CHAPTER 6

Statistical Quality Control

Before studying this chapter you should know or, if necessary, review

1. Quality as a competitive priority, Chapter 2, page 00.
2. Total quality management (TQM) concepts, Chapter 5, pages 00–00.

LEARNING OBJECTIVES

After studying this chapter you should be able to

1. Describe categories of statistical quality control (SQC).
2. Explain the use of descriptive statistics in measuring quality characteristics.
3. Identify and describe causes of variation.
4. Describe the use of control charts.
5. Identify the differences between x-bar, R-, p-, and c-charts.
6. Explain the meaning of process capability and the process capability index.
7. Explain the term Six Sigma.
8. Explain the process of acceptance sampling and describe the use of operating characteristic (OC) curves.
9. Describe the challenges inherent in measuring quality in service organizations.

CHAPTER OUTLINE

We have all had the experience of purchasing a product only to discover that it is defective in some way or does not function the way it was designed to. This could be a new backpack with a broken zipper or an "out of the box" malfunctioning computer printer. Many of us have struggled to assemble a product the manufacturer has indicated would need only "minor" assembly, only to find that a piece of the product is missing or defective. As consumers, we expect the products we purchase to function as intended. However, producers of products know that it is not always possible to inspect every product and every aspect of the production process at all times. The challenge is to design ways to maximize the ability to monitor the quality of products being produced and eliminate defects.

One way to ensure a quality product is to build quality into the process. Consider Steinway & Sons, the premier maker of pianos used in concert halls all over the world. Steinway has been making pianos since the 1880s. Since that time the company's manufacturing process has not changed significantly. It takes the company nine months to a year to produce a piano by fashioning some 12,000-hand crafted parts, carefully measuring and monitoring every part of the process. While many of Steinway's competitors have moved to mass production, where pianos can be assembled in 20 days, Steinway has maintained a strategy of quality defined by skill and craftsmanship. Steinway's production process is focused on meticulous process precision and extremely high product consistency. This has contributed to making its name synonymous with top quality.

WHAT IS STATISTICAL QUALITY CONTROL?

Marketing, Management, Engineering

▶ **Statistica1 quality control (SQC)**
The general category of statistical tools used to evaluate organizational quality.

▶ **Descriptive statistics**
Statistics used to describe quality characteristics and relationships.

In Chapter 5 we learned that total quality management (TQM) addresses organizational quality from managerial and philosophical viewpoints. TQM focuses on customer-driven quality standards, managerial leadership, continuous improvement, quality built into product and process design, quality identified problems at the source, and quality made everyone's responsibility. However, talking about solving quality problems is not enough. We need specific tools that can help us make the right quality decisions. These tools come from the area of statistics and are used to help identify quality problems in the production process as well as in the product itself. Statistical quality control is the subject of this chapter.

Statistica1 quality control (SQC) is the term used to describe the set of statistical tools used by quality professionals. Statistical quality control can be divided into three broad categories:

1. **Descriptive statistics** are used to describe quality characteristics and relationships. Included are statistics such as the mean, standard deviation, the range, and a measure of the distribution of data.

2. **Statistical process control (SPC)** involves inspecting a random sample of the output from a process and deciding whether the process is producing products with characteristics that fall within a predetermined range. SPC answers the question of whether the process is functioning properly or not.
3. **Acceptance sampling** is the process of randomly inspecting a sample of goods and deciding whether to accept the entire lot based on the results. Acceptance sampling determines whether a batch of goods should be accepted or rejected.

▶ **Statistical process control (SPC)** A statistical tool that involves inspecting a random sample of the output from a process and deciding whether the process is producing products with characteristics that fall within a predetermined range.

▶ **Acceptance sampling** The process of randomly inspecting a sample of goods and deciding whether to accept the entire lot based on the results.

