expectations, the Ritz-Carlton risks losing that guest to competition.

One way the company has put more meaning behind its quality efforts is to organize its employees into "self-directed" work teams. Employee teams determine work scheduling, what work needs to be done, and what to do about quality problems in their own areas. In order to see the relationship of their specific area to the overall goals, employees are also given the opportunity to take additional training in hotel operations. Ritz-Carlton believes that a more educated and informed employee is in a better position to make decisions in the best interest of the organization.

Discussion Questions*

1. In what ways could the Ritz-Carlton monitor its success in achieving quality?
2. Many companies say that their goal is to provide quality products or services. What actions might you expect from a company that intends quality to be more than a slogan or buzzword?
3. Why might it cost the Ritz-Carlton less to "do things right" the first time?
4. How could control charts, Pareto diagrams, and cause-and-effect diagrams be used to identify quality problems at a hotel?
5. What are some nonfinancial measures of customer satisfaction that might be used by the Ritz-Carlton?

*You may wish to view the video that accompanies this case before addressing these questions.

Source: Adapted from C. T. Horngren, S. M. Datar, and G. Foster, *Cost Accounting*, 15th ed. (Upper Saddle River, NJ: Prentice Hall, 2014).

- **Additional Case Study:** Visit MyOMLab for this free case study:
  Westover Electrical, Inc.: This electric motor manufacturer has a large log of defects in its wiring process.

Endnotes

1. Philip B. Crosby, *Quality Is Free* (New York: McGraw-Hill, 1979). Further, J. M. Juran states, in his book *Juran on Quality by Design* (The Free Press 1992, p. 119), that costs of poor quality "are huge, but the amounts are not known with precision. In most companies the accounting system provides only a minority of the information needed to quantify this cost of poor quality. It takes a great deal of time and effort to extend the accounting system so as to provide full coverage."
2. To train employees in how to improve quality and its relationship to customers, there are three other key players in the Six Sigma program: Master Black Belts, Black Belts, and Green Belts.
3. "The Straining of Quality," *The Economist* (January 14, 1995): 55. We also see that this is one of the strengths of Southwest Airlines, which offers bare-bones domestic service but whose friendly and humorous employees help it obtain number-one ranking for quality. (See *Fortune* [March 6, 2006]: 65–69.)

Chapter 6 *Rapid* Review

Main Heading	Review Material	MyOMLab
QUALITY AND STRATEGY (pp. 216–217)	Managing quality helps build successful strategies of differentiation, low cost, and *response.* Two ways that quality improves profitability are: ■ *Sales gains* via improved response, price flexibility, increased market share, and/or improved reputation ■ *Reduced costs* via increased productivity, lower rework and scrap costs, and/or lower warranty costs	Concept Questions: 1.1–1.4 **VIDEO 6.1** The Culture and Quality at Arnold Palmer Hospital
DEFINING QUALITY (pp. 217–219)	An operations manager's objective is to build a total quality management system that identifies and satisfies customer needs. ■ **Quality**—The ability of a product or service to meet customer needs. The American Society for Quality (ASQ) defines quality as "the totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs." The two most well-known quality awards are: ■ *U.S.*: Malcolm Baldrige National Quality Award, named after a former secretary of commerce ■ *Japan*: Deming Prize, named after an American, Dr. W. Edwards Deming ■ **ISO 9000**—A set of quality standards developed by the International Organization for Standardization (ISO). ISO 9000 is the only quality standard with international recognition. To do business globally, being listed in the ISO directory is critical. ■ **Cost of quality (COQ)**—The cost of doing things wrong; that is, the price of nonconformance. The four major categories of costs associated with quality are *prevention costs, appraisal costs, internal failure costs,* and *external failure costs.* Four leaders in the field of quality management are W. Edwards Deming, Joseph M. Juran, Armand Feigenbaum, and Philip B. Crosby.	Concept Questions: 2.1–2.4
TOTAL QUALITY MANAGEMENT (pp. 219–226)	■ **Total quality management (TQM)**—Management of an entire organization so that it excels in all aspects of products and services that are important to the customer. Seven concepts for an effective TQM program are (1) continuous improvement, (2) Six Sigma, (3) employee empowerment, (4) benchmarking, (5) just-in-time (JIT), (6) Taguchi concepts, and (7) knowledge of TQM tools. ■ **PDCA**—A continuous improvement model that involves four stages: plan, do, check, and act. The Japanese use the word *kaizen* to describe the ongoing process of unending improvement—the setting and achieving of ever-higher goals. ■ **Six Sigma**—A program to save time, improve quality, and lower costs. In a statistical sense, Six Sigma describes a process, product, or service with an extremely high capability—99.9997% accuracy, or 3.4 defects per million. ■ **Employee empowerment**—Enlarging employee jobs so that the added responsibility and authority are moved to the lowest level possible in the organization. Business literature suggests that some 85% of quality problems have to do with materials and processes, not with employee performance. ■ **Quality circle**—A group of employees meeting regularly with a facilitator to solve work-related problems in their work area. ■ **Benchmarking**—Selecting a demonstrated standard of performance that represents the very best performance for a process or an activity. The philosophy behind just-in-time (JIT) involves continuing improvement and enforced problem solving. JIT systems are designed to produce or deliver goods just as they are needed. ■ **Quality robust**—Products that are consistently built to meet customer needs, despite adverse conditions in the production process. ■ **Target-oriented quality**—A philosophy of continuous improvement to bring the product exactly on target. ■ **Quality loss function (QLF)**—A mathematical function that identifies all costs connected with poor quality and shows how these costs increase as output moves away from the target value.	Concept Questions: 3.1–3.4

Chapter 6 *Rapid Review* continued

Main Heading	Review Material	MyOMLab
TOOLS OF TQM (pp. 226–230)	TQM tools that generate ideas include the *check sheet* (organized method of recording data), *scatter diagram* (graph of the value of one variable vs. another variable), and *cause-and-effect diagram*. Tools for organizing the data are the *Pareto chart* and *flowchart*. Tools for identifying problems are the *histogram* (distribution showing the frequency of occurrences of a variable) and *statistical process control chart*. ■ **Cause-and-effect diagram**—A schematic technique used to discover possible locations of quality problems. (Also called an Ishikawa diagram or a fish-bone chart.) The 4 *M*s (material, machinery/equipment, manpower, and methods) may be broad "causes." ■ **Pareto chart**—A graphic that identifies the few critical items as opposed to many less important ones. ■ **Flowchart**—A block diagram that graphically describes a process or system. ■ **Statistical process control (SPC)**—A process used to monitor standards, make measurements, and take corrective action as a product or service is being produced. ■ **Control chart**—A graphic presentation of process data over time, with predetermined control limits.	Concept Questions: 4.1–4.4 Problems: 6.1, 6.3, 6.5, 6.8–6.14, 6.16–6.20 **ACTIVE MODEL 6.1** Virtual Office Hours for Solved Problem: 6.1
THE ROLE OF INSPECTION (pp. 230–233)	■ **Inspection**—A means of ensuring that an operation is producing at the quality level expected. ■ **Source inspection**—Controlling or monitoring at the point of production or purchase: at the source. ■ **Poka-yoke**—Literally translated, "mistake proofing"; it has come to mean a device or technique that ensures the production of a good unit every time. ■ **Checklist**—A type of poka-yoke that lists the steps needed to ensure consistency and completeness in a task. ■ **Attribute inspection**—An inspection that classifies items as being either good or defective. ■ **Variable inspection**—Classifications of inspected items as falling on a continuum scale, such as dimension, size, or strength.	Concept Questions: 5.1–5.4 **VIDEO 6.2** Quality Counts at Alaska Airlines
TQM IN SERVICES (pp. 233–235)	Determinants of service quality: reliability, responsiveness, competence, access, courtesy, communication, credibility, security, understanding/knowing the customer, and tangibles. ■ **Service recovery**—Training and empowering frontline workers to solve a problem immediately. ■ **SERVQUAL**—A popular measurement scale for service quality that compares service expectations with service performance.	Concept Questions: 6.1–6.4 Problem: 6.21 **VIDEO 6.3** TQM at Ritz-Carlton Hotels

Self Test

■ **Before taking the self-test,** refer to the learning objectives listed at the beginning of the chapter and the key terms listed at the end of the chapter.

LO 6.1 In this chapter, *quality* is defined as:
- **a)** the degree of excellence at an acceptable price and the control of variability at an acceptable cost.
- **b)** how well a product fits patterns of consumer preferences.
- **c)** the totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs.
- **d)** being impossible to define, but you know what it is.

LO 6.2 ISO 9000 is an international standard that addresses _____.

LO 6.3 If 1 million passengers pass through the Jacksonville Airport with checked baggage each year, a successful Six Sigma program for baggage handling would result in how many passengers with misplaced luggage?
- **a)** 3.4
- **b)** 6.0
- **c)** 34
- **d)** 2,700
- **e)** 6 times the monthly standard deviation of passengers

LO 6.4 The process of identifying other organizations that are best at some facet of your operations and then modeling your organization after them is known as:
- **a)** continuous improvement.
- **b)** employee empowerment.
- **c)** benchmarking.
- **d)** copycatting.
- **e)** patent infringement.

LO 6.5 The Taguchi method includes all except which of the following major concepts?
- **a)** Employee involvement
- **b)** Remove the effects of adverse conditions
- **c)** Quality loss function
- **d)** Target specifications

LO 6.6 The seven tools of total quality management are ______, ______, ______, ______, ______, ______, and ______.

Answers: LO 6.1. c; LO 6.2. quality management systems; LO 6.3. a; LO 6.4. c; LO 6.5. a; LO 6.6. check sheets, scatter diagrams, cause-and-effect diagrams, Pareto charts, flowcharts, histograms, SPC charts.

Statistical Process Control

SUPPLEMENT 6

SUPPLEMENT OUTLINE

- Statistical Process Control (SPC) *246*
- Process Capability *260*
- Acceptance Sampling *262*

Alaska Airlines

Alaska Airlines

LEARNING OBJECTIVES

LO S6.1 ***Explain*** the purpose of a control chart 247

LO S6.2 ***Explain*** the role of the central limit theorem in SPC 248

LO S6.3 ***Build*** $\bar{x}$-charts and *R*-charts 250

LO S6.4 ***List*** the five steps involved in building control charts 254

LO S6.5 ***Build*** *p*-charts and *c*-charts 256

LO S6.6 ***Explain*** process capability and compute C_p and C_{pk} 260

LO S6.7 ***Explain*** acceptance sampling 262

As part of its statistical process control system, Flowers Bakery, in Georgia, uses a digital camera to inspect just-baked sandwich buns as they move along the production line. Items that don't measure up in terms of color, shape, seed distribution, or size are identified and removed automatically from the conveyor.


Georgia Tech

Statistical Process Control (SPC)

Statistical process control (SPC)
A process used to monitor standards by taking measurements and corrective action as a product or service is being produced.

Control chart
A graphical presentation of process data over time.

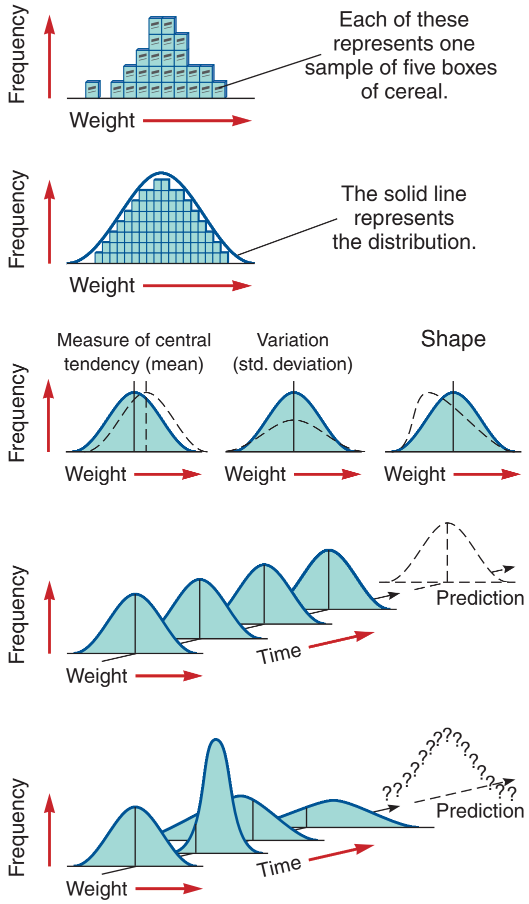
In this supplement, we address statistical process control—the same techniques used at BetzDearborn, at Arnold Palmer Hospital, at GE, and at Southwest Airlines to achieve quality standards. **Statistical process control (SPC)** is the application of statistical techniques to ensure that processes meet standards. All processes are subject to a certain degree of variability. While studying process data in the 1920s, Walter Shewhart of Bell Laboratories made the distinction between the common (natural) and special (assignable) causes of variation. He developed a simple but powerful tool to separate the two—the **control chart**.

A process is said to be operating *in statistical control* when the only source of variation is common (natural) causes. The process must first be brought into statistical control by detecting and eliminating special (assignable) causes of variation.[1] Then its performance is predictable, and its ability to meet customer expectations can be assessed. The *objective* of a process control system is to *provide a statistical signal when assignable causes of variation are present*. Such a signal can quicken appropriate action to eliminate assignable causes.

Natural variations
Variability that affects every production process to some degree and is to be expected; also known as common cause.

Natural Variations Natural variations affect almost every process and are to be expected. **Natural variations** are the many sources of variation that occur within a process, even one that is in statistical control. Natural variations form a pattern that can be described as a *distribution*.

As long as the distribution (output measurements) remains within specified limits, the process is said to be "in control," and natural variations are tolerated.



(a) Samples of the product, say five boxes of cereal taken off the filling machine line, vary from one another in weight.

(b) After enough sample means are taken from a stable process, they form a pattern called a *distribution*.

(c) There are many types of distributions, including the normal (bell-shaped) distribution, but distributions do differ in terms of central tendency (mean), standard deviation or variance, and shape.

(d) If only natural causes of variation are present, the output of a process forms a distribution that is stable over time and is predictable.

(e) If assignable causes of variation are present, the process output is not stable over time and is not predictable. That is, when causes that are not an expected part of the process occur, the samples will yield unexpected distributions that vary by central tendency, standard deviation, and shape.

Figure **S6.1**

Natural and Assignable Variation

Assignable Variations **Assignable variation** in a process can be traced to a specific reason. Factors such as machine wear, misadjusted equipment, fatigued or untrained workers, or new batches of raw material are all potential sources of assignable variations.

Assignable variation
Variation in a production process that can be traced to specific causes.

Natural and assignable variations distinguish two tasks for the operations manager. The first is to *ensure that the process is capable* of operating under control with only natural variation. The second is, of course, to *identify and eliminate assignable variations* so that the processes will remain under control.

Samples Because of natural and assignable variation, statistical process control uses averages of small samples (often of four to eight items) as opposed to data on individual parts. Individual pieces tend to be too erratic to make trends quickly visible.

Figure S6.1 provides a detailed look at the important steps in determining process variation. The horizontal scale can be weight (as in the number of ounces in boxes of cereal) or length (as in fence posts) or any physical measure. The vertical scale is frequency. The samples of five boxes of cereal in Figure S6.1 **(a)** are weighed, **(b)** form a distribution, and **(c)** can vary. The distributions formed in **(b)** and **(c)** will fall in a predictable pattern **(d)** if only natural variation is present. If assignable causes of variation are present, then we can expect either the mean to vary or the dispersion to vary, as is the case in **(e)**.

Control Charts The process of building control charts is based on the concepts presented in Figure S6.2. This figure shows three distributions that are the result of outputs from three types of processes. We plot small samples and then examine characteristics of the resulting data to see if the process is within "control limits." The purpose of control charts is to help distinguish between natural variations and variations due to assignable causes. As seen in Figure S6.2, a process is **(a)** in control *and the process is capable of producing within established control limits*, **(b)** in control *but the process is not capable of producing within established*

LO S6.1 *Explain* the purpose of a control chart

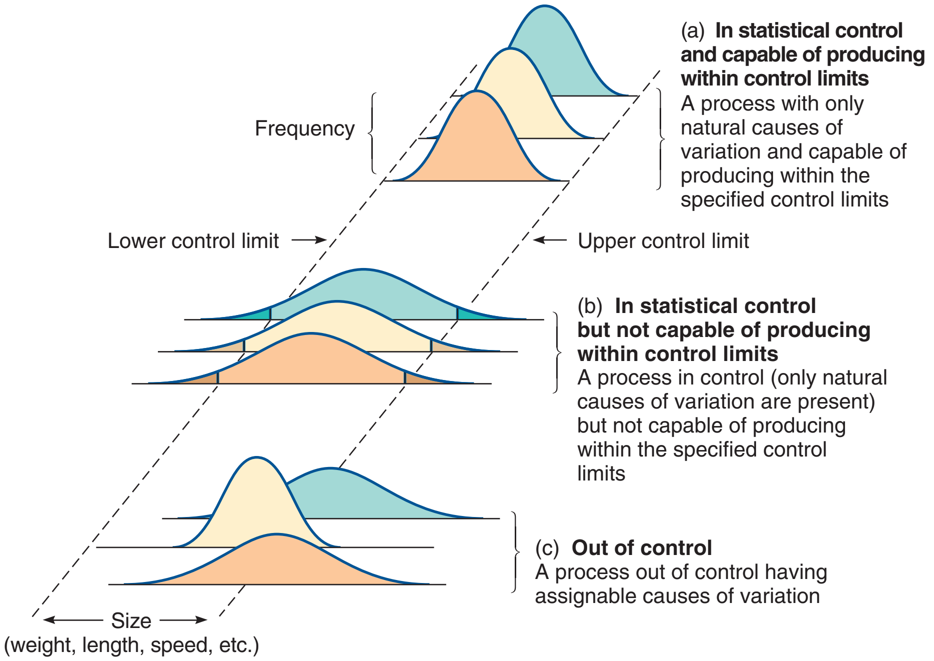


Figure **S6.2**

Process Control: Three Types of Process Outputs

limits, or **(c)** out of control. We now look at ways to build control charts that help the operations manager keep a process under control.

