Managing Quality

CHAPTER 6

CHAPTER OUTLINE

GLOBAL COMPANY PROFILE: *Arnold Palmer Hospital*

- Quality and Strategy *216*
- Defining Quality *217*
- Total Quality Management *219*
- Tools of TQM *226*
- The Role of Inspection *230*
- TQM in Services *233*

Alaska Air lines

Alaska Air lines

10 OM STRATEGY DECISIONS

- Design of Goods and Services
- *Managing Quality*
- Process Strategy
- Location Strategies
- Layout Strategies
- Human Resources
- Supply-Chain Management
- 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.

LEARNING OBJECTIVES

LO 6.1 ***Define*** quality and TQM 217

LO 6.2 ***Describe*** the ISO international quality standards 218

LO 6.3 ***Explain*** Six Sigma 221

LO 6.4 ***Explain*** how benchmarking is used in TQM 223

LO 6.5 ***Explain*** quality robust products and Taguchi concepts 225

LO 6.6 ***Use*** the seven tools of TQM 226

Quality and Strategy

VIDEO 6.1
The Culture of Quality at Arnold Palmer Hospital

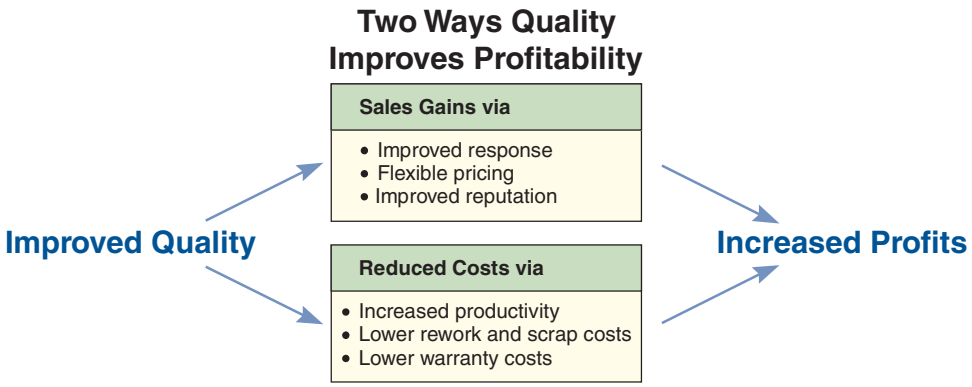
As Arnold Palmer Hospital and many other organizations have found, quality is a wonderful tonic for improving operations. Managing quality helps build successful strategies of *differentiation*, *low cost*, and *response*. For instance, defining customer quality expectations has helped Bose Corp. successfully *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