The tools in each of these categories provide different types of information for use in analyzing quality. Descriptive statistics are used to describe certain quality characteristics, such as the central tendency and variability of observed data. Although descriptions of certain characteristics are helpful, they are not enough to help us evaluate whether there is a problem with quality. Acceptance sampling can help us do this. Acceptance sampling helps us decide whether desirable quality has been achieved for a batch of products, and whether to accept or reject the items produced. Although this information is helpful in making the quality acceptance decision *after* the product has been produced, it does not help us identify and catch a quality problem *during* the production process. For this we need tools in the statistical process control (SPC) category.

All three of these statistical quality control categories are helpful in measuring and evaluating the quality of products or services. However, statistical process control (SPC) tools are used most frequently because they identify quality problems during the production process. For this reason, we will devote most of the chapter to this category of tools. The quality control tools we will be learning about do not only measure the value of a quality characteristic. They also help us identify a *change* or variation in some quality characteristic of the product or process. We will first see what types of variation we can observe when measuring quality. Then we will be able to identify specific tools used for measuring this variation.

LINKS TO PRACTICE

Intel Corporation
www.intel.com

Variation in the production process leads to quality defects and lack of product consistency. The Intel Corporation, the world's largest and most profitable manufacturer of microprocessors, understands this. Therefore, Intel has implemented a program it calls "copy-exactly" at all its manufacturing facilities. The idea is that regardless of whether the chips are made in Arizona, New Mexico, Ireland, or any of its other plants, they are made in exactly the same way. This means using the same equipment, the same exact materials, and workers performing the same tasks in the exact same order. The level of detail to which the "copy-exactly" concept goes is meticulous. For example, when a chipmaking machine was found to be a few feet longer at one facility than another, Intel made them match. When water quality was found to be different at one facility, Intel instituted a purification system to eliminate any differences. Even when a worker was found polishing equipment in one direction, he was asked to do it in the approved circular pattern. Why such attention to exactness of detail? The reason is to minimize all variation. Now let's look at the different types of variation that exist.

SOURCES OF VARIATION: COMMON AND ASSIGNABLE CAUSES

If you look at bottles of a soft drink in a grocery store, you will notice that no two bottles are filled to exactly the same level. Some are filled slightly higher and some slightly lower. Similarly, if you look at blueberry muffins in a bakery, you will notice that some are slightly larger than others and some have more blueberries than others. These types of differences are completely normal. No two products are exactly alike because of slight differences in materials, workers, machines, tools, and other factors. These are called **common, or random, causes of variation.** Common causes of variation are based on random causes that we cannot identify. These types of variation are unavoidable and are due to slight differences in processing.

▶ **Common causes of variation**
Random causes that cannot be identified.

An important task in quality control is to find out the range of natural random variation in a process. For example, if the average bottle of a soft drink called Cocoa Fizz contains 16 ounces of liquid, we may determine that the amount of natural variation is between 15.8 and 16.2 ounces. If this were the case, we would monitor the production process to make sure that the amount stays within this range. If production goes out of this range—bottles are found to contain on average 15.6 ounces—this would lead us to believe that there is a problem with the process because the variation is greater than the natural random variation.

The second type of variation that can be observed involves variations where the causes can be precisely identified and eliminated. These are called **assignable causes of variation.** Examples of this type of variation are poor quality in raw materials, an employee who needs more training, or a machine in need of repair. In each of these examples the problem can be identified and corrected. Also, if the problem is allowed to persist, it will continue to create a problem in the quality of the product. In the example of the soft drink bottling operation, bottles filled with 15.6 ounces of liquid would signal a problem. The machine may need to be readjusted. This would be an assignable cause of variation. We can assign the variation to a particular cause (machine needs to be readjusted) and we can correct the problem (readjust the machine).

▶ **Assignable causes of variation**
Causes that can be identified and eliminated.

DESCRIPTIVE STATISTICS

Descriptive statistics can be helpful in describing certain characteristics of a product and a process. The most important descriptive statistics are measures of central tendency such as the mean, measures of variability such as the standard deviation and range, and measures of the distribution of data. We first review these descriptive statistics and then see how we can measure their changes.