Control Charts for Variables

$\bar{x}$-chart
A quality control chart for variables that indicates when changes occur in the central tendency of a production process.

R-chart
A control chart that tracks the "range" within a sample; it indicates that a gain or loss in uniformity has occurred in dispersion of a production process.

The variables of interest here are those that have continuous dimensions. They have an infinite number of possibilities. Examples are weight, speed, length, or strength. Control charts for the mean, $\bar{x}$ or x-bar, and the range, R, are used to monitor processes that have continuous dimensions. The **$\bar{x}$-chart** tells us whether changes have occurred in the central tendency (the mean, in this case) of a process. These changes might be due to such factors as tool wear, a gradual increase in temperature, a different method used on the second shift, or new and stronger materials. The **R-chart** values indicate that a gain or loss in dispersion has occurred. Such a change may be due to worn bearings, a loose tool, an erratic flow of lubricants to a machine, or to sloppiness on the part of a machine operator. The two types of charts go hand in hand when monitoring variables because they measure the two critical parameters: central tendency and dispersion.

The Central Limit Theorem

Central limit theorem
The theoretical foundation for $\bar{x}$-charts, which states that regardless of the distribution of the population of all parts or services, the distribution of $\bar{x}$s tends to follow a normal curve as the number of samples increases.

The theoretical foundation for $\bar{x}$-charts is the **central limit theorem**. This theorem states that regardless of the distribution of the population, the distribution of $\bar{x}$s (each of which is a mean of a sample drawn from the population) will tend to follow a normal curve as the number of samples increases. Fortunately, even if each sample (n) is fairly small (say, 4 or 5), the distributions of the averages will still roughly follow a normal curve. The theorem also states that: (1) the mean of the distribution of the $\bar{x}$s (called $\bar{\bar{x}}$) will equal the mean of the overall population (called μ); and (2) the standard deviation of the *sampling distribution*, $\sigma_{\bar{x}}$, will be the *population (process) standard deviation*, divided by the square root of the sample size, n. In other words:[2]

$$\bar{\bar{x}} = \mu \qquad \text{(S6-1)}$$

LO S6.2 *Explain* the role of the central limit theorem in SPC

and

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}} \qquad \text{(S6-2)}$$

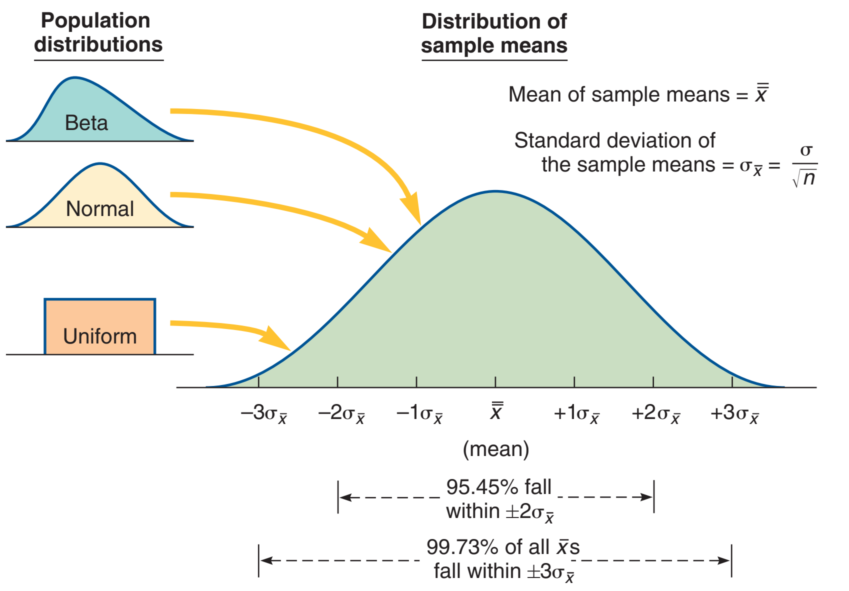


Figure **S6.3**

The Relationship Between Population and Sampling Distributions

Even though the population distributions will differ (e.g., normal, beta, uniform), each with its own mean (μ) and standard deviation (σ), the distribution of sample means always approaches a normal distribution.

Figure S6.3 shows three possible population distributions, each with its own mean, μ, and standard deviation, σ. If a series of random samples ($\bar{x}_1$, $\bar{x}_2$, $\bar{x}_3$, $\bar{x}_4$, and so on), each of size n, is drawn from any population distribution (which could be normal, beta, uniform, and so on), the resulting distribution of $\bar{x}_i$s will approximate a normal distribution (see Figure S6.3).

Moreover, the sampling distribution, as is shown in Figure S6.4(a), will have less variability than the process distribution. Because the sampling distribution is normal, we can state that:

- 95.45% of the time, the sample averages will fall within $\pm 2\sigma_{\bar{x}}$ if the process has only natural variations.
- 99.73% of the time, the sample averages will fall within $\pm 3\sigma_{\bar{x}}$ if the process has only natural variations.

If a point on the control chart falls outside of the $\pm 3\sigma_{\bar{x}}$ control limits, then we are 99.73% sure the process has changed. Figure S6.4(b) shows that as the sample size increases, the sampling distribution becomes narrower. So the sample statistic is closer to the true value of the population for larger sample sizes. This is the theory behind control charts.

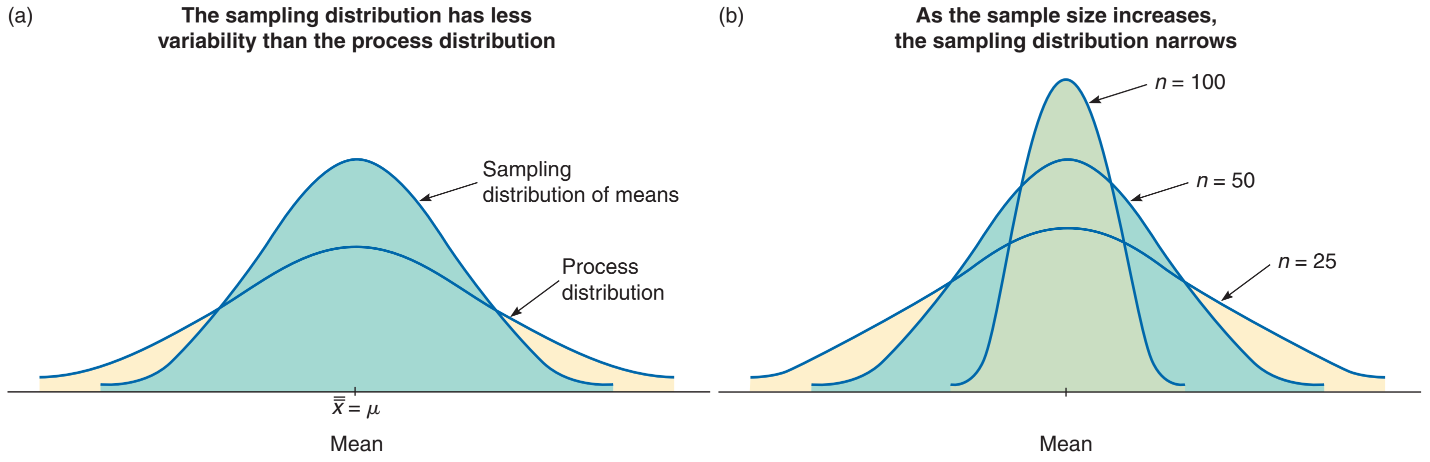


Figure **S6.4**

The Sampling Distribution of Means Is Normal

The process distribution from which the sample was drawn was also normal, but it could have been any distribution.

Setting Mean Chart Limits ($\bar{x}$-Charts)

If we know, through past data, the standard deviation of the population (process), σ, we can set upper and lower control limits[3] by using these formulas:

$$\text{Upper control limit (UCL)} = \bar{\bar{x}} + z\sigma_{\bar{x}} \tag{S6-3}$$

$$\text{Lower control limit (LCL)} = \bar{\bar{x}} - z\sigma_{\bar{x}} \tag{S6-4}$$

LO S6.3 *Build* $\bar{x}$*-charts and* *R*-charts

where

$\bar{\bar{x}}$ = mean of the sample means or a target value set for the process
z = number of normal standard deviations (2 for 95.45% confidence, 3 for 99.73%)
$\sigma_{\bar{x}}$ = standard deviation of the sample means = $\sigma/\sqrt{n}$
σ = population (process) standard deviation
n = sample size

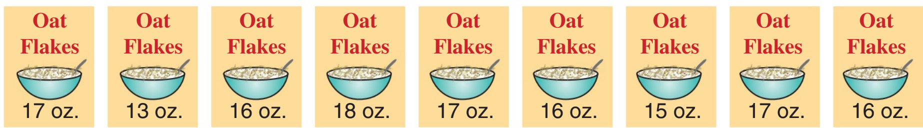
Example S1 shows how to set control limits for sample means using standard deviations.

Example S1

SETTING CONTROL LIMITS USING SAMPLES

The weights of boxes of Oat Flakes within a large production lot are sampled each hour. Managers want to set control limits that include 99.73% of the sample means.

APPROACH ▶ Randomly select and weigh nine ($n = 9$) boxes each hour. Then find the overall mean and use Equations (S6-3) and (S6-4) to compute the control limits. Here are the nine boxes chosen for Hour 1:



STUDENT TIP If you want to see an example of such variability in your supermarket, go to the soft drink section and line up a few 2-liter bottles of Coke or Pepsi.

SOLUTION ▶

$$\text{The average weight in the first hourly sample} = \frac{17 + 13 + 16 + 18 + 17 + 16 + 15 + 17 + 16}{9} = 16.1 \text{ ounces.}$$

Also, the *population (process)* standard deviation (σ) is known to be 1 ounce. We do not show each of the boxes randomly selected in hours 2 through 12, but here are all 12 hourly samples:

WEIGHT OF SAMPLE		WEIGHT OF SAMPLE		WEIGHT OF SAMPLE	
HOUR	(AVG. OF 9 BOXES)	HOUR	(AVG. OF 9 BOXES)	HOUR	(AVG. OF 9 BOXES)
1	16.1	5	16.5	9	16.3
2	16.8	6	16.4	10	14.8
3	15.5	7	15.2	11	14.2
4	16.5	8	16.4	12	17.3

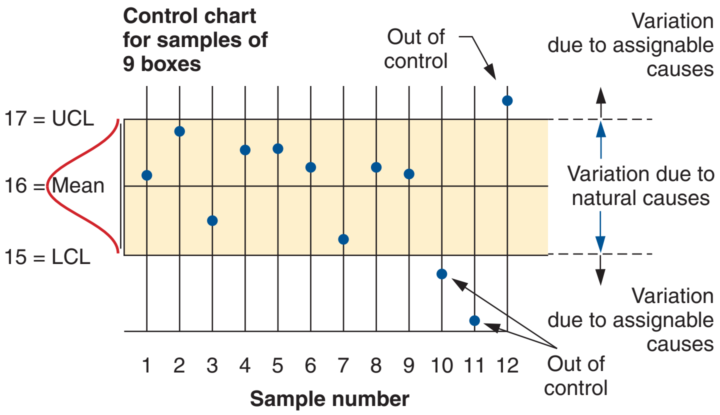
The average mean $\bar{\bar{x}}$ of the 12 samples is calculated to be exactly 16 ounces $\left[\bar{\bar{x}} = \frac{\sum_{i=1}^{12} (\text{Avg. of 9 Boxes})}{12}\right]$.

We therefore have $\bar{\bar{x}}$ = 16 ounces, σ = 1 ounce, n = 9, and z = 3. The control limits are:

$$UCL_{\bar{x}} = \bar{\bar{x}} + z\sigma_{\bar{x}} = 16 + 3\left(\frac{1}{\sqrt{9}}\right) = 16 + 3\left(\frac{1}{3}\right) = 17 \text{ ounces}$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - z\sigma_{\bar{x}} = 16 - 3\left(\frac{1}{\sqrt{9}}\right) = 16 - 3\left(\frac{1}{3}\right) = 15 \text{ ounces}$$

The 12 samples are then plotted on the following control chart:



INSIGHT ▶ Because the means of recent sample averages fall outside the upper and lower control limits of 17 and 15, we can conclude that the process is becoming erratic and is *not* in control.

LEARNING EXERCISE ▶ If Oat Flakes's population standard deviation (σ) is 2 (instead of 1), what is your conclusion? [Answer: LCL = 14, UCL = 18; the process would be in control.]

RELATED PROBLEMS ▶ S6.1, S6.2, S6.4, S6.8, S6.10a,b (S6.28 is available in MyOMLab)

ACTIVE MODEL S6.1 This example is further illustrated in Active Model S6.1 in MyOMLab.

EXCEL OM Data File **CH06ExS1.XLS** can be found in MyOMLab.

Because process standard deviations are often not available, we usually calculate control limits based on the average *range* values rather than on standard deviations. Table S6.1 provides the necessary conversion for us to do so. The *range* (R_i) is defined as the difference between the largest and smallest items in one sample. For example, the heaviest box of Oat Flakes in Hour 1 of Example S1 was 18 ounces and the lightest was 13 ounces, so the range for that hour is 5 ounces. We use Table S6.1 and the equations:

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R} \qquad \text{(S6-5)}$$

and:

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R} \qquad \text{(S6-6)}$$

where $\bar{R} = \frac{\sum_{i=1}^{k} R_i}{k}$ = average range of all the samples; R_i = range for sample i

A_2 = value found in Table S6.1 $\qquad$ k = total number of samples

$\bar{\bar{x}}$ = mean of the sample means

Example S2 shows how to set control limits for sample means by using Table S6.1 and the average range.

TABLE S6.1 Factors for Computing Control Chart Limits (3 sigma)

SAMPLE SIZE, n	MEAN FACTOR, A_2	UPPER RANGE, D_4	LOWER RANGE, D_3
2	1.880	3.268	0
3	1.023	2.574	0
4	.729	2.282	0
5	.577	2.115	0
6	.483	2.004	0
7	.419	1.924	0.076
8	.373	1.864	0.136
9	.337	1.816	0.184
10	.308	1.777	0.223
12	.266	1.716	0.284

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Example S2

SETTING MEAN LIMITS USING TABLE VALUES

Super Cola bottles soft drinks labeled "net weight 12 ounces." Indeed, an overall process average of 12 ounces has been found by taking 10 samples, in which each sample contained 5 bottles. The OM team wants to determine the upper and lower control limits for averages in this process.

APPROACH ▶ Super Cola first examines the 10 samples to compute the average range of the process. Here are the data and calculations:

SAMPLE	WEIGHT OF LIGHTEST BOTTLE IN SAMPLE OF $n = 5$	WEIGHT OF HEAVIEST BOTTLE IN SAMPLE OF $n = 5$	RANGE (R_i) = DIFFERENCE BETWEEN THESE TWO
1	11.50	11.72	.22
2	11.97	12.00	.03
3	11.55	12.05	.50
4	12.00	12.20	.20
5	11.95	12.00	.05
6	10.55	10.75	.20
7	12.50	12.75	.25
8	11.00	11.25	.25
9	10.60	11.00	.40
10	11.70	12.10	.40
			$\sum R_i = 2.50$

$$\text{Average Range} = \frac{2.50}{10 \text{ samples}} = .25 \text{ ounces}$$

Now Super Cola applies Equations (S6-5) and (S6-6) and uses the A_2 column of Table S6.1.

SOLUTION ▶ Looking in Table S6.1 for a sample size of 5 in the mean factor A_2 column, we find the value .577. Thus, the upper and lower control chart limits are:

$$\begin{aligned} \text{UCL}_{\bar{x}} &= \bar{\bar{x}} + A_2\bar{R} \\ &= 12 + (.577)(.25) \\ &= 12 + .144 \\ &= 12.144 \text{ ounces} \end{aligned}$$

$$\text{LCL}_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R}$$
$$= 12 - .144$$
$$= 11.856 \text{ ounces}$$

INSIGHT ▶ The advantage of using this range approach, instead of the standard deviation, is that it is easy to apply and may be less confusing.