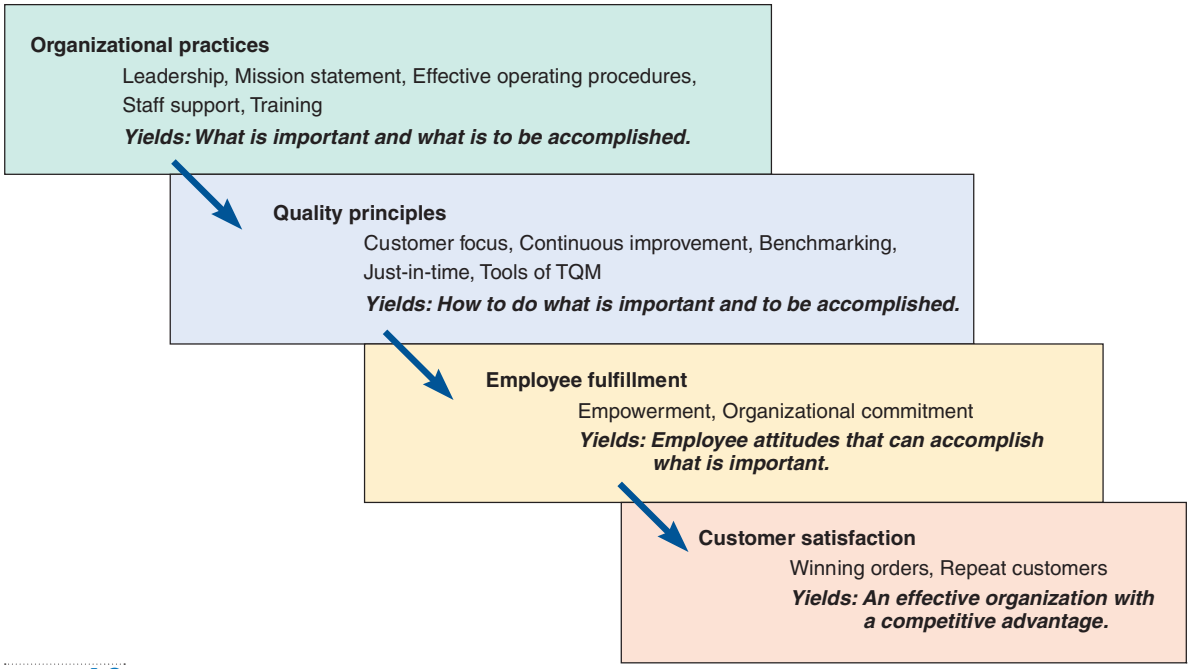


Figure 6.2

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.

LO 6.1 *Define* quality and TQM

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.

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.

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]

巧

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

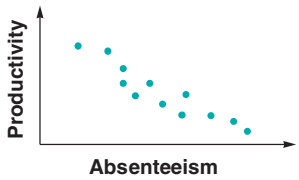
Total quality management (TQM) refers to a quality emphasis that encompasses the entire organization, from supplier to customer. TQM stresses a commitment by management to have a continuing companywide drive toward excellence in all aspects of products and services that are

Tools for Generating Ideas

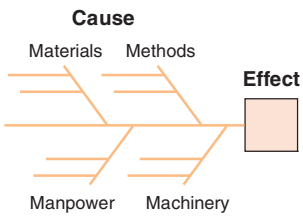
(a) *Check Sheet:* An organized method of recording data

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

(b) *Scatter Diagram:* A graph of the value of one variable vs. another variable

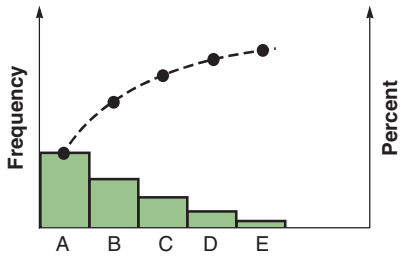


(c) *Cause-and-Effect Diagram:* A tool that identifies process elements (causes) that may affect an outcome

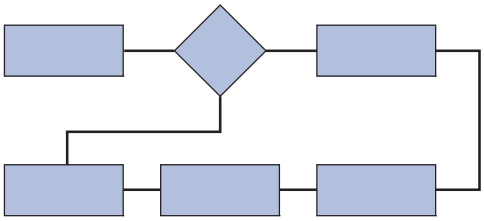


Tools for Organizing the Data

(d) *Pareto Chart:* A graph that identifies and plots problems or defects in descending order of frequency

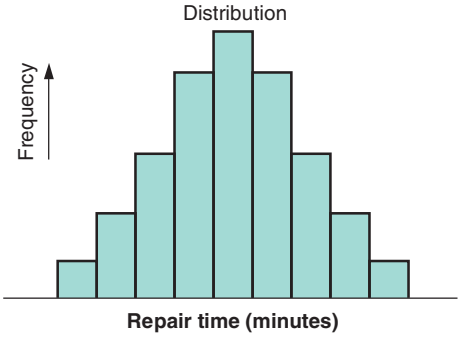


(e) *Flowchart (Process Diagram):* A chart that describes the steps in a process



Tools for Identifying Problems

(f) *Histogram:* A distribution that shows the frequency of occurrences of a variable