The Mean

In the soft drink bottling example, we stated that the average bottle is filled with 16 ounces of liquid. The arithmetic average, or the **mean,** is a statistic that measures the central tendency of a set of data. Knowing the central point of a set of data is highly important. Just think how important that number is when you receive test scores!

▶ **Mean (average)**
A statistic that measures the central tendency of a set of data.

To compute the mean we simply sum all the observations and divide by the total number of observations. The equation for computing the mean is

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

where $\bar{x}$ = the mean
x_i = observation i, $i = 1, \ldots, n$
n = number of observations

The Range and Standard Deviation

In the bottling example we also stated that the amount of natural variation in the bottling process is between 15.8 and 16.2 ounces. This information provides us with the amount of variability of the data. It tells us how spread out the data is around the mean. There are two measures that can be used to determine the amount of variation in the data. The first measure is the **range,** which is the difference between the largest and smallest observations. In our example, the range for natural variation is 0.4 ounces.

▶ **Range**
The difference between the largest and smallest observations in a set of data.

Another measure of variation is the **standard deviation.** The equation for computing the standard deviation is

▶ **Standard deviation**
A statistic that measures the amount of data dispersion around the mean.

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

where σ = standard deviation of a sample
$\bar{x}$ = the mean
x_i = observation i, $i = 1, \ldots, n$
n = the number of observations in the sample

Small values of the range and standard deviation mean that the observations are closely clustered around the mean. Large values of the range and standard deviation mean that the observations are spread out around the mean. Figure 6-1 illustrates the differences between a small and a large standard deviation for our bottling operation. You can see that the figure shows two distributions, both with a mean of 16 ounces. However, in the first distribution the standard deviation is large and the data are spread out far around the mean. In the second distribution the standard deviation is small and the data are clustered close to the mean.

FIGURE 6-1 Normal distributions with varying standard deviations

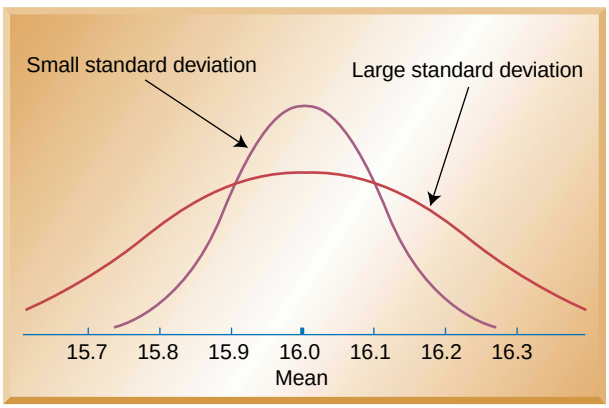
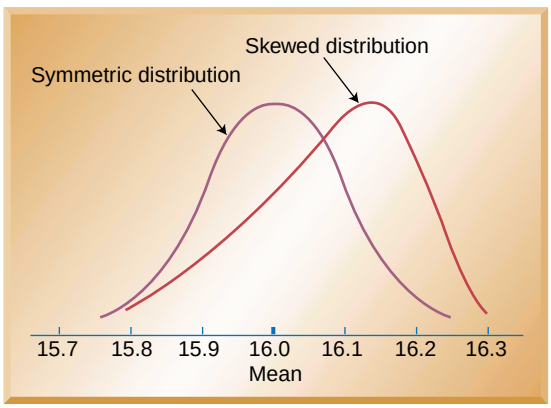


FIGURE 6-2 Differences between symmetric and skewed distributions



Distribution of Data

A third descriptive statistic used to measure quality characteristics is the shape of the distribution of the observed data. When a distribution is symmetric, there are the same number of observations below and above the mean. This is what we commonly find when only normal variation is present in the data. When a disproportionate number of observations are either above or below the mean, we say that the data has a *skewed distribution.* Figure 6-2 shows symmetric and skewed distributions for the bottling operation.