LEARNING EXERCISE ▶ If the sample size was $n = 4$ and the average range $= .20$ ounces, what are the revised $\text{UCL}_{\bar{x}}$ and $\text{LCL}_{\bar{x}}$? [Answer: 12.146, 11.854.]

RELATED PROBLEMS ▶ S6.3a, S6.5, S6.6, S6.7, S6.9, S6.10b,c,d, S6.11, S6.26 (S6.29a, S6.30a, S6.31a, S6.32a, S6.33a are available in MyOMLab)

EXCEL OM Data File **CH06ExS2.xls** can be found in MyOMLab.

Setting Range Chart Limits (*R*-Charts)

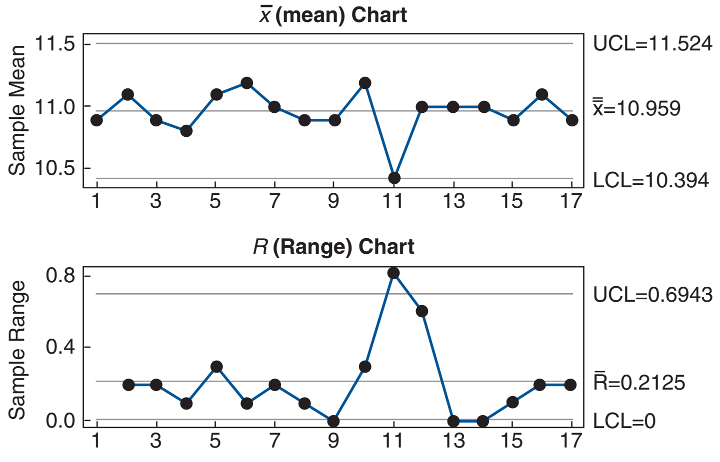
In Examples S1 and S2, we determined the upper and lower control limits for the process *average*. In addition to being concerned with the process average, operations managers are interested in the process *dispersion*, or *range*. Even though the process average is under control, the dispersion of the process may not be. For example, something may have worked itself loose in a piece of equipment that fills boxes of Oat Flakes. As a result, the average of the samples may remain the same, but the variation within the samples could be entirely too large. For this reason, operations managers use control charts for ranges to monitor the process variability, as well as control charts for averages, which monitor the process central tendency. The theory behind the control charts for ranges is the same as that for process average control charts. Limits are established that contain ± 3 standard deviations of the distribution for the average range $\bar{R}$. We can use the following equations to set the upper and lower control limits for ranges:

$$\text{UCL}_R = D_4\bar{R} \quad \text{(S6-7)}$$

$$\text{LCL}_R = D_3\bar{R} \quad \text{(S6-8)}$$

where

UCL_R = upper control chart limit for the range
LCL_R = lower control chart limit for the range
D_4 and D_3 = values from Table S6.1



Salmon filets are monitored by Darden Restaurant's SPC software, which includes $\bar{x}$-(mean) charts and R-(range) charts. Darden uses average weight as a measure of central tendency for salmon filets. The range is the difference between the heaviest and the lightest filets in each sample. The video case study "Farm to Fork," at the end of this supplement, asks you to interpret these figures.

VIDEO S6.1
Farm to Fork: Quality of Darden Restaurants

Example S3 shows how to set control limits for sample ranges using Table S6.1 and the average range.

Example S3

SETTING RANGE LIMITS USING TABLE VALUES

Roy Clinton's mail-ordering business wants to measure the response time of its operators in taking customer orders over the phone. Clinton lists below the time recorded (in minutes) from five different samples of the ordering process with four customer orders per sample. He wants to determine the upper and lower range control chart limits.

APPROACH ▶ Looking in Table S6.1 for a sample size of 4, he finds that $D_4 = 2.282$ and $D_3 = 0$.

SOLUTION ▶

SAMPLE	OBSERVATIONS (MINUTES)	SAMPLE RANGE (R_i)
1	5, 3, 6, 10	10 − 3 = 7
2	7, 5, 3, 5	7 − 3 = 4
3	1, 8, 3, 12	12 − 1 = 11
4	7, 6, 2, 1	7 − 1 = 6
5	3, 15, 6, 12	15 − 3 = 12
		$\Sigma R_i = 40$

$$\overline{R} = \frac{40}{5} = 8$$

$$\text{UCL}_R = 2.282(8) = 18.256 \text{ minutes}$$

$$\text{LCL}_R = 0(8) = 0 \text{ minutes}$$

INSIGHT ▶ Computing ranges with Table S6.1 is straightforward and an easy way to evaluate dispersion. No sample ranges are out of control.

LEARNING EXERCISE ▶ Clinton decides to increase the sample size to $n = 6$ (with no change in average range, $\overline{R}$). What are the new UCL_R and LCL_R values? [Answer: 16.032, 0.]

RELATED PROBLEMS ▶ S6.3b, S6.5, S6.6, S6.7, S6.9, S6.10c, S6.11, S6.12, S6.26 (S6.29b, S6.30b, S6.31b, S6.32b, S6.33b are available in MyOMLab)

Using Mean and Range Charts

The normal distribution is defined by two parameters, the *mean* and *standard deviation*. The $\bar{x}$ (mean)-chart and the *R*-chart mimic these two parameters. The $\bar{x}$-chart is sensitive to shifts in the process mean, whereas the *R*-chart is sensitive to shifts in the process standard deviation. Consequently, by using both charts we can track changes in the process distribution.

For instance, the samples and the resulting $\bar{x}$-chart in Figure S6.5(a) show the shift in the process mean, but because the dispersion is constant, no change is detected by the *R*-chart. Conversely, the samples and the $\bar{x}$-chart in Figure S6.5(b) detect no shift (because none is present), but the *R*-chart does detect the shift in the dispersion. Both charts are required to track the process accurately.

LO S6.4 *List* the five steps involved in building control charts

Steps to Follow When Building Control Charts There are five steps that are generally followed in building $\bar{x}$- and *R*-charts:

1. Collect 20 to 25 samples, often of $n = 4$ or $n = 5$ observations each, from a stable process, and compute the mean and range of each.
2. Compute the overall means ($\bar{\bar{x}}$ and $\overline{R}$), set appropriate control limits, usually at the 99.73% level, and calculate the preliminary upper and lower control limits. Refer to Table S6.2 for other control limits. *If the process is not currently stable and in control*, use the desired mean, μ, instead of $\bar{\bar{x}}$ to calculate limits.

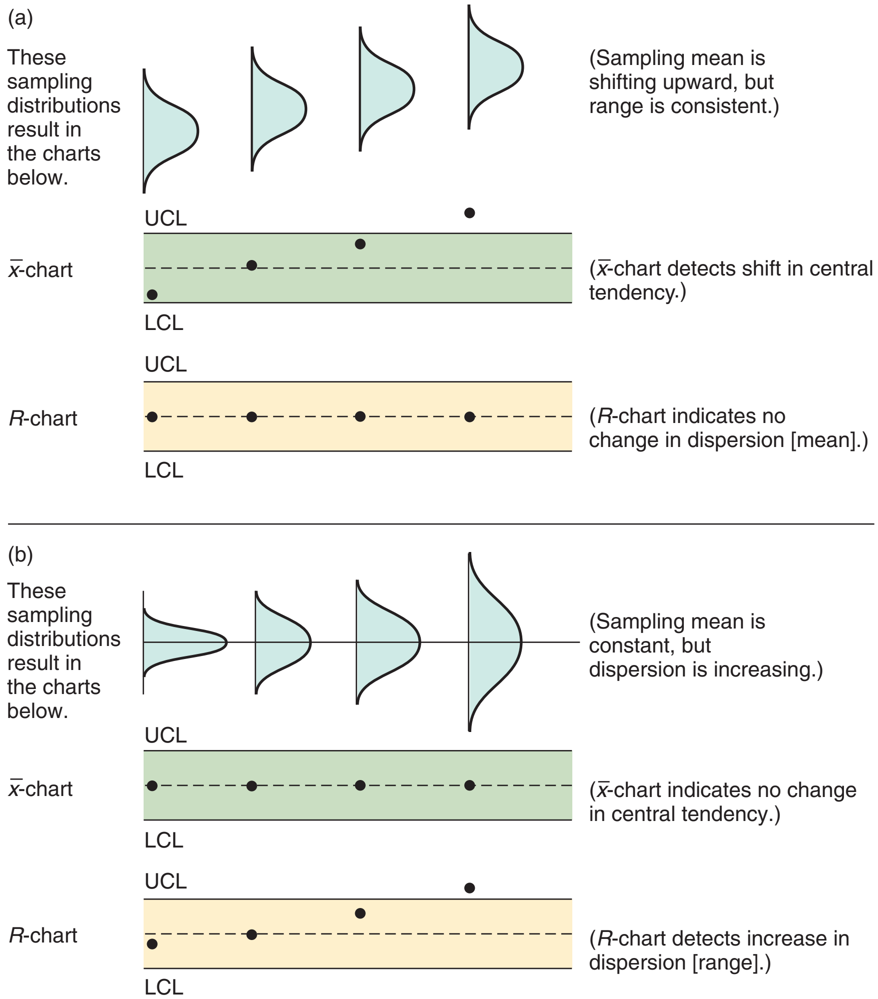


Figure **S6.5**

Mean and Range Charts Complement Each Other by Showing the Mean and Dispersion of the Normal Distribution

STUDENT TIP

Mean ($\bar{x}$) charts are a measure of *central tendency*, while range (*R*) charts are a measure of *dispersion*. SPC requires both charts for a complete assessment because a sample mean could be out of control while the range is in control and vice versa.

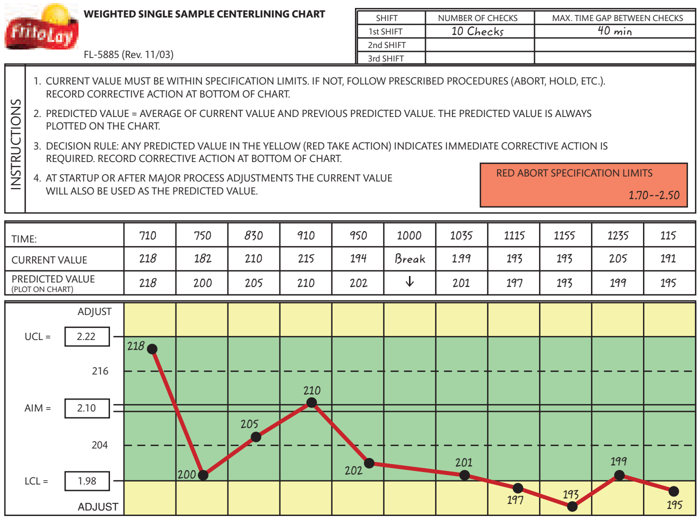
TABLE S6.2

Common *z* Values

DESIRED CONTROL LIMIT (%)	*Z*-VALUE (STANDARD DEVIATION REQUIRED FOR DESIRED LEVEL OF CONFIDENCE)
90.0	1.65
95.0	1.96
95.45	2.00
99.0	2.58
99.73	3.00

3. Graph the sample means and ranges on their respective control charts, and determine whether they fall outside the acceptable limits.
4. Investigate points or patterns that indicate the process is out of control. Try to assign causes for the variation, address the causes, and then resume the process.
5. Collect additional samples and, if necessary, revalidate the control limits using the new data.

Donna McWilliam/AP Images



Frito-Lay uses $\bar{x}$ charts to control production quality at critical points in the process. About every 40 minutes, three batches of chips are taken from the conveyor (on the left) and analyzed electronically to get an average salt content, which is plotted on an $\bar{x}$-chart (on the right). Points plotted in the green zone are "in control," while those in the yellow zone are "out of control." The SPC chart is displayed where all production employees can monitor process stability.

Control Charts for Attributes

LO S6.5 *Build p-charts and c-charts*

Control charts for $\bar{x}$ and R do not apply when we are sampling *attributes*, which are typically classified as *defective* or *nondefective*. Measuring defectives involves counting them (for example, number of bad lightbulbs in a given lot, or number of letters or data entry records typed with errors), whereas *variables* are usually measured for length or weight. There are two kinds of attribute control charts: (1) those that measure the *percent* defective in a sample—called *p*-charts—and (2) those that count the *number* of defects—called *c*-charts.

***p*-chart**
A quality control chart that is used to control attributes.

***p*-Charts** Using ***p*-charts** is the chief way to control attributes. Although attributes that are either good or bad follow the binomial distribution, the normal distribution can be used to calculate *p*-chart limits when sample sizes are large. The procedure resembles the $\bar{x}$-chart approach, which is also based on the central limit theorem.

The formulas for *p*-chart upper and lower control limits follow:

VIDEO S6.2
Frito-Lay's Quality-Controlled Potato Chips

$$UCL_p = \bar{p} + z\sigma_p \qquad \text{(S6-9)}$$

$$LCL_p = \bar{p} - z\sigma_p \qquad \text{(S6-10)}$$

where $\bar{p}$ = mean fraction (percent) defective in the samples = $\dfrac{\text{total number of defects}}{\text{sample size} \times \text{number of samples}}$

z = number of standard deviations ($z = 2$ for 95.45% limits; $z = 3$ for 99.73% limits)

σ_p = standard deviation of the sampling distribution

σ_p is estimated by the formula:

$$\hat{\sigma}_p = \sqrt{\frac{\bar{p}(1 - \bar{p})}{n}} \qquad \text{(S6-11)}$$

where n = number of observations in *each* sample[4]

Example S4 shows how to set control limits for *p*-charts for these standard deviations.

Example S4

SETTING CONTROL LIMITS FOR PERCENT DEFECTIVE

Clerks at Mosier Data Systems key in thousands of insurance records each day for a variety of client firms. CEO Donna Mosier wants to set control limits to include 99.73% of the random variation in the data entry process when it is in control.

APPROACH ▶ Samples of the work of 20 clerks are gathered (and shown in the table). Mosier carefully examines 100 records entered by each clerk and counts the number of errors. She also computes the fraction defective in each sample. Equations (S6-9), (S6-10), and (S6-11) are then used to set the control limits.

SAMPLE NUMBER	NUMBER OF ERRORS	FRACTION DEFECTIVE	SAMPLE NUMBER	NUMBER OF ERRORS	FRACTION DEFECTIVE
1	6	.06	11	6	.06
2	5	.05	12	1	.01
3	0	.00	13	8	.08
4	1	.01	14	7	.07
5	4	.04	15	5	.05
6	2	.02	16	4	.04
7	5	.05	17	11	.11
8	3	.03	18	3	.03
9	3	.03	19	0	.00
10	2	.02	20	4	.04
				80	

SOLUTION ▶

$$\bar{p} = \frac{\text{Total number of errors}}{\text{Total number of records examined}} = \frac{80}{(100)(20)} = .04$$

$$\hat{\sigma}_p = \sqrt{\frac{(.04)(1 - .04)}{100}} = .02 \text{ (rounded up from .0196)}$$

(*Note:* 100 is the size of *each* sample $= n$.)

$$UCL_p = \bar{p} + z\hat{\sigma}_p = .04 + 3(.02) = .10$$

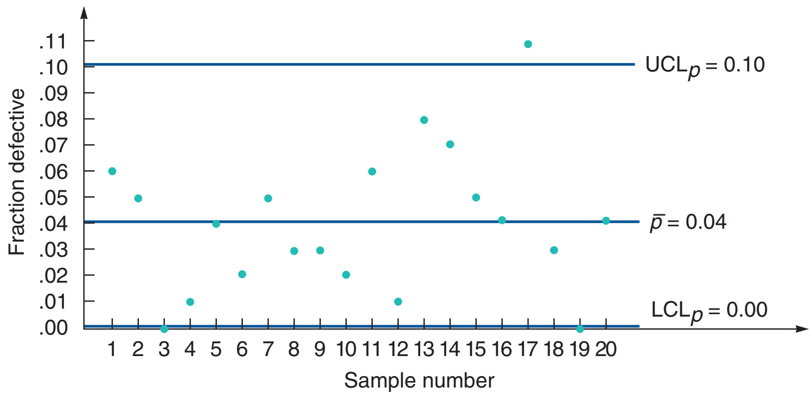
$$LCL_p = \bar{p} - z\hat{\sigma}_p = .04 - 3(.02) = 0$$

(because we cannot have a negative percentage defective)

INSIGHT ▶ When we plot the control limits and the sample fraction defectives, we find that only one data-entry clerk (number 17) is out of control. The firm may wish to examine that individual's work a bit more closely to see if a serious problem exists (see Figure S6.6).

Figure **S6.6**

***p*-Chart for Data Entry for Example S4**



STUDENT TIP We are always pleased to be at zero or below the center line in a *p*-chart.

LEARNING EXERCISE ▶ Mosier decides to set control limits at 95.45% instead. What are the new UCL_p and LCL_p? [Answer: 0.08, 0]

RELATED PROBLEMS ▶ S6.13–S6.20, S6.25, S6.27 (S6.35–S6.39 are available in MyOMLab)

ACTIVE MODEL S6.2 This example is further illustrated in Active Model S6.2 in MyOMLab.