(g) *Statistical Process Control Chart:* A chart with time on the horizontal axis for plotting values of a statistic

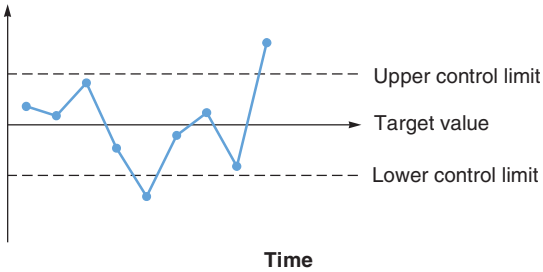


Figure 6.6

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.

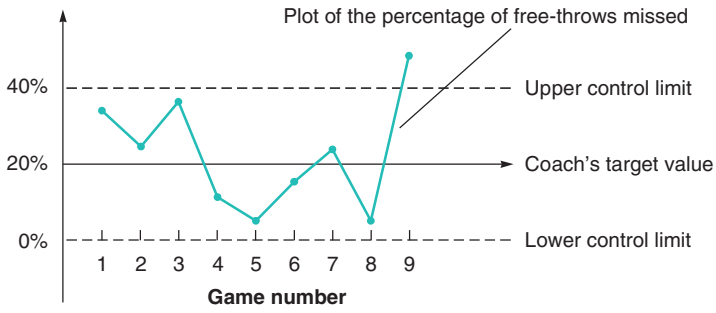
Check Sheets

LO 6.6 *Use* the seven tools of TQM

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 6.8

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.

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.

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.

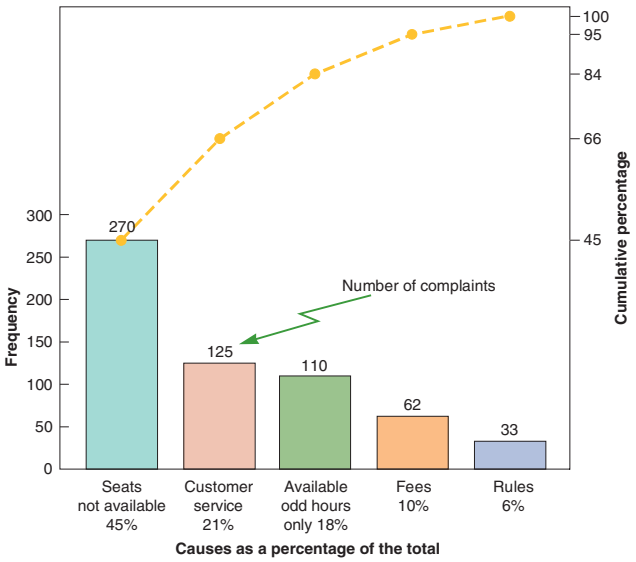
SOLVED PROBLEM 6.1

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 *M*s" 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	✓✓	✓✓✓	✓✓✓	✓	

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

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

6 SUPPLEMENT

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)

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**.

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.[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 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*.

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

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

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

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.

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 ±.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 products against predetermined standards.