EXCEL OM Data File **Ch06ExS4.xls** can be found in MyOMLab.

The *OM in Action* box "Trying to Land a Seat with Frequent Flyer Miles" provides a real-world follow-up to Example S4.

***c*-Charts** In Example S4, we counted the number of defective records entered. A defective record was one that was not exactly correct because it contained at least one defect. However, a bad record may contain more than one defect. We use ***c*-charts** to control the *number* of defects per unit of output (or per insurance record, in the preceding case).

***c*-chart**
A quality control chart used to control the number of defects per unit of output.

OM in Action Trying to Land a Seat with Frequent Flyer Miles

How hard is it to redeem your 25,000 frequent flyer points for airline tickets? That depends on the airline. (It also depends on the city. Don't try to get into or out of San Francisco!) When the consulting firm Idea Works made 280 requests for a standard mileage award to each of 24 airlines' Web sites (a total of 6,720 requests), the success rates ranged from a low of 25.7% and 27.1% (at US Airways and Delta, respectively) to a high of 100% at GOL-Brazil and 99.3% at Southwest.

The overall average of 68.6% for the two dozen carriers provides the center line in a *p*-chart. With 3-sigma upper and lower control limits of 82.5% and 54.7%, the other top and bottom performers are easily spotted. "Out of control" (but in a positive *outperforming* way) are GOL and Southwest, Lufthansa (85.0%), Singapore (90.7%), Virgin Australia (91.4%), and Air Berlin (96.4%).

Out of control *on the negative side* are US Airways and Delta, plus Emirates (35.7%), AirTran (47.1%), Turkish (49.3%), and SAS (52.9%).

Control charts can help airlines see where they stand relative to competitors in such customer service activities as lost bags, on-time rates, and ease of redeeming mileage points. "I think airlines are getting the message that availability is important. Are airlines where they need to be? I don't think so," says the president of Idea Works.

Sources: Wall Street Journal (May 26, 2011); and *Consumer Reports* (November 2014).


Charles O'Rear/Corbis

Sampling wine from these wooden barrels, to make sure it is aging properly, uses both SPC (for alcohol content and acidity) and subjective measures (for taste).

Control charts for defects are helpful for monitoring processes in which a large number of potential errors can occur, but the actual number that do occur is relatively small. Defects may be errors in newspaper words, bad circuits in a microchip, blemishes on a table, or missing pickles on a fast-food hamburger.

The Poisson probability distribution,[5] which has a variance equal to its mean, is the basis for *c*-charts. Because $\bar{c}$ is the mean number of defects per unit, the standard deviation is equal to $\sqrt{\bar{c}}$. To compute 99.73% control limits for $\bar{c}$, we use the formula:

$$\text{Control limits} = \bar{c} \pm 3\sqrt{\bar{c}} \qquad \text{(S6-12)}$$

Example S5 shows how to set control limits for a $\bar{c}$-chart.

Example S5

SETTING CONTROL LIMITS FOR NUMBER OF DEFECTS

Red Top Cab Company receives several complaints per day about the behavior of its drivers. Over a 9-day period (where days are the units of measure), the owner, Gordon Hoft, received the following numbers of calls from irate passengers: 3, 0, 8, 9, 6, 7, 4, 9, 8, for a total of 54 complaints. Hoft wants to compute 99.73% control limits.

APPROACH ▶ He applies Equation (S6–12).

SOLUTION ▶ $\bar{c} = \frac{54}{9} = 6$ complaints per day

Thus:

$$UCL_c = \bar{c} + 3\sqrt{\bar{c}} = 6 + 3\sqrt{6} = 6 + 3(2.45) = 13.35, \text{ or } 13$$

$$LCL_c = \bar{c} - 3\sqrt{\bar{c}} = 6 - 3\sqrt{6} = 6 - 3(2.45) = 0 \leftarrow \text{(since it cannot be negative)}$$

INSIGHT ▶ After Hoft plotted a control chart summarizing these data and posted it prominently in the drivers' locker room, the number of calls received dropped to an average of three per day. Can you explain why this occurred?

LEARNING EXERCISE ▶ Hoft collects 3 more days' worth of complaints (10, 12, and 8 complaints) and wants to combine them with the original 9 days to compute updated control limits. What are the revised UCL_c and LCL_c? [Answer: 14.94, 0.]

RELATED PROBLEMS ▶ S6.21, S6.22, S6.23, S6.24

EXCEL OM Data File **Ch06SExS5.xls** can be found in MyOMLab.

TABLE S6.3 Helping You Decide Which Control Chart to Use

VARIABLE DATA USING AN $\bar{x}$-CHART AND AN *R*-CHART
1. Observations are *variables*, which are usually products measured for size or weight. Examples are the width or length of a wire and the weight of a can of Campbell's soup. **2.** Collect 20 to 25 samples, usually of $n = 4$, $n = 5$, or more, each from a stable process, and compute the means for an $\bar{x}$-chart and the ranges for an *R*-chart. **3.** We track samples of *n* observations each, as in Example S1.
ATTRIBUTE DATA USING A *p*-CHART
1. Observations are *attributes* that can be categorized as good or bad (or pass–fail, or functional–broken); that is, in two states. **2.** We deal with fraction, proportion, or percent defectives. **3.** There are several samples, with many observations in each. For example, 20 samples of $n = 100$ observations in each, as in Example S4.
ATTRIBUTE DATA USING A *c*-CHART
1. Observations are *attributes* whose defects per unit of output can be counted. **2.** We deal with the number counted, which is a small part of the possible occurrences. **3.** Defects may be: number of blemishes on a desk; flaws in a bolt of cloth; crimes in a year; broken seats in a stadium; typos in a chapter of this text; or complaints in a day, as is shown in Example S5.

STUDENT TIP
This is a really useful table. When you are not sure which control chart to use, turn here for clarification.

Managerial Issues and Control Charts

In an ideal world, there is no need for control charts. Quality is uniform and so high that employees need not waste time and money sampling and monitoring variables and attributes. But because most processes have not reached perfection, managers must make three major decisions regarding control charts.

First, managers must select the points in their process that need SPC. They may ask "Which parts of the job are critical to success?" or "Which parts of the job have a tendency to become out of control?"

Second, managers need to decide if variable charts (i.e., $\bar{x}$ and *R*) or attribute charts (i.e., *p* and *c*) are appropriate. Variable charts monitor weights or dimensions. Attribute charts are more of a "yes–no" or "go–no go" gauge and tend to be less costly to implement. Table S6.3 can help you understand when to use each of these types of control charts.

Third, the company must set clear and specific SPC policies for employees to follow. For example, should the data-entry process be halted if a trend is appearing in percent defective records being keyed? Should an assembly line be stopped if the average length of five successive samples is above the centerline? Figure S6.7 illustrates some of the patterns to look for over time in a process.

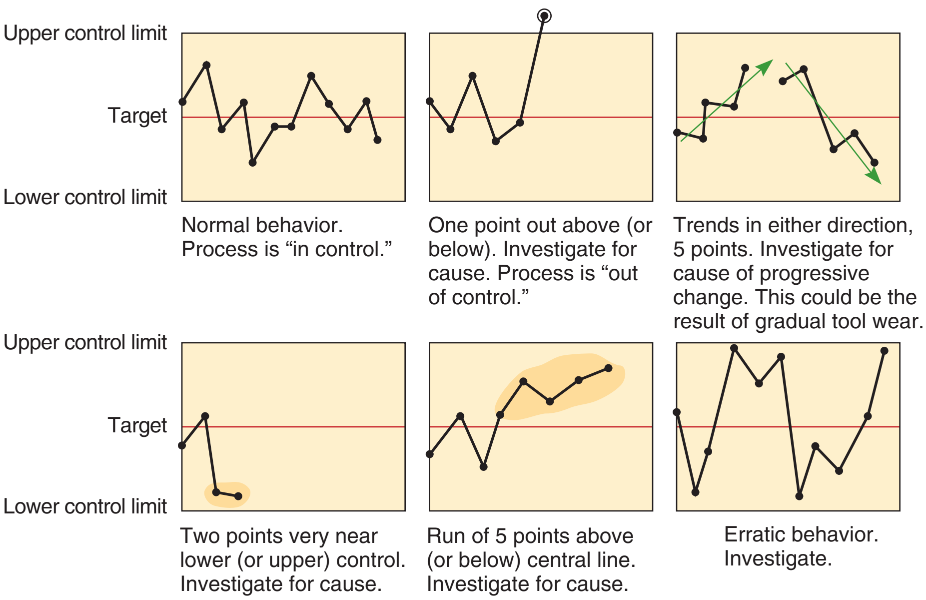


Figure **S6.7**

Patterns to Look for on Control Charts

Source: Adapted from Bertrand L. Hansen, *Quality Control: Theory and Applications* (1991): 65. Reprinted by permission of Prentice Hall, Upper Saddle River, NJ.

STUDENT TIP
Workers in companies such as Frito-Lay are trained to follow rules like these.

Run test
A test used to examine the points in a control chart to see if nonrandom variation is present.

A tool called a **run test** is available to help identify the kind of abnormalities in a process that we see in Figure S6.7. In general, a run of 5 points above or below the target or centerline may suggest that an assignable, or nonrandom, variation is present. When this occurs, even though all the points may fall inside the control limits, a flag has been raised. This means the process may not be statistically in control. A variety of run tests are described in books on the subject of quality methods.

STUDENT TIP Here we deal with whether a process meets the specification it was *designed* to yield.

Process Capability

Statistical process control means keeping a process in control. This means that the natural variation of the process must be stable. However, a process that is in statistical control may not yield goods or services that meet their *design specifications* (tolerances). In other words, the variation should be small enough to produce consistent output within specifications. The ability of a process to meet design specifications, which are set by engineering design or customer requirements, is called **process capability**. Even though that process may be statistically in control (stable), the output of that process may not conform to specifications.

Process capability
The ability to meet design specifications.

For example, let's say the time a customer expects to wait for the completion of a lube job at Quik Lube is 12 minutes, with an acceptable tolerance of ± 2 minutes. This tolerance gives an upper specification of 14 minutes and a lower specification of 10 minutes. The lube process has to be capable of operating within these design specifications—if not, some customers will not have their requirements met. As a manufacturing example, the tolerances for Harley-Davidson cam gears are extremely low, only 0.0005 inch—and a process must be designed that is capable of achieving this tolerance.

LO S6.6 *Explain* process capability and compute C_p and C_{pk}

There are two popular measures for quantitatively determining if a process is capable: process capability ratio (C_p) and process capability index (C_{pk}).

Process Capability Ratio (C_p)

For a process to be capable, its values must fall within upper and lower specifications. This typically means the process capability is within ± 3 standard deviations from the process mean. Because this range of values is 6 standard deviations, a capable process tolerance, which is the difference between the upper and lower specifications, must be greater than or equal to 6.

C_p
A ratio for determining whether a process meets design specifications; a ratio of the specification to the process variation.

The process capability ratio, **C_p**, is computed as:

$$C_p = \frac{\text{Upper specification} - \text{Lower specification}}{6\sigma} \tag{S6-13}$$

Example S6 shows the computation of C_p.

Example S6

PROCESS CAPABILITY RATIO (C_p)

In a GE insurance claims process, $\bar{x} = 210.0$ minutes, and $\sigma = .516$ minutes.

The design specification to meet customer expectations is 210 ± 3 minutes. So the Upper Specification is 213 minutes and the lower specification is 207 minutes. The OM manager wants to compute the process capability ratio.

APPROACH ▶ GE applies Equation (S6-13).

SOLUTION ▶ $C_p = \dfrac{\text{Upper specification} - \text{Lower specification}}{6\sigma} = \dfrac{213 - 207}{6(.516)} = 1.938$

INSIGHT ▶ Because a ratio of 1.00 means that 99.73% of a process's outputs are within specifications, this ratio suggests a very capable process, with nonconformance of less than 4 claims per million.

LEARNING EXERCISE ▶ If $\sigma = .60$ (instead of .516), what is the new C_p? [Answer: 1.667, a very capable process still.]

RELATED PROBLEMS ▶ S6.40, S6.41 (S6.50 is available in MyOMLab)

ACTIVE MODEL S6.3 This example is further illustrated in Active Model S6.3 in MyOMLab.

EXCEL OM Data File **Ch06SExS6.xls** can be found in MyOMLab.

A capable process has a C_p of at least 1.0. If the C_p is less than 1.0, the process yields products or services that are outside their allowable tolerance. With a C_p of 1.0, 2.7 parts in 1,000 can be expected to be "out of spec."[6] The higher the process capability ratio, the greater the likelihood the process will be within design specifications. Many firms have chosen a C_p of 1.33 (a 4-sigma standard) as a target for reducing process variability. This means that only 64 parts per million can be expected to be out of specification.

Recall that in Chapter 6 we mentioned the concept of *Six Sigma* quality, championed by GE and Motorola. This standard equates to a C_p of 2.0, with only 3.4 defective parts per million (very close to zero defects) instead of the 2.7 parts per 1,000 with 3-sigma limits.

Although C_p relates to the spread (dispersion) of the process output relative to its tolerance, it does not look at how well the process average is centered on the target value.

Process Capability Index (C_{pk})

The process capability index, C_{pk}, measures the difference between the desired and actual dimensions of goods or services produced.

C_{pk}
A proportion of variation (3σ) between the center of the process and the nearest specification limit.

The formula for C_{pk} is:

$$C_{pk} = \text{Minimum of}\left[\frac{\text{Upper specification limit} - \overline{X}}{3\sigma}, \frac{\overline{X} - \text{Lower specification limit}}{3\sigma}\right] \tag{S6-14}$$

where $\overline{X}$ = process mean
σ = standard deviation of the process population

When the C_{pk} index for both the upper and lower specification limits equals 1.0, the process variation is centered and the process is capable of producing within ± 3 standard deviations (fewer than 2,700 defects per million). A C_{pk} of 2.0 means the process is capable of producing fewer than 3.4 defects per million. For C_{pk} to exceed 1, σ must be less than $\frac{1}{3}$ of the difference between the specification and the process mean ($\overline{X}$). Figure S6.8 shows the meaning of various measures of C_{pk}, and Example S7 shows an application of C_{pk}.

Example S7

PROCESS CAPABILITY INDEX (C_{pk})

You are the process improvement manager and have developed a new machine to cut insoles for the company's top-of-the-line running shoes. You are excited because the company's goal is no more than 3.4 defects per million, and this machine may be the innovation you need. The insoles cannot be more than $\pm .001$ of an inch from the required thickness of .250″. You want to know if you should replace the existing machine, which has a C_{pk} of 1.0.

Mean of the new process $\overline{X}$ = .250 inches.
Standard deviation of the new process = σ = .0005 inches.

APPROACH ▶ You decide to determine the C_{pk}, using Equation (S6-14), for the new machine and make a decision on that basis.

SOLUTION ▶ Upper specification limit = .251 inches

Lower specification limit = .249 inches

$$C_{pk} = \text{Minimum of}\left[\frac{\text{Upper specification limit} - \overline{X}}{3\sigma}, \frac{\overline{X} - \text{Lower specification limit}}{3\sigma}\right]$$

$$C_{pk} = \text{Minimum of}\left[\frac{.251 - .250}{(3).0005}, \frac{.250 - .249}{(3).0005}\right]$$

Both calculations result in: $\frac{.001}{.0015} = .67.$

INSIGHT ▶ Because the new machine has a C_{pk} of only 0.67, the new machine should *not* replace the existing machine.

LEARNING EXERCISE ▶ If the insoles can be $\pm .002''$ (instead of .001") from the required .250", what is the new C_{pk}? [Answer: 1.33 and the new machine *should* replace the existing one.]

RELATED PROBLEMS ▶ S6.41–S6.45 (S6.46–S6.49 are available in MyOMLab)

ACTIVE MODEL S6.2 This example is further illustrated in Active Model S6.2 in MyOMLab.

EXCEL OM Data File **Ch06SExS7.xls** can be found in MyOMLab.

Note that C_p and C_{pk} will be the same when the process is centered. However, if the mean of the process is not centered on the desired (specified) mean, then the smaller numerator in Equation (S6-14) is used (the minimum of the difference between the upper specification limit and the mean or the lower specification limit and the mean). This application of C_{pk} is shown in Solved Problem S6.4. C_{pk} is the standard criterion used to express process performance.

Acceptance Sampling[7]

Acceptance sampling
A method of measuring random samples of lots or batches of finished products against predetermined standards.

LO S6.7 *Explain* acceptance sampling

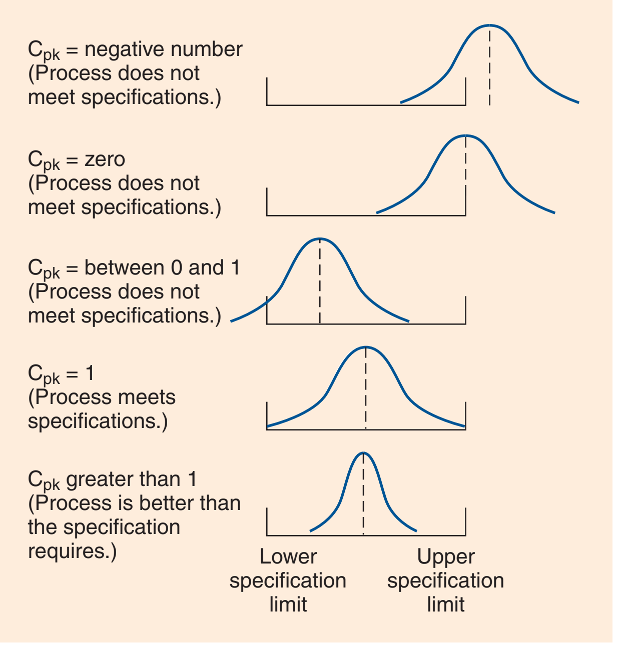
Acceptance sampling is a form of testing that involves taking random samples of "lots," or batches, of finished products and measuring them against predetermined standards. Sampling is more economical than 100% inspection. The quality of the sample is used to judge the quality of all items in the lot. Although both attributes and variables can be inspected by acceptance sampling, attribute inspection is more commonly used, as illustrated in this section.

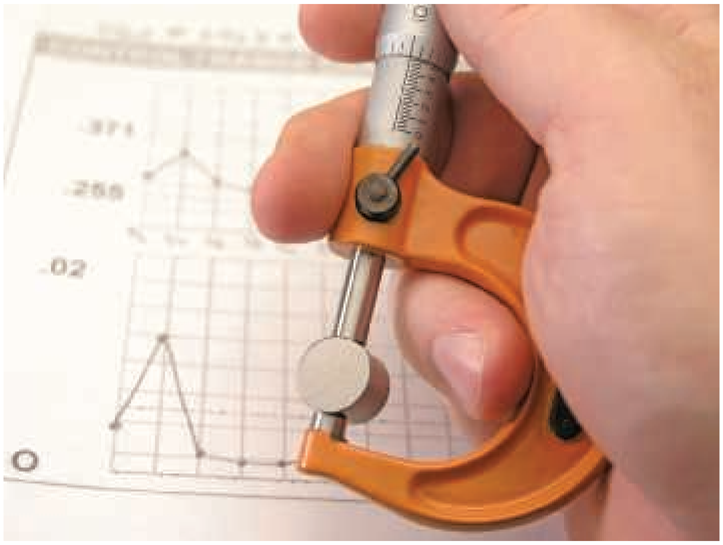
Acceptance sampling can be applied either when materials arrive at a plant or at final inspection, but it is usually used to control incoming lots of purchased products. A lot of items rejected, based on an unacceptable level of defects found in the sample, can (1) be returned to the supplier or (2) be 100% inspected to cull out all defects, with the cost of this screening usually billed to the supplier. However, acceptance sampling is not a substitute for adequate process controls. In fact, the current approach is to build statistical quality controls at suppliers so that acceptance sampling can be eliminated.

Figure **S6.8**

Meanings of C_{pk} Measures

A C_{pk} index of 1.0 for both the upper and lower specification limits indicates that the process variation is within the upper and lower specification limits. As the C_{pk} index goes above 1.0, the process becomes increasingly target oriented, with fewer defects. If the C_{pk} is less than 1.0, the process will not produce within the specified tolerance. Because a process may not be centered, or may "drift," a C_{pk} above 1 is desired.





Lyroky/Alamy

Richard T. Nowitz/Flirt/Alamy

Raw data for Statistical Process Control is collected in a wide variety of ways. Here physical measures using a micrometer (on the left) and a microscope (on the right) are being made.

Operating Characteristic Curve

The **operating characteristic (OC) curve** describes how well an acceptance plan discriminates between good and bad lots. A curve pertains to a specific plan—that is, to a combination of n (sample size) and c (acceptance level). It is intended to show the probability that the plan will accept lots of various quality levels.

Operating characteristic (OC) curve
A graph that describes how well an acceptance plan discriminates between good and bad lots.

With acceptance sampling, two parties are usually involved: the producer of the product and the consumer of the product. In specifying a sampling plan, each party wants to avoid costly mistakes in accepting or rejecting a lot. The producer usually has the responsibility of replacing all defects in the rejected lot or of paying for a new lot to be shipped to the customer. The producer, therefore, wants to avoid the mistake of having a good lot rejected (**producer's risk**). On the other hand, the customer or consumer wants to avoid the mistake of accepting a bad lot because defects found in a lot that has already been accepted are usually the responsibility of the customer (**consumer's risk**). The OC curve shows the features of a particular sampling plan, including the risks of making a wrong decision. The steeper the curve, the better the plan distinguishes between good and bad lots.[8]

Producer's risk
The mistake of having a producer's good lot rejected through sampling.

Consumer's risk
The mistake of a customer's acceptance of a bad lot overlooked through sampling.

Figure S6.9 can be used to illustrate one sampling plan in more detail. Four concepts are illustrated in this figure.

The **acceptable quality level (AQL)** is the poorest level of quality that we are willing to accept. In other words, we wish to accept lots that have this or a better level of quality, but no worse. If an acceptable quality level is 20 defects in a lot of 1,000 items or parts, then AQL is $20/1{,}000 = 2\%$ defectives.

Acceptable quality level (AQL)
The quality level of a lot considered good.

The **lot tolerance percentage defective (LTPD)** is the quality level of a lot that we consider bad. We wish to reject lots that have this or a poorer level of quality. If it is agreed that an unacceptable quality level is 70 defects in a lot of 1,000, then the LTPD is $70/1{,}000 = 7\%$ defective.

Lot tolerance percentage defective (LTPD)
The quality level of a lot considered bad.

To derive a sampling plan, producer and consumer must define not only "good lots" and "bad lots" through the AQL and LTPD, but they must also specify risk levels.

Producer's risk (α) is the probability that a "good" lot will be rejected. This is the risk that a random sample might result in a much higher proportion of defects than the population of all items. A lot with an acceptable quality level of AQL still has an α chance of being rejected. Sampling plans are often designed to have the producer's risk set at $\alpha = .05$, or 5%.

Consumer's risk (β) is the probability that a "bad" lot will be accepted. This is the risk that a random sample may result in a lower proportion of defects than the overall population of items. A common value for consumer's risk in sampling plans is $\beta = .10$, or 10%.

The probability of rejecting a good lot is called a **type I error**. The probability of accepting a bad lot is a **type II error**.

Type I error
Statistically, the probability of rejecting a good lot.

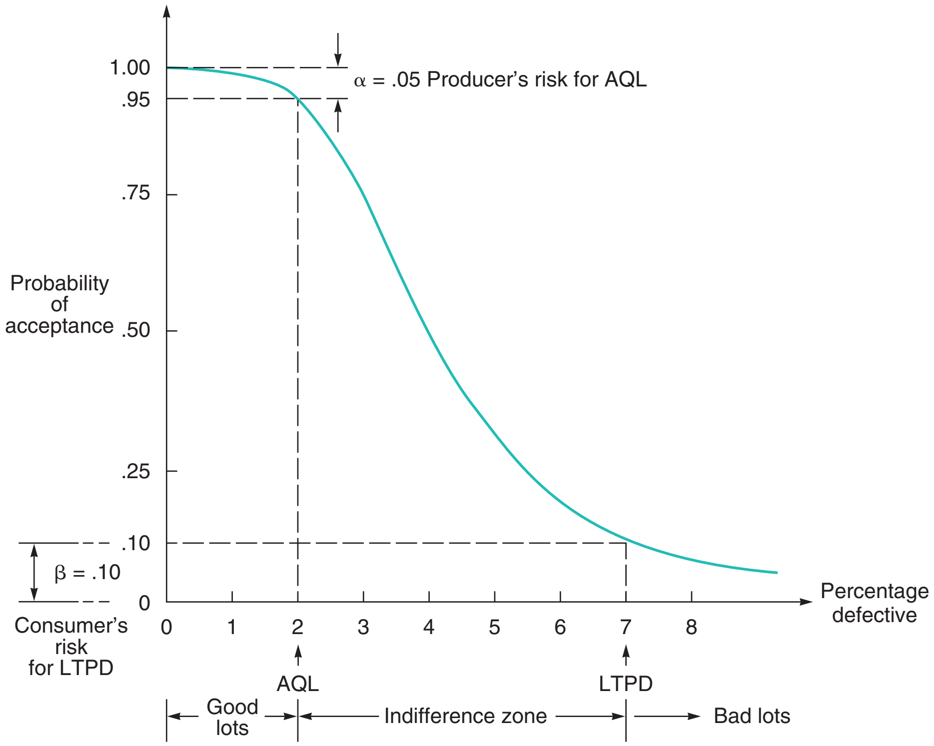
Type II error
Statistically, the probability of accepting a bad lot.

Sampling plans and OC curves may be developed by computer (as seen in the software available with this text), by published tables, or by calculation, using binomial or Poisson distributions.

Figure **S6.9**

An Operating Characteristic (OC) Curve Showing Producer's and Consumer's Risks

A good lot for this particular acceptance plan has less than or equal to 2% defectives. A bad lot has 7% or more defectives.



Average Outgoing Quality

Average outgoing quality (AOQ)
The percentage defective in an average lot of goods inspected through acceptance sampling.

In most sampling plans, when a lot is rejected, the entire lot is inspected and all defective items replaced. Use of this replacement technique improves the average outgoing quality in terms of percent defective. In fact, given (1) any sampling plan that replaces all defective items encountered and (2) the true incoming percent defective for the lot, it is possible to determine the **average outgoing quality (AOQ)** in percentage defective. The equation for AOQ is:

$$\text{AOQ} = \frac{(P_d)(P_a)(N - n)}{N} \quad \text{(S6-15)}$$

where

P_d = true percentage defective of the lot
P_a = probability of accepting the lot for a given sample size and quantity defective
N = number of items in the lot
n = number of items in the sample

The maximum value of AOQ corresponds to the highest average percentage defective or the lowest average quality for the sampling plan. It is called the *average outgoing quality limit (AOQL)*.

This laser tracking device, by Faro Technologies, enables quality control personnel to measure and inspect parts and tools during production. The portable tracker can measure objects from 262 feet away and takes to up 1,000 accurate readings per second.

Faro Technologies

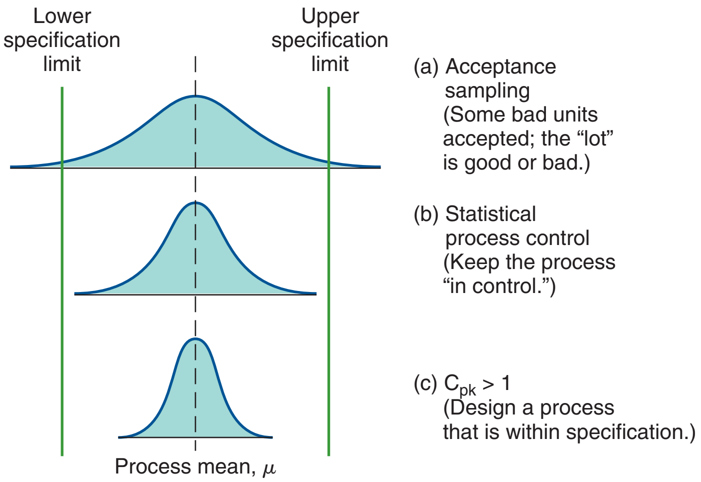


Figure **S6.10**

The Application of Statistical Process Control Techniques Contributes to the Identification and Systematic Reduction of Process Variability

Acceptance sampling is useful for screening incoming lots. When the defective parts are replaced with good parts, acceptance sampling helps to increase the quality of the lots by reducing the outgoing percent defective.

Figure S6.10 compares acceptance sampling, SPC, and C_{pk}. As the figure shows, (a) acceptance sampling by definition accepts some bad units, (b) control charts try to keep the process in control, but (c) the C_{pk} index places the focus on improving the process. As operations managers, that is what we want to do—improve the process.

Summary

Statistical process control is a major statistical tool of quality control. Control charts for SPC help operations managers distinguish between natural and assignable variations. The $\bar{x}$-chart and the R-chart are used for variable sampling, and the p-chart and the c-chart for attribute sampling. The C_{pk} index is a way to express process capability. Operating characteristic (OC) curves facilitate acceptance sampling and provide the manager with tools to evaluate the quality of a production run or shipment.

Key Terms

Statistical process control (SPC) (p. 246)
Control chart (p. 246)
Natural variations (p. 246)
Assignable variation (p. 247)
$\bar{x}$-chart (p. 248)
R-chart (p. 248)
Central limit theorem (p. 248)
p-chart (p. 255)
c-chart (p. 257)
Run test (p. 260)
Process capability (p. 260)
C_p (p. 260)
C_{pk} (p. 261)
Acceptance sampling (p. 262)
Operating characteristic (OC) curve (p. 263)
Producer's risk (p. 263)
Consumer's risk (p. 263)
Acceptable quality level (AQL) (p. 263)
Lot tolerance percentage defective (LTPD) (p. 263)
Type I error (p. 263)
Type II error (p. 263)
Average outgoing quality (AOQ) (p. 264)

Discussion Questions

1. List Shewhart's two types of variation. What are they also called?
2. Define "in statistical control."
3. Explain briefly what an $\bar{x}$-chart and an R-chart do.
4. What might cause a process to be out of control?
5. List five steps in developing and using $\bar{x}$-charts and R-charts.
6. List some possible causes of assignable variation.
7. Explain how a person using 2-sigma control charts will more easily find samples "out of bounds" than 3-sigma control charts. What are some possible consequences of this fact?
8. When is the desired mean, μ, used in establishing the centerline of a control chart instead of $\bar{\bar{x}}$?
9. Can a production process be labeled as "out of control" because it is too good? Explain.
10. In a control chart, what would be the effect on the control limits if the sample size varied from one sample to the next?
11. Define C_{pk} and explain what a C_{pk} of 1.0 means. What is C_p?
12. What does a run of 5 points above or below the centerline in a control chart imply?
13. What are the acceptable quality level (AQL) and the lot tolerance percentage defective (LTPD)? How are they used?
14. What is a run test, and when is it used?
15. Discuss the managerial issues regarding the use of control charts.
16. What is an OC curve?

17. What is the purpose of acceptance sampling?

18. What two risks are present when acceptance sampling is used?

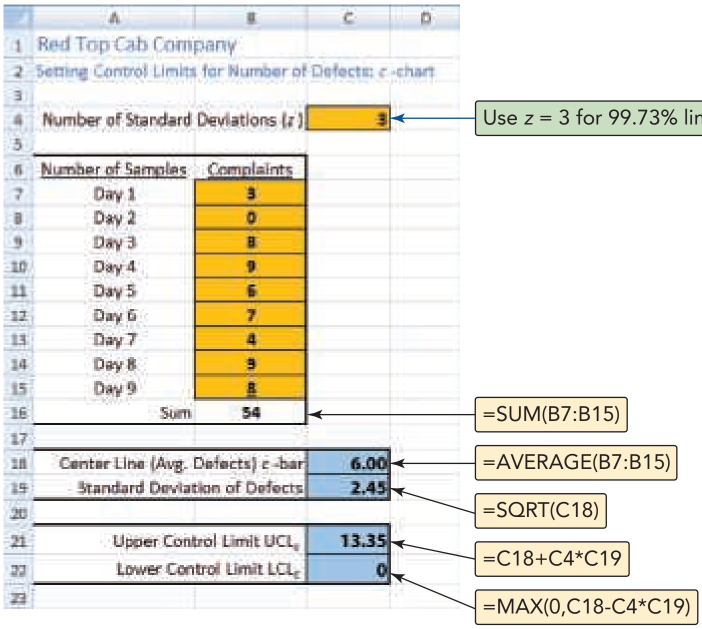
19. Is a *capable* process a *perfect* process? That is, does a capable process generate only output that meets specifications? Explain.

Using Software for SPC

Excel, Excel OM, and POM for Windows may be used to develop control charts for most of the problems in this chapter.

CREATING YOUR OWN EXCEL SPREADSHEETS TO DETERMINE CONTROL LIMITS FOR A *C*-CHART

Excel and other spreadsheets are extensively used in industry to maintain control charts. Program S6.1 is an example of how to use Excel to determine the control limits for a *c*-chart. A *c*-chart is used when the number of defects per unit of output is known. The data from Example S5 are used here. In this example, 54 complaints occurred over 9 days. Excel also contains a built-in graphing ability with Chart Wizard.