LO S6.7 *Explain* acceptance sampling

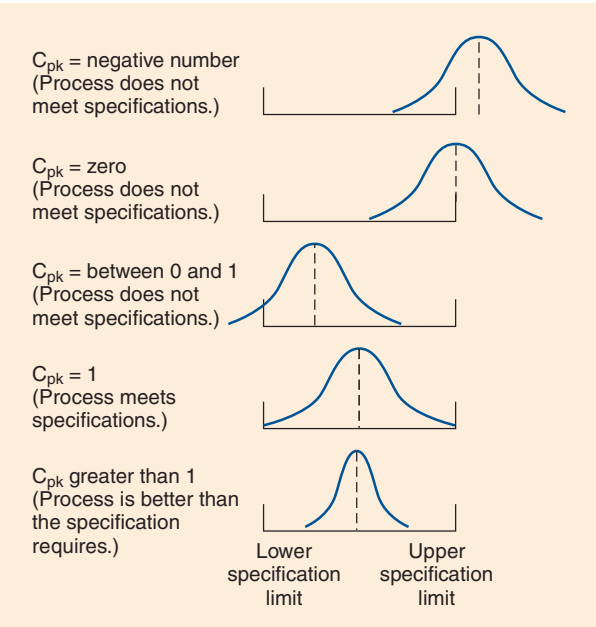
Acceptance sampling is a form of testing that involves taking random samples of "lots," or batches, of finished products and measuring them against predetermined standards. Sampling is more economical than 100% inspection. The quality of the sample is used to judge the quality of all items in the lot. 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.



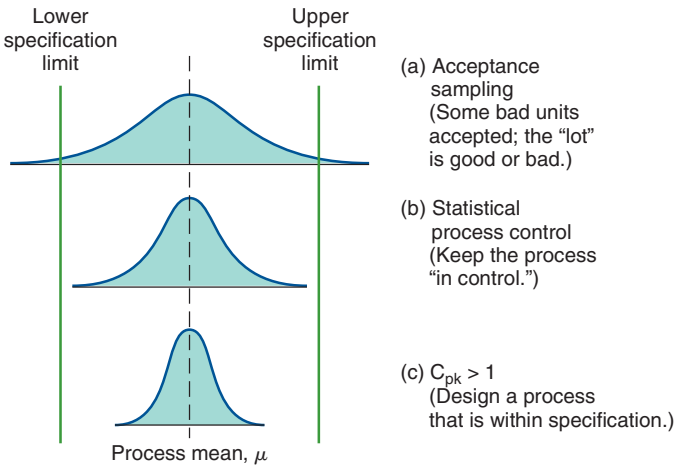


Figure **S6.10**

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?

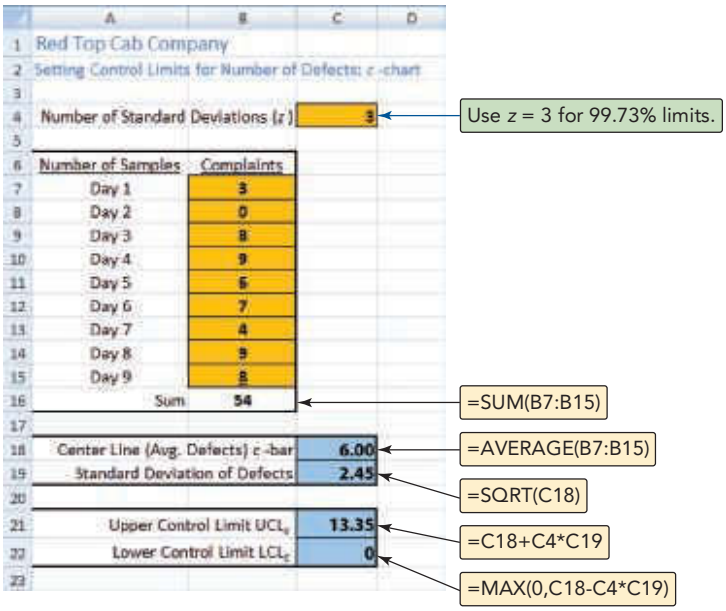
17. What is the purpose of acceptance sampling?
18. What two risks are present when acceptance sampling is used?
19. Is a *capable* process a *perfect* process? That is, does a capable process generate only output that meets specifications? Explain.

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.