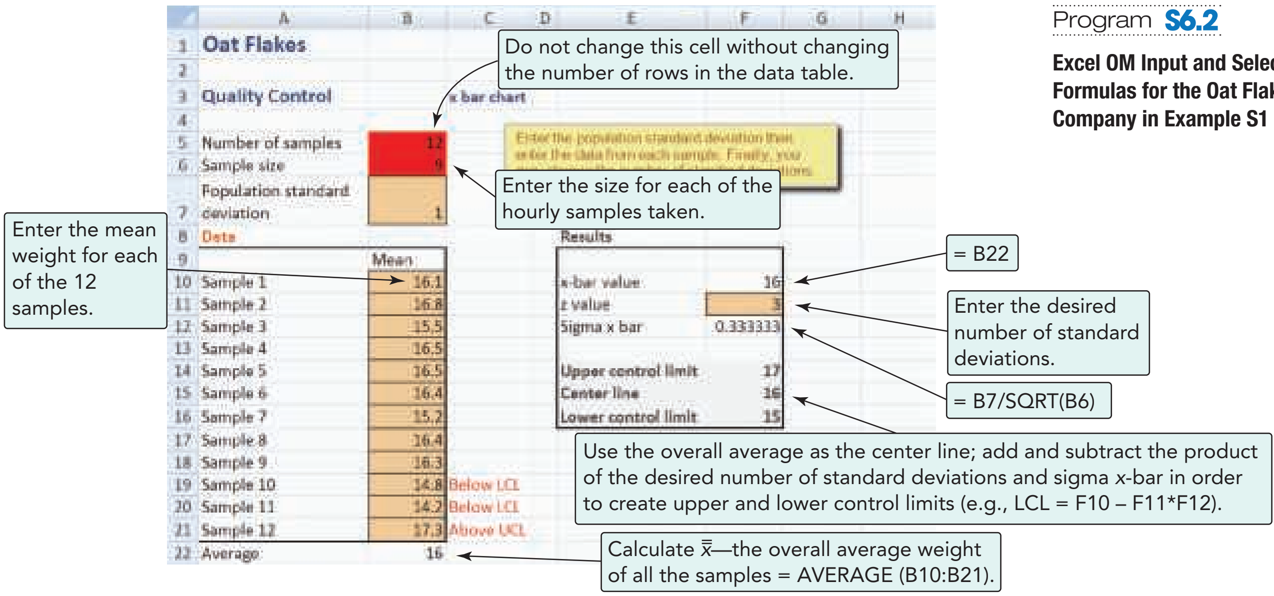


Program **S6.1**

An Excel Spreadsheet for Creating a *c*-Chart for Example S5

USING EXCEL OM

Excel OM's Quality Control module has the ability to develop $\bar{x}$-charts, *p*-charts, and *c*-charts. It also handles OC curves, acceptance sampling, and process capability. Program S6.2 illustrates Excel OM's spreadsheet approach to computing the $\bar{x}$ control limits for the Oat Flakes company in Example S1.



Program **S6.2**

Excel OM Input and Selected Formulas for the Oat Flakes Company in Example S1

USING POM FOR WINDOWS

The POM for Windows Quality Control module has the ability to compute all the SPC control charts we introduced in this supplement, as well as OC curves, acceptance sampling, and process capability. See Appendix IV for further details.

Solved Problems

Virtual Office Hours help is available in MyOMLab.

SOLVED PROBLEM S6.1

A manufacturer of precision machine parts produces round shafts for use in the construction of drill presses. The average diameter of a shaft is .56 inch. Inspection samples contain 6 shafts each. The average range of these samples is .006 inch. Determine the upper and lower $\bar{x}$ control chart limits.

SOLUTION

The mean factor A_2 from Table S6.1, where the sample size is 6, is seen to be .483. With this factor, you can obtain the upper and lower control limits:

$$\begin{aligned} UCL_{\bar{x}} &= .56 + (.483)(.006) \\ &= .56 + .0029 \\ &= .5629 \text{ inch} \\ LCL_{\bar{x}} &= .56 - .0029 \\ &= .5571 \text{ inch} \end{aligned}$$

SOLVED PROBLEM S6.2

Nocaf Drinks, Inc., a producer of decaffeinated coffee, bottles Nocaf. Each bottle should have a net weight of 4 ounces. The machine that fills the bottles with coffee is new, and the operations manager wants to make sure that it is properly adjusted. Bonnie Crutcher, the operations manager, randomly selects and weighs $n = 8$ bottles and records the average and range in ounces for each sample. The data for several samples is given in the following table. Note that every sample consists of 8 bottles.

SAMPLE	SAMPLE RANGE	SAMPLE AVERAGE	SAMPLE	SAMPLE RANGE	SAMPLE AVERAGE
A	.41	4.00	E	.56	4.17
B	.55	4.16	F	.62	3.93
C	.44	3.99	G	.54	3.98
D	.48	4.00	H	.44	4.01

Is the machine properly adjusted and in control?

SOLUTION

We first find that $\bar{\bar{x}} = 4.03$ and $\bar{R} = .505$. Then, using Table S6.1, we find:

$$\begin{aligned} UCL_{\bar{x}} &= \bar{\bar{x}} + A_2\bar{R} = 4.03 + (.373)(.505) = 4.22 \\ LCL_{\bar{x}} &= \bar{\bar{x}} - A_2\bar{R} = 4.03 - (.373)(.505) = 3.84 \\ UCL_R &= D_4\bar{R} = (1.864)(.505) = .94 \\ LCL_R &= D_3\bar{R} = (.136)(.505) = .07 \end{aligned}$$

It appears that the process average and range are both in statistical control.

The operations manager needs to determine if a process with a mean (4.03) slightly above the desired mean of 4.00 is satisfactory; if it is not, the process will need to be changed.

SOLVED PROBLEM S6.3

Altman Distributors, Inc., fills catalog orders. Samples of size $n = 100$ orders have been taken each day over the past 6 weeks. The average defect rate was .05. Determine the upper and lower limits for this process for 99.73% confidence.

SOLUTION

$z = 3$, $\bar{p} = .05$. Using Equations (S6-9), (S6-10), and (S6-11):

$$\begin{aligned} UCL_p &= \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = .05 + 3\sqrt{\frac{(.05)(1-.05)}{100}} \\ &= .05 + 3(0.0218) = .1154 \\ LCL_p &= \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = .05 - 3(0.0218) \\ &= .05 - .0654 = 0 \quad \text{(because percentage defective cannot be negative)} \end{aligned}$$

SOLVED PROBLEM S6.4

Ettlie Engineering has a new catalyst injection system for your countertop production line. Your process engineering department has conducted experiments and determined that the mean is 8.01 grams with a standard deviation of .03. Your specifications are: $\mu = 8.0$ and $\sigma = .04$, which means an upper specification limit of 8.12 [= 8.0 + 3(.04)] and a lower specification limit of 7.88 [= 8.0 − 3(.04)].

What is the C_{pk} performance of the injection system?

SOLUTION

Using Equation (S6-14):

$$C_{pk} = \text{Minimum of}\left[\frac{\text{Upper specification limit} - \overline{X}}{3\sigma}, \frac{\overline{X} - \text{Lower specification limit}}{3\sigma}\right]$$

where

$\overline{X}$ = process mean

σ = standard deviation of the process population

$$C_{pk} = \text{Minimum of}\left[\frac{8.12 - 8.01}{(3)(.03)}, \frac{8.01 - 7.88}{(3)(.03)}\right]$$

$$\left[\frac{.11}{.09} = 1.22\ , \frac{.13}{.09} = 1.44\right]$$

The minimum is 1.22, so the C_{pk} is within specifications and has an implied error rate of less than 2,700 defects per million.

SOLVED PROBLEM S6.5

Airlines lose thousands of checked bags every day, and America South Airlines is no exception to the industry rule. Over the past 6 weeks, the number of bags "misplaced" on America South flights has been 18, 10, 4, 6, 12, and 10. The head of customer service wants to develop a *c*-chart at 99.73% levels.

SOLUTION

She first computes $\bar{c} = \dfrac{18 + 10 + 4 + 6 + 12 + 10}{6} = \dfrac{60}{6} = 10$ bags/week

Then, using Equation (S6-12):

$$UCL_c = \bar{c} + 3\sqrt{\bar{c}} = 10 + 3\sqrt{10} = 10 + 3(3.16) = 19.48 \text{ bags}$$

$$LCL_C = \bar{c} - 3\sqrt{\bar{c}} = 10 - 3\sqrt{10} = 10 - 3(3.16) = .52 \text{ bag}$$

Problems

Note: PX means the problem may be solved with POM for Windows and/or Excel OM/Excel.

Problems S6.1–S6.39 relate to Statistical Process Control (SPC)

• **S6.1** Boxes of Honey-Nut Oatmeal are produced to contain 14 ounces, with a standard deviation of .1 ounce. Set up the 3-sigma $\bar{x}$-chart for a sample size of 36 boxes. PX

• **S6.2** The overall average on a process you are attempting to monitor is 50 units. The process population standard deviation is 1.72. Determine the upper and lower control limits for a mean chart, if you choose to use a sample size of 5. PX
a) Set $z = 3$.
b) Now set $z = 2$. How do the control limits change?

• **S6.3** Thirty-five samples of size 7 each were taken from a fertilizer-bag-filling machine. The results were overall mean = 57.75 lb; average range = 1.78 lb.
a) Determine the upper and lower control limits of the $\bar{x}$-chart, where $\sigma = 3$.
b) Determine the upper and lower control limits of the R-chart, where $\sigma = 3$. PX

• **S6.4** Rosters Chicken advertises “lite” chicken with 30% fewer calories than standard chicken. When the process for “lite” chicken breast production is in control, the average chicken breast contains 420 calories, and the standard deviation in caloric content of the chicken breast population is 25 calories.

Rosters wants to design an $\bar{x}$-chart to monitor the caloric content of chicken breasts, where 25 chicken breasts would be chosen at random to form each sample.
a) What are the lower and upper control limits for this chart if these limits are chosen to be *four* standard deviations from the target?
b) What are the limits with three standard deviations from the target? PX

• **S6.5** Ross Hopkins is attempting to monitor a filling process that has an overall average of 705 cc. The average range is 6 cc. If you use a sample size of 10, what are the upper and lower control limits for the mean and range?

•• **S6.6** Sampling four pieces of precision-cut wire (to be used in computer assembly) every hour for the past 24 hours has produced the following results:

HOUR	$\bar{X}$	R	HOUR	$\bar{X}$	R
1	3.25″	.71″	13	3.11″	.85″
2	3.10	1.18	14	2.83	1.31
3	3.22	1.43	15	3.12	1.06
4	3.39	1.26	16	2.84	.50
5	3.07	1.17	17	2.86	1.43
6	2.86	.32	18	2.74	1.29
7	3.05	.53	19	3.41	1.61
8	2.65	1.13	20	2.89	1.09
9	3.02	.71	21	2.65	1.08
10	2.85	1.33	22	3.28	.46
11	2.83	1.17	23	2.94	1.58
12	2.97	.40	24	2.64	.97

Develop appropriate control charts and determine whether there is any cause for concern in the cutting process. Plot the information and look for patterns. PX

•• **S6.7** Auto pistons at Wemming Chung’s plant in Shanghai are produced in a forging process, and the diameter is a critical factor that must be controlled. From sample sizes of 10 pistons produced each day, the mean and the range of this diameter have been as follows:

DAY	MEAN (MM)	RANGE (MM)
1	156.9	4.2
2	153.2	4.6
3	153.6	4.1
4	155.5	5.0
5	156.6	4.5

a) What is the value of $\bar{\bar{x}}$?
b) What is the value of $\bar{R}$?
c) What are the $UCL_{\bar{x}}$ and $LCL_{\bar{x}}$, using 3σ? Plot the data.
d) What are the UCL_R and LCL_R, using 3σ? Plot the data.
e) If the true diameter mean should be 155 mm and you want this as your center (nominal) line, what are the new $UCL_{\bar{x}}$ and $LCL_{\bar{x}}$? PX

•• **S6.8** A. Choudhury’s bowling ball factory in Illinois makes bowling balls of adult size and weight only. The standard deviation in the weight of a bowling ball produced at the factory is known to be 0.12 pounds. Each day for 24 days, the average weight, in pounds, of nine of the bowling balls produced that day has been assessed as follows:

DAY	AVERAGE (lb)	DAY	AVERAGE (lb)
1	16.3	13	16.3
2	15.9	14	15.9
3	15.8	15	16.3
4	15.5	16	16.2
5	16.3	17	16.1
6	16.2	18	15.9
7	16.0	19	16.2
8	16.1	20	15.9
9	15.9	21	15.9
10	16.2	22	16.0
11	15.9	23	15.5
12	15.9	24	15.8

a) Establish a control chart for monitoring the average weights of the bowling balls in which the upper and lower control limits are each two standard deviations from the mean. What are the values of the control limits?
b) If three standard deviations are used in the chart, how do these values change? Why? PX

• • **S6.9** Organic Grains LLC uses statistical process control to ensure that its health-conscious, low-fat, multigrain sandwich loaves have the proper weight. Based on a previously stable and in-control process, the control limits of the $\bar{x}$- and R-charts are $UCL_{\bar{x}} = 6.56$. $LCL_{\bar{x}} = 5.84$, $UCL_R = 1.141$, $LCL_R = 0$. Over the past few days, they have taken five random samples of four loaves each and have found the following:

SAMPLE	NET WEIGHT			
	LOAF #1	LOAF #2	LOAF #3	LOAF #4
1	6.3	6.0	5.9	5.9
2	6.0	6.0	6.3	5.9
3	6.3	4.8	5.6	5.2
4	6.2	6.0	6.2	5.9
5	6.5	6.6	6.5	6.9

Is the process still in control? Explain why or why not. PX

• • • **S6.10** A process that is considered to be in control measures an ingredient in ounces. Below are the last 10 samples (each of size $n = 5$) taken. The population process standard deviation, σ, is 1.36.

SAMPLES									
1	2	3	4	5	6	7	8	9	10
10	9	13	10	12	10	10	13	8	10
9	9	9	10	10	10	11	10	8	12
10	11	10	11	9	8	10	8	12	9
9	11	10	10	11	12	8	10	12	8
12	10	9	10	10	9	9	8	9	12

a) What is $\sigma_{\bar{x}}$?
b) If $z = 3$, what are the control limits for the mean chart?
c) What are the control limits for the range chart?
d) Is the process in control? PX

• • • **S6.11** Twelve samples, each containing five parts, were taken from a process that produces steel rods at Emmanuel Kodzi's factory. The length of each rod in the samples was determined. The results were tabulated and sample means and ranges were computed. The results were:

SAMPLE	SAMPLE MEAN (in.)	RANGE (in.)
1	10.002	0.011
2	10.002	0.014
3	9.991	0.007
4	10.006	0.022
5	9.997	0.013
6	9.999	0.012
7	10.001	0.008
8	10.005	0.013
9	9.995	0.004
10	10.001	0.011
11	10.001	0.014
12	10.006	0.009

a) Determine the upper and lower control limits and the overall means for $\bar{x}$-charts and R-charts.
b) Draw the charts and plot the values of the sample means and ranges.
c) Do the data indicate a process that is in control?
d) Why or why not? PX

• • **S6.12** Eagletrons are all-electric automobiles produced by Mogul Motors, Inc. One of the concerns of Mogul Motors is that the Eagletrons be capable of achieving appropriate maximum speeds. To monitor this, Mogul executives take samples of eight Eagletrons at a time. For each sample, they determine the average maximum speed and the range of the maximum speeds within the sample. They repeat this with 35 samples to obtain 35 sample means and 35 ranges. They find that the average sample mean is 88.50 miles per hour, and the average range is 3.25 miles per hour. Using these results, the executives decide to establish an R chart. They would like this chart to be established so that when it shows that the range of a sample is not within the control limits, there is only approximately a 0.0027 probability that this is due to natural variation. What will be the upper control limit (UCL) and the lower control limit (LCL) in this chart? PX

• • **S6.13** The defect rate for data entry of insurance claims has historically been about 1.5%.
a) What are the upper and lower control chart limits if you wish to use a sample size of 100 and 3-sigma limits?
b) What if the sample size used were 50, with 3σ?
c) What if the sample size used were 100, with 2σ?
d) What if the sample size used were 50, with 2σ?
e) What happens to $\hat{\sigma}_p$ when the sample size is larger?
f) Explain why the lower control limit cannot be less than 0. PX

• • **S6.14** You are attempting to develop a quality monitoring system for some parts purchased from Charles Sox Manufacturing Co. These parts are either good or defective. You have decided to take a sample of 100 units. Develop a table of the appropriate upper and lower control chart limits for various values of the average fraction defective in the samples taken. The values for $\bar{p}$ in this table should range from 0.02 to 0.10 in increments of 0.02. Develop the upper and lower control limits for a 99.73% confidence level.

$N = 100$		
$\bar{P}$	UCL	LCL
0.02		
0.04		
0.06		
0.08		
0.10		

PX

• • **S6.15** The results of an inspection of DNA samples taken over the past 10 days are given below. Sample size is 100.

DAY	1	2	3	4	5	6	7	8	9	10
DEFECTIVES	7	6	6	9	5	6	0	8	9	1

a) Construct a 3-sigma p-chart using this information.
b) Using the control chart in part (a), and finding that the number of defectives on the next three days are 12, 5, and 13, is the process in control? PX

• **S6.16** In the past, the defective rate for your product has been 1.5%. What are the upper and lower control chart limits if you wish to use a sample size of 500 and $z = 3$? PX

• **S6.17** Refer to Problem S6.16. If the defective rate was 3.5% instead of 1.5%, what would be the control limits ($z = 3$)? PX

• • **S6.18** Five data entry operators work at the data processing department of the Birmingham Bank. Each day for 30 days, the number of defective records in a sample of 250 records typed by these operators has been noted, as follows:

SAMPLE NO.	NO. DEFECTIVE	SAMPLE NO.	NO. DEFECTIVE	SAMPLE NO.	NO. DEFECTIVE
1	7	11	18	21	17
2	5	12	5	22	12
3	19	13	16	23	6
4	10	14	4	24	7
5	11	15	11	25	13
6	8	16	8	26	10
7	12	17	12	27	14
8	9	18	4	28	6
9	6	19	6	29	12
10	13	20	16	30	3

a) Establish 3σ upper and lower control limits.
b) Why can the lower control limit not be a negative number?
c) The industry standards for the upper and lower control limits are 0.10 and 0.01, respectively. What does this imply about Birmingham Bank's own standards?

• • **S6.19** Houston North Hospital is trying to improve its image by providing a positive experience for its patients and their relatives. Part of the "image" program involves providing tasty, inviting patient meals that are also healthful. A questionnaire accompanies each meal served, asking the patient, among other things, whether he or she is satisfied or unsatisfied with the meal. A 100-patient sample of the survey results over the past 7 days yielded the following data:

DAY	NO. OF UNSATISFIED PATIENTS	SAMPLE SIZE
1	24	100
2	22	100
3	8	100
4	15	100
5	10	100
6	26	100
7	17	100

Construct a *p*-chart that plots the percentage of patients unsatisfied with their meals. Set the control limits to include 99.73% of the random variation in meal satisfaction. Comment on your results.

Corbis Super RF/Alamy

• • **S6.20** Jamison Kovach Supply Company manufactures paper clips and other office products. Although inexpensive, paper clips have provided the firm with a high margin of profitability. Sample size is 200. Results are given for the last 10 samples:

SAMPLE	1	2	3	4	5	6	7	8	9	10
DEFECTIVES	5	7	4	4	6	3	5	6	2	8

a) Establish upper and lower control limits for the control chart and graph the data.
b) Has the process been in control?
c) If the sample size were 100 instead, how would your limits and conclusions change?

• **S6.21** Peter Ittig's department store, Ittig Brothers, is Amherst's largest independent clothier. The store receives an average of six returns per day. Using $z = 3$, would nine returns in a day warrant action?

• • **S6.22** An ad agency tracks the complaints, by week received, about the billboards in its city:

WEEK	NO. OF COMPLAINTS
1	4
2	5
3	4
4	11
5	3
6	9

a) What type of control chart would you use to monitor this process? Why?
b) What are the 3-sigma control limits for this process? Assume that the historical complaint rate is unknown.
c) Is the process in control, according to the control limits? Why or why not?
d) Assume now that the historical complaint rate has been four calls a week. What would the 3-sigma control limits for this process be now? Has the process been in control according to the control limits?

• • **S6.23** The school board is trying to evaluate a new math program introduced to second-graders in five elementary schools across the county this year. A sample of the student scores on standardized math tests in each elementary school yielded the following data:

SCHOOL	NO. OF TEST ERRORS
A	52
B	27
C	35
D	44
E	55

Construct a *c*-chart for test errors, and set the control limits to contain 99.73% of the random variation in test scores. What does the chart tell you? Has the new math program been effective?

•• **S6.24** Telephone inquiries of 100 IRS "customers" are monitored daily at random. Incidents of incorrect information or other nonconformities (such as impoliteness to customers) are recorded. The data for last week follow:

DAY	NO. OF NONCONFORMITIES
1	5
2	10
3	23
4	20
5	15

a) Construct a 3-standard deviation *c*-chart of nonconformities.
b) What does the control chart tell you about the IRS telephone operators?

••• **S6.25** The accounts receivable department at Rick Wing Manufacturing has been having difficulty getting customers to pay the full amount of their bills. Many customers complain that the bills are not correct and do not reflect the materials that arrived at their receiving docks. The department has decided to implement SPC in its billing process. To set up control charts, 10 samples of 50 bills each were taken over a month's time and the items on the bills checked against the bill of lading sent by the company's shipping department to determine the number of bills that were not correct. The results were:

SAMPLE NO.	NO. OF INCORRECT BILLS	SAMPLE NO.	NO. OF INCORRECT BILLS
1	6	6	5
2	5	7	3
3	11	8	4
4	4	9	7
5	0	10	2

a) Determine the value of *p*-bar, the mean fraction defective. Then determine the control limits for the *p*-chart using a 99.73% confidence level (3 standard deviations). Has this process been in control? If not, which samples were out of control?
b) How might you use the quality tools discussed in Chapter 6 to determine the source of the billing defects and where you might start your improvement efforts to eliminate the causes?

••• **S6.26** West Battery Corp. has recently been receiving complaints from retailers that its 9-volt batteries are not lasting as long as other name brands. James West, head of the TQM program at West's Austin plant, believes there is no problem because his batteries have had an average life of 50 hours, about 10% longer than competitors' models. To raise the lifetime above this level would require a new level of technology not available to West. Nevertheless, he is concerned enough to set up hourly assembly line checks. Previously, after ensuring that the process was running properly, West took size $n = 5$ samples of 9-volt batteries for each of 25 hours to establish the standards for control chart limits. Those samples are shown in the following table:

West Battery Data—Battery Lifetimes (in hours)

HOUR SAMPLE TAKEN	SAMPLE						
	1	2	3	4	5	$\overline{X}$	R
1	51	50	49	50	50	50.0	2
2	45	47	70	46	36	48.8	34
3	50	35	48	39	47	43.8	15
4	55	70	50	30	51	51.2	40
5	49	38	64	36	47	46.8	28
6	59	62	40	54	64	55.8	24
7	36	33	49	48	56	44.4	23
8	50	67	53	43	40	50.6	27
9	44	52	46	47	44	46.6	8
10	70	45	50	47	41	50.6	29
11	57	54	62	45	36	50.8	26
12	56	54	47	42	62	52.2	20
13	40	70	58	45	44	51.4	30
14	52	58	40	52	46	49.6	18
15	57	42	52	58	59	53.6	17
16	62	49	42	33	55	48.2	29
17	40	39	49	59	48	47.0	20
18	64	50	42	57	50	52.6	22
19	58	53	52	48	50	52.2	10
20	60	50	41	41	50	48.4	19
21	52	47	48	58	40	49.0	18
22	55	40	56	49	45	49.0	16
23	47	48	50	50	48	48.6	3
24	50	50	49	51	51	50.2	2
25	51	50	51	51	62	53.0	12

With these limits established, West now takes 5 more hours of data, which are shown in the following table:

	SAMPLE				
HOUR	1	2	3	4	5
26	48	52	39	57	61
27	45	53	48	46	66
28	63	49	50	45	53
29	57	70	45	52	61
30	45	38	46	54	52

a) Determine means and the upper and lower control limits for $\overline{x}$ and R (using the first 25 hours only).
b) Has the manufacturing process been in control?
c) Comment on the lifetimes observed.

•••• **S6.27** One of New England Air's top competitive priorities is on-time arrivals. Quality VP Clair Bond decided to personally monitor New England Air's performance. Each week for the past 30 weeks, Bond checked a random sample of 100 flight arrivals for on-time performance. The table that follows contains the number of flights that did not meet New England Air's definition of "on time":

SAMPLE (WEEK)	LATE FLIGHTS	SAMPLE (WEEK)	LATE FLIGHTS
1	2	16	2
2	4	17	3
3	10	18	7
4	4	19	3
5	1	20	2
6	1	21	3
7	13	22	7
8	9	23	4
9	11	24	3
10	0	25	2
11	3	26	2
12	4	27	0
13	2	28	1
14	2	29	3
15	8	30	4

a) Using a 95% confidence level, plot the overall percentage of late flights ($\bar{p}$) and the upper and lower control limits on a control chart.
b) Assume that the airline industry's upper and lower control limits for flights that are not on time are .1000 and .0400, respectively. Draw them on your control chart.
c) Plot the percentage of late flights in each sample. Do all samples fall within New England Air's control limits? When one falls outside the control limits, what should be done?
d) What can Clair Bond report about the quality of service? PX

Additional problems **S6.28–S6.39** *are available in* MyOMLab.

Problems S6.40–S6.50 relate to Process Capability

• **S6.40** The difference between the upper specification and the lower specification for a process is 0.6". The standard deviation is 0.1". What is the process capability ratio, C_p? Interpret this number. PX

•• **S6.41** Meena Chavan Corp.'s computer chip production process yields DRAM chips with an average life of 1,800 hours and $\sigma = 100$ hours. The tolerance upper and lower specification limits are 2,400 hours and 1,600 hours, respectively. Is this process capable of producing DRAM chips to specification? PX

•• **S6.42** Linda Boardman, Inc., an equipment manufacturer in Boston, has submitted a sample cutoff valve to improve your manufacturing process. Your process engineering department has conducted experiments and found that the valve has a mean (μ) of 8.00 and a standard deviation (σ) of .04. Your desired performance is $\mu = 8.0 \pm 3\sigma$, where $\sigma = .045$. What is the C_{pk} of the Boardman valve? PX

•• **S6.43** The specifications for a plastic liner for concrete highway projects calls for a thickness of 3.0 mm $\pm$.1 mm. The standard deviation of the process is estimated to be .02 mm. What are the upper and lower specification limits for this product? The process is known to operate at a mean thickness of 3.0 mm. What is the C_{pk} for this process? About what percentage of all units of this liner will meet specifications? PX

•• **S6.44** Frank Pianki, the manager of an organic yogurt processing plant, desires a quality specification with a mean of 16 ounces, an upper specification limit of 16.5, and a lower specification limit of 15.5. The process has a mean of 16 ounces and a standard deviation of 1 ounce. Determine the C_{pk} of the process. PX

•• **S6.45** A process filling small bottles with baby formula has a target of 3 ounces $\pm$0.150 ounce. Two hundred bottles from the process were sampled. The results showed the average amount of formula placed in the bottles to be 3.042 ounces. The standard deviation of the amounts was 0.034 ounce. Determine the value of C_{pk}. Roughly what proportion of bottles meet the specifications? PX

Additional problems **S6.46–S6.50** *are available in* MyOMLab.

Problems S6.51–S6.55 relate to Acceptance Sampling

•• **S6.51** As the supervisor in charge of shipping and receiving, you need to determine *the average outgoing quality* in a plant where the known incoming lots from your assembly line have an average defective rate of 3%. Your plan is to sample 80 units of every 1,000 in a lot. The number of defects in the sample is not to exceed 3. Such a plan provides you with a probability of acceptance of each lot of .79 (79%). What is your average outgoing quality? PX

•• **S6.52** An acceptance sampling plan has lots of 500 pieces and a sample size of 60. The number of defects in the sample may not exceed 2. This plan, based on an OC curve, has a probability of .57 of accepting lots when the incoming lots have a defective rate of 4%, which is the historical average for this process. What do you tell your customer the average outgoing quality is? PX

•• **S6.53** The percent defective from an incoming lot is 3%. An OC curve showed the probability of acceptance to be 0.55. Given a lot size of 2,000 and a sample of 100, determine the average outgoing quality in percent defective.

•• **S6.54** In an acceptance sampling plan developed for lots containing 1,000 units, the sample size n is 85. The percent defective of the incoming lots is 2%, and the probability of acceptance is 0.64. What is the average outgoing quality?

•• **S6.55** We want to determine the AOQ for an acceptance sampling plan when the quality of the incoming lots in percent defective is 1.5%, and then again when the incoming percent defective is 5%. The sample size is 80 units for a lot size of 550 units. Furthermore, P_a at 1.5% defective levels is 0.95. At 5% incoming defective levels, the P_a is found to be 0.5. Determine the average outgoing quality for both incoming percent defective levels.

CASE STUDIES

Bayfield Mud Company

In November 2015, John Wells, a customer service representative of Bayfield Mud Company, was summoned to the Houston warehouse of Wet-Land Drilling, Inc., to inspect three boxcars of mudtreating agents that Bayfield had shipped to the Houston firm. (Bayfield's corporate offices and its largest plant are located in Orange, Texas, which is just west of the Louisiana–Texas border.) Wet-Land had filed a complaint that the 50-pound bags of treating agents just received from Bayfield were short-weight by approximately 5%.

The short-weight bags were initially detected by one of Wet-Land's receiving clerks, who noticed that the railroad scale tickets indicated that net weights were significantly less on all three boxcars than those of identical shipments received on October 25, 2015. Bayfield's traffic department was called to determine if lighter-weight pallets were used on the shipments. (This might explain the lighter net weights.) Bayfield indicated, however, that no changes had been made in loading or palletizing procedures. Thus, Wet-Land engineers randomly checked 50 bags and discovered that the average net weight was 47.51 pounds. They noted from past shipments that the process yielded bag net weights averaging exactly 50.0 pounds, with an acceptable standard deviation σ of 1.2 pounds. Consequently, they concluded that the sample indicated a significant short-weight. (The reader may wish to verify this conclusion.) Bayfield was then contacted, and Wells was sent to investigate the complaint. Upon arrival, Wells verified the complaint and issued a 5% credit to Wet-Land.

Wet-Land management, however, was not completely satisfied with the issuance of credit. The charts followed by their mud engineers on the drilling platforms were based on 50-pound bags of treating agents. Lighter-weight bags might result in poor chemical control during the drilling operation and thus adversely affect drilling efficiency. (Mud-treating agents are used to control the pH and other chemical properties of the core during drilling operation.) This defect could cause severe economic consequences because of the extremely high cost of oil and natural gas well-drilling operations. Consequently, special-use instructions had to accompany the delivery of these shipments to the drilling platforms. Moreover, the short-weight shipments had to be isolated in Wet-Land's warehouse, causing extra handling and poor space utilization. Thus, Wells was informed that Wet-Land might seek a new supplier of mud-treating agents if, in the future, it received bags that deviated significantly from 50 pounds.

The quality control department at Bayfield suspected that the lightweight bags might have resulted from "growing pains" at the Orange plant. Because of the earlier energy crisis, oil and natural gas exploration activity had greatly increased. In turn, this increased activity created increased demand for products produced by related industries, including drilling muds. Consequently, Bayfield had to expand from a one-shift (6:00 A.M. to 2:00 P.M.) to a two-shift (2:00 P.M. to 10:00 P.M.) operation in mid-2010, and finally to a three-shift operation (24 hours per day) in the fall of 2015.

		RANGE				RANGE	
TIME	AVERAGE WEIGHT (POUNDS)	SMALLEST	LARGEST	TIME	AVERAGE WEIGHT (POUNDS)	SMALLEST	LARGEST
6:00 A.M.	49.6	48.7	50.7	6:00 P.M.	46.8	41.0	51.2
7:00	50.2	49.1	51.2	7:00	50.0	46.2	51.7
8:00	50.6	49.6	51.4	8:00	47.4	44.0	48.7
9:00	50.8	50.2	51.8	9:00	47.0	44.2	48.9
10:00	49.9	49.2	52.3	10:00	47.2	46.6	50.2
11:00	50.3	48.6	51.7	11:00	48.6	47.0	50.0
12 noon	48.6	46.2	50.4	12 midnight	49.8	48.2	50.4
1:00 P.M.	49.0	46.4	50.0	1:00 A.M.	49.6	48.4	51.7
2:00	49.0	46.0	50.6	2:00	50.0	49.0	52.2
3:00	49.8	48.2	50.8	3:00	50.0	49.2	50.0
4:00	50.3	49.2	52.7	4:00	47.2	46.3	50.5
5:00	51.4	50.0	55.3	5:00	47.0	44.1	49.7
6:00	51.6	49.2	54.7	6:00	48.4	45.0	49.0
7:00	51.8	50.0	55.6	7:00	48.8	44.8	49.7
8:00	51.0	48.6	53.2	8:00	49.6	48.0	51.8
9:00	50.5	49.4	52.4	9:00	50.0	48.1	52.7
10:00	49.2	46.1	50.7	10:00	51.0	48.1	55.2
11:00	49.0	46.3	50.8	11:00	50.4	49.5	54.1
12 midnight	48.4	45.4	50.2	12 noon	50.0	48.7	50.9
1:00 A.M.	47.6	44.3	49.7	1:00 P.M.	48.9	47.6	51.2
2:00	47.4	44.1	49.6	2:00	49.8	48.4	51.0
3:00	48.2	45.2	49.0	3:00	49.8	48.8	50.8
4:00	48.0	45.5	49.1	4:00	50.0	49.1	50.6
5:00	48.4	47.1	49.6	5:00	47.8	45.2	51.2

(cont'd)

		RANGE				*RANGE*	
TIME	**AVERAGE WEIGHT (POUNDS)**	**SMALLEST**	**LARGEST**	**TIME**	**AVERAGE WEIGHT (POUNDS)**	**SMALLEST**	**LARGEST**
6:00 A.M.	48.6	47.4	52.0	6:00 P.M.	46.4	44.0	49.7
7:00	50.0	49.2	52.2	7:00	46.4	44.4	50.0
8:00	49.8	49.0	52.4	8:00	47.2	46.6	48.9
9:00	50.3	49.4	51.7	9:00	48.4	47.2	49.5
10:00	50.2	49.6	51.8	10:00	49.2	48.1	50.7
11:00	50.0	49.0	52.3	11:00	48.4	47.0	50.8
12 noon	50.0	48.8	52.4	12 midnight	47.2	46.4	49.2
1:00 P.M.	50.1	49.4	53.6	1:00 A.M.	47.4	46.8	49.0
2:00	49.7	48.6	51.0	2:00	48.8	47.2	51.4
3:00	48.4	47.2	51.7	3:00	49.6	49.0	50.6
4:00	47.2	45.3	50.9	4:00	51.0	50.5	51.5
5:00	46.8	44.1	49.0	5:00	50.5	50.0	51.9

The additional night-shift bagging crew was staffed entirely by new employees. The most experienced foremen were temporarily assigned to supervise the night-shift employees. Most emphasis was placed on increasing the output of bags to meet ever-increasing demand. It was suspected that only occasional reminders were made to double-check the bag weight-feeder. (A double-check is performed by systematically weighing a bag on a scale to determine if the proper weight is being loaded by the weight-feeder. If there is significant deviation from 50 pounds, corrective adjustments are made to the weight-release mechanism.)