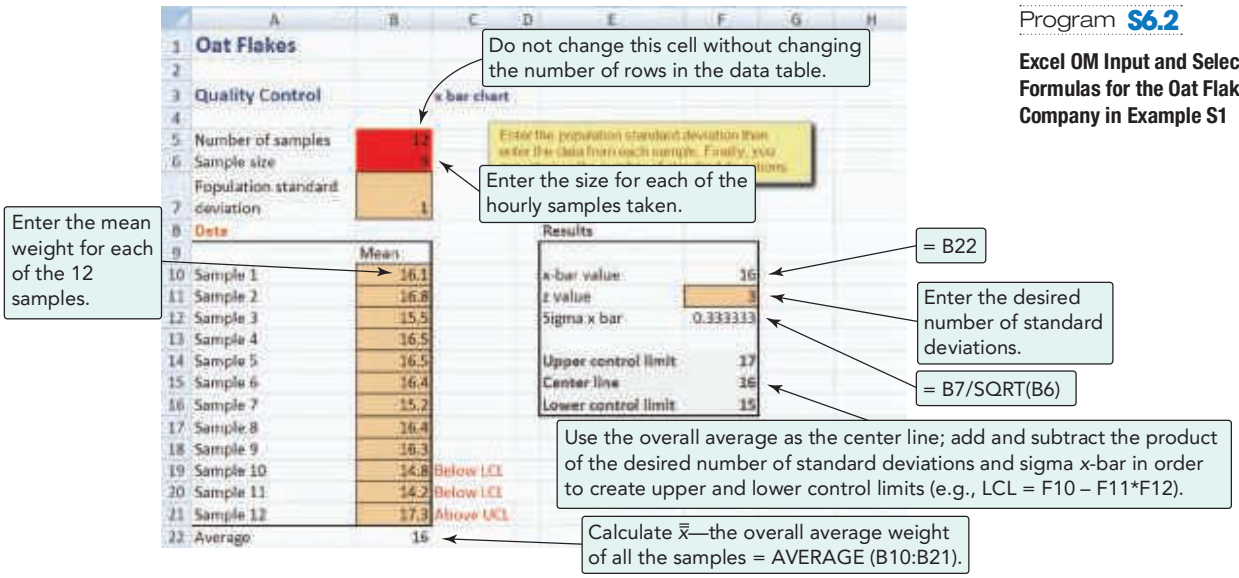


Program **S6.1**

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:

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

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:

$$\text{UCL}_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R} = 4.03 + (.373)(.505) = 4.22$$

$$\text{LCL}_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R} = 4.03 - (.373)(.505) = 3.84$$

$$\text{UCL}_R = D_4\bar{R} = (1.864)(.505) = .94$$

$$\text{LCL}_R = D_3\bar{R} = (.136)(.505) = .07$$

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):

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

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

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)

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 $\sigma = \sqrt{\dfrac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$. 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: $\bar{\bar{x}} = \mu$ (S6-1) $\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$ (S6-2) The $\bar{x}$-chart limits, if we know the true standard deviation σ of the process population, are: Upper control limit (UCL) $= \bar{\bar{x}} + z\sigma_{\bar{x}}$ (S6-3) Lower control limit (LCL) $= \bar{\bar{x}} - z\sigma_{\bar{x}}$ (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: $\text{UCL}_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R}$ (S6-5) $\text{LCL}_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R}$ (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: $\text{UCL}_R = D_4\bar{R}$ (S6-7) $\text{LCL}_R = D_3\bar{R}$ (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: $\text{UCL}_p = \bar{p} + z\sigma_p$ (S6-9) $\text{LCL}_p = \bar{p} - z\sigma_p$ (S6-10) $\hat{\sigma}_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$ (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: Control limits $= \bar{c} \pm 3\sqrt{\bar{c}}$ (S6-12) ■ **Run test**—A test used to examine the points in a control chart to determine whether nonrandom variation is present.	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: $$C_{pk} = \text{Minimum of}\left[\frac{\text{Upper spec limit} - \bar{X}}{3\sigma}, \frac{\bar{X} - \text{Lower spec limit}}{3\sigma}\right] \quad \text{(S6-14)}$$	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) $\bar{x}$-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) $\bar{x}$-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