To verify this expectation, the quality control staff randomly sampled the bag output and prepared the chart on the previous page. Six bags were sampled and weighed each hour.

Discussion Questions

1. What is your analysis of the bag-weight problem?
2. What procedures would you recommend to maintain proper quality control?

Source: Professor Jerry Kinard, Western Carolina University. Reprinted with permission.

Frito-Lay's Quality-Controlled Potato Chips — Video Case

Frito-Lay, the multi-billion-dollar snack food giant, produces billions of pounds of product every year at its dozens of U.S. and Canadian plants. From the farming of potatoes—in Florida, North Carolina, and Michigan—to factory and to retail stores, the ingredients and final product of Lay's chips, for example, are inspected at least 11 times: in the field, before unloading at the plant, after washing and peeling, at the sizing station, at the fryer, after seasoning, when bagged (for weight), at carton filling, in the warehouse, and as they are placed on the store shelf by Frito-Lay personnel. Similar inspections take place for its other famous products, including Cheetos, Fritos, Ruffles, and Tostitos.

In addition to these employee inspections, the firm uses proprietary vision systems to look for defective potato chips. Chips are pulled off the high-speed line and checked twice if the vision system senses them to be too brown.

The company follows the very strict standards of the American Institute of Baking (AIB), standards that are much tougher than those of the U.S. Food and Drug Administration. Two unannounced AIB site visits per year keep Frito-Lay's plants on their toes. Scores, consistently in the "excellent" range, are posted, and every employee knows exactly how the plant is doing.

There are two key metrics in Frito-Lay's continuous improvement quality program: (1) total customer complaints (measured on a complaints per million bag basis) and (2) hourly or daily statistical process control scores (for oil, moisture, seasoning, and salt content, for chip thickness, for fryer temperature, and for weight).

In the Florida plant, Angela McCormack, who holds engineering and MBA degrees, oversees a 15-member quality assurance staff. They watch all aspects of quality, including training employees on the factory floor, monitoring automated processing equipment, and developing and updating statistical process control (SPC) charts. The upper and lower control limits for one checkpoint, salt content in Lay's chips, are 2.22% and 1.98%, respectively. To see exactly how these limits are created using SPC, watch the video that accompanies this case.

Discussion Questions*

1. Angela is now going to evaluate a new salt process delivery system and wants to know if the upper and lower control limits at 3 standard deviations for the new system will meet the upper and lower control specifications noted earlier.

    The data (in percents) from the initial trial samples are:

    Sample 1: 1.98, 2.11, 2.15, 2.06
    Sample 2: 1.99, 2.0, 2.08, 1.99
    Sample 3: 2.20, 2.10. 2.20, 2.05
    Sample 4: 2.18, 2.01, 2.23, 1.98
    Sample 5: 2.01, 2.08, 2.14, 2.16

    Provide the report to Angela.
2. What are the advantages and disadvantages of Frito-Lay drivers stocking their customers' shelves?
3. Why is quality a critical function at Frito-Lay?

*You may wish to view the video that accompanies this case before answering these questions.

Farm to Fork: Quality at Darden Restaurants

Video Case

Darden Restaurants, the \$6.3 billion owner of such popular brands as Olive Garden, Seasons 52, and Bahama Breeze, serves more than 320 million meals annually in its 1,500 restaurants across the U.S. and Canada. Before any one of these meals is placed before a guest, the ingredients for each recipe must pass quality control inspections at the source, ranging from measurement and weighing to tasting, touching, or lab testing. Darden has differentiated itself from its restaurant peers by developing the gold standard in continuous improvement.

To assure both customers and the company that quality expectations are met, Darden uses a rigorous inspection process, employing statistical process control (SPC) as part of its "Farm to Fork" program. More than 50 food scientists, microbiologists, and public health professionals report to Ana Hooper, vice president of quality assurance.

As part of Darden's Point Source program, Hooper's team, based in Southeast Asia (in China, Thailand, and Singapore) and Latin America (in Equador, Honduras, and Chile), approves and inspects—and works with Darden buyers to purchase—more than 50 million pounds of seafood each year for restaurant use. Darden used to build quality in at the end by inspecting shipments as they reached U.S. distribution centers. Now, thanks to coaching and partnering with vendors abroad, Darden needs but a few domestic inspection labs to verify compliance to its exacting standards. Food vendors in source countries know that when supplying Darden, they are subject to regular audits that are stricter than U.S. Food and Drug Administration (FDA) standards.

Two Quality Success Stories

Quality specialists' jobs include raising the bar and improving quality and safety at all plants in their geographic area. The Thai quality representative, for example, worked closely with several of Darden's largest shrimp vendors to convert them to a production-line-integrated quality assurance program. The vendors were able to improve the quality of shrimp supplied and reduce the percentage of defects by 19%.

Likewise, when the Darden quality teams visited fields of growers/shippers in Mexico recently, it identified challenges such as low employee hygiene standards, field food safety problems, lack of portable toilets, child labor, and poor working conditions. Darden addressed these concerns and hired third-party independent food safety verification firms to ensure continued compliance to standards.

SPC Charts

SPC charts, such as the one shown on page 253 in this supplement, are particularly important. These charts document precooked food weights; meat, seafood and poultry temperatures; blemishes on produce; and bacteria counts on shrimp—just to name a few. Quality assurance is part of a much bigger process that is key to Darden's success—its supply chain (see Chapters 2 and 11 for discussion and case studies on this topic). That's because quality comes from the source and flows through distribution to the restaurant and guests.

Discussion Questions*

1. How does Darden build quality into the supply chain?
2. Select two potential problems—one in the Darden supply chain and one in a restaurant—that can be analyzed with a fish-bone chart. Draw a complete chart to deal with each problem.
3. Darden applies SPC in many product attributes. Identify where these are probably used.
4. The SPC chart on page 253 illustrates Darden's use of control charts to monitor the weight of salmon filets. Given these data, what conclusion do you, as a Darden quality control inspector, draw? What report do you issue to your supervisor? How do you respond to the salmon vendor?

*You might want to view the video that accompanies this case before answering these questions.

- **Additional Case Study:** Visit MyOMLab for this free case study:
  Green River Chemical Company: Involves a company that needs to set up a control chart to monitor sulfate content because of customer complaints.

Endnotes

1. Removing assignable causes is work. Quality expert W. Edwards Deming observed that a state of statistical control is not a natural state for a manufacturing process. Deming instead viewed it as an achievement, arrived at by elimination, one by one, by determined effort, of special causes of excessive variation.
2. The standard deviation is easily calculated as

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

. For a good review of this and other statistical terms, refer to Tutorial 1, "Statistical Review for Managers," in MyOMLab.
3. Lower control limits cannot take negative values in control charts. So the LCL = max $(0, \bar{\bar{x}} - z\sigma_{\bar{x}})$.
4. If the sample sizes are not the same, other techniques must be used.
5. A Poisson probability distribution is a discrete distribution commonly used when the items of interest (in this case, defects) are infrequent or occur in time or space.
6. This is because a C_p of 1.0 has 99.73% of outputs within specifications. So 1.00 − .9973 = .0027; with 1,000 parts, there are .0027 = 1,000 = 2.7 defects.
   For a C_p of 2.0, 99.99966% of outputs are "within spec." So 1.00 − .9999966 = .0000034; with 1 million parts, there are 3.4 defects.
7. Refer to Tutorial 2 in MyOMLab for an extended discussion of acceptance sampling.
8. Note that sampling always runs the danger of leading to an erroneous conclusion. Let us say that in one company the total population under scrutiny is a load of 1,000 computer chips, of which in reality only 30 (or 3%) are defective. This means that we would want to accept the shipment of chips, because for this particular firm 4% is the allowable defect rate. However, if a random sample of n = 50 chips was drawn, we could conceivably end up with 0 defects and accept that shipment (that is, it is okay), or we could find all 30 defects in the sample. If the latter happened, we could wrongly conclude that the whole population was 60% defective and reject them all.

Supplement 6 *Rapid* Review

Main Heading | **Review Material** | MyOMLab

STATISTICAL PROCESS CONTROL (SPC)
(pp. 246–260)

- **Statistical process control (SPC)**—A process used to monitor standards by taking measurements and corrective action as a product or service is being produced.
- **Control chart**—A graphical presentation of process data over time.

A process is said to be operating *in statistical control* when the only source of variation is common (natural) causes. The process must first be brought into statistical control by detecting and eliminating special (assignable) causes of variation.
The objective of a process control system is to provide a statistical signal when assignable causes of variation are present.

- **Natural variations**—The variability that affects every production process to some degree and is to be expected; also known as common cause.

When natural variations form a *normal distribution,* they are characterized by two parameters:

- Mean, μ (the measure of central tendency—in this case, the average value)
- Standard deviation, σ (the measure of dispersion)

As long as the distribution (output measurements) remains within specified limits, the process is said to be "in control," and natural variations are tolerated.

- **Assignable variation**—Variation in a production process that can be traced to specific causes.

Control charts for the mean, $\bar{x}$, and the range, R, are used to monitor *variables* (outputs with continuous dimensions), such as weight, speed, length, or strength.

- **$\bar{x}$-chart**—A quality control chart for variables that indicates when changes occur in the central tendency of a production process.
- ***R*-chart**—A control chart that tracks the range within a sample; it indicates that a gain or loss in uniformity has occurred in dispersion of a production process.
- **Central limit theorem**—The theoretical foundation for $\bar{x}$-charts, which states that regardless of the distribution of the population of all parts or services, the $\bar{x}$ distribution will tend to follow a normal curve as the number of samples increases:

$$\bar{\bar{x}} = \mu \qquad \text{(S6-1)}$$

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}} \qquad \text{(S6-2)}$$

The $\bar{x}$-chart limits, if we know the true standard deviation σ of the process population, are:

$$\text{Upper control limit (UCL)} = \bar{\bar{x}} + z\sigma_{\bar{x}} \qquad \text{(S6-3)}$$

$$\text{Lower control limit (LCL)} = \bar{\bar{x}} - z\sigma_{\bar{x}} \qquad \text{(S6-4)}$$

where z = confidence level selected (e.g., $z = 3$ is 99.73% confidence).

The *range*, R, of a sample is defined as the difference between the largest and smallest items. If we do not know the true standard deviation, σ, of the population, the $\bar{x}$-chart limits are:

$$\text{UCL}_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R} \qquad \text{(S6-5)}$$

$$\text{LCL}_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R} \qquad \text{(S6-6)}$$

In addition to being concerned with the process average, operations managers are interested in the process dispersion, or range. The R-chart control limits for the range of a process are:

$$\text{UCL}_R = D_4\bar{R} \qquad \text{(S6-7)}$$

$$\text{LCL}_R = D_3\bar{R} \qquad \text{(S6-8)}$$

Attributes are typically classified as *defective* or *nondefective*. The two attribute charts are (1) p-charts (which measure the *percent* defective in a sample), and (2) c-charts (which *count* the number of defects in a sample).

- ***p*-chart**—A quality control chart that is used to control attributes:

$$\text{UCL}_p = \bar{p} + z\sigma_p \qquad \text{(S6-9)}$$

$$\text{LCL}_p = \bar{p} - z\sigma_p \qquad \text{(S6-10)}$$

$$\hat{\sigma}_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad \text{(S6-11)}$$

- ***c*-chart**—A quality control chart used to control the number of defects per unit of output. The Poisson distribution is the basis for c-charts, whose 99.73% limits are computed as:

$$\text{Control limits} = \bar{c} \pm 3\sqrt{\bar{c}} \qquad \text{(S6-12)}$$

- **Run test**—A test used to examine the points in a control chart to determine whether nonrandom variation is present.

MyOMLab

Concept Questions: 1.1–1.4

Problems: S6.1–S6.39

VIDEO S6.1
Farm to Fork: Quality at Darden Restaurants

Virtual Office Hours for Solved Problems: S6.1–S6.3

ACTIVE MODELS S6.1 and S6.2

VIDEO S6.2
Frito-Lay's Quality-Controlled Potato Chips

Virtual Office Hours for Solved Problem: S6.5

Supplement 6 *Rapid* Review *continued*

Main Heading	Review Material	MyOMLab
PROCESS CAPABILITY (pp. 260–262)	■ **Process capability**—The ability to meet design specifications. ■ **C_p**—A ratio for determining whether a process meets design specifications. $$C_p = \frac{(\text{Upper specification} - \text{Lower specification})}{6\sigma} \quad \text{(S6-13)}$$ ■ **C_{pk}**—A proportion of variation (3σ) between the center of the process and the nearest specification limit: $$C_{pk} = \text{Minimum of}\left[\frac{\text{Upper spec limit} - \overline{X}}{3\sigma}, \frac{\overline{X} - \text{Lower spec limit}}{3\sigma}\right] \quad \text{(S6-14)}$$	Concept Questions: 2.1–2.4 Problems: S6.40-S6.50 Virtual Office Hours for Solved Problems: S6.4 ACTIVE MODEL S6.3
ACCEPTANCE SAMPLING (pp. 262–265)	■ **Acceptance sampling**—A method of measuring random samples of lots or batches of products against predetermined standards. ■ **Operating characteristic (OC) curve**—A graph that describes how well an acceptance plan discriminates between good and bad lots. ■ **Producer's risk**—The mistake of having a producer's good lot rejected through sampling. ■ **Consumer's risk**—The mistake of a customer's acceptance of a bad lot overlooked through sampling. ■ **Acceptable quality level (AQL)**—The quality level of a lot considered good. ■ **Lot tolerance percent defective (LTPD)**—The quality level of a lot considered bad. ■ **Type I error**—Statistically, the probability of rejecting a good lot. ■ **Type II error**—Statistically, the probability of accepting a bad lot. ■ **Average outgoing quality (AOQ)**—The percent defective in an average lot of goods inspected through acceptance sampling: $$\text{AOQ} = \frac{(P_d)(P_a)(N - n)}{N} \quad \text{(S6-15)}$$	Concept Questions: 3.1–3.4 Problems: S6.51–S6.55

Self Test

■ **Before taking the self-test,** refer to the learning objectives listed at the beginning of the supplement and the key terms listed at the end of the supplement.

LO S6.1 If the mean of a particular sample is within control limits and the range of that sample is not within control limits:
- **a)** the process is in control, with only assignable causes of variation.
- **b)** the process is not producing within the established control limits.
- **c)** the process is producing within the established control limits, with only natural causes of variation.
- **d)** the process has both natural and assignable causes of variation.

LO S6.2 The central limit theorem:
- **a)** is the theoretical foundation of the *c*-chart.
- **b)** states that the average of assignable variations is zero.
- **c)** allows managers to use the normal distribution as the basis for building some control charts.
- **d)** states that the average range can be used as a proxy for the standard deviation.
- **e)** controls the steepness of an operating characteristic curve.

LO S6.3 The type of chart used to control the central tendency of variables with continuous dimensions is:
- **a)** $\overline{x}$-chart.
- **b)** *R*-chart.
- **c)** *p*-chart.
- **d)** *c*-chart.
- **e)** none of the above.

LO S6.4 If parts in a sample are measured and the mean of the sample measurement is outside the control limits:
- **a)** the process is out of control, and the cause should be established.
- **b)** the process is in control but not capable of producing within the established control limits.
- **c)** the process is within the established control limits, with only natural causes of variation.
- **d)** all of the above are true.

LO S6.5 Control charts for attributes are:
- **a)** *p*-charts.
- **b)** *c*-charts.
- **c)** *R*-charts.
- **d)** $\overline{x}$-charts.
- **e)** both a and b.

LO S6.6 The ability of a process to meet design specifications is called:
- **a)** Taguchi.
- **b)** process capability.
- **c)** capability index.
- **d)** acceptance sampling.
- **e)** average outgoing quality.

LO S6.7 The _______ risk is the probability that a lot will be rejected despite the quality level exceeding or meeting the _______.

Answers: LO S6.1. b; LO S6.2. c; LO S6.3. a; LO S6.4. a; LO S6.5. e; LO S6.6. b; LO S6.7. producer's, AQL