STATISTICAL PROCESS CONTROL METHODS

Statistical process control methods extend the use of descriptive statistics to monitor the quality of the product and process. As we have learned so far, there are common and assignable causes of variation in the production of every product. Using statistical process control we want to determine the amount of variation that is common or normal. Then we monitor the production process to make sure production stays within this normal range. That is, we want to make sure the process is in a *state of control.* The most commonly used tool for monitoring the production process is a control chart. Different types of control charts are used to monitor different aspects of the production process. In this section we will learn how to develop and use control charts.

Developing Control Charts

▶ **Control chart**
A graph that shows whether a sample of data falls within the common or normal range of variation.

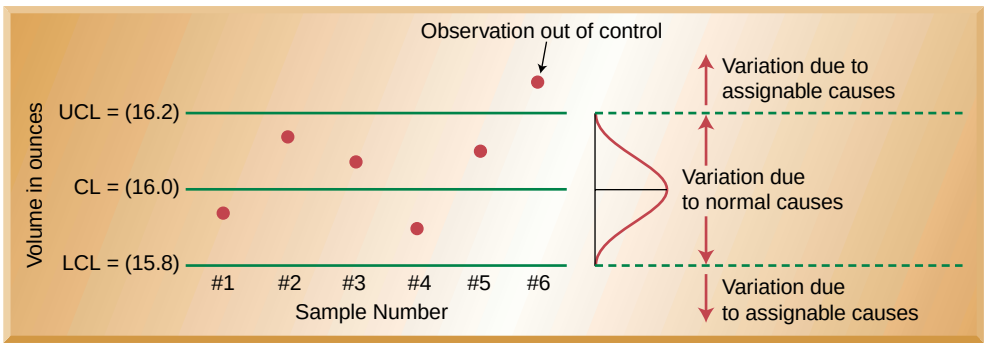
▶ **Out of control**
The situation in which a plot of data falls outside preset control limits.

A **control chart** (also called process chart or quality control chart) is a graph that shows whether a sample of data falls within the common or normal range of variation. A control chart has upper and lower control limits that separate common from assignable causes of variation. The common range of variation is defined by the use of control chart limits. We say that a process is **out of control** when a plot of data reveals that one or more samples fall outside the control limits.

Figure 6-3 shows a control chart for the Cocoa Fizz bottling operation. The *x* axis represents samples (#1, #2, #3, etc.) taken from the process over time. The *y* axis represents the quality characteristic that is being monitored (ounces of liquid). The center line (CL) of the control chart is the mean, or average, of the quality characteristic that is being measured. In Figure 6-3 the mean is 16 ounces. The upper control limit (UCL) is the maximum acceptable variation from the mean for a process that is in a state of control. Similarly, the lower control limit (LCL) is the minimum acceptable variation from the mean for a process that is in a state of control. In our example, the

FIGURE 6-3

Quality control chart for Cocoa Fizz



upper and lower control limits are 16.2 and 15.8 ounces, respectively. You can see that if a sample of observations falls outside the control limits we need to look for assignable causes.

The upper and lower control limits on a control chart are usually set at ±3 standard deviations from the mean. If we assume that the data exhibit a normal distribution, these control limits will capture 99.74 percent of the normal variation. Control limits can be set at ±2 standard deviations from the mean. In that case, control limits would capture 95.44 percent of the values. Figure 6-4 shows the percentage of values that fall within a particular range of standard deviation.

Looking at Figure 6-4, we can conclude that observations that fall outside the set range represent assignable causes of variation. However, there is a small probability that a value that falls outside the limits is still due to normal variation. This is called Type I error, with the error being the chance of concluding that there are assignable causes of variation when only normal variation exists. Another name for this is alpha risk (α), where alpha refers to the sum of the probabilities in both tails of the distribution that falls outside the confidence limits. The chance of this happening is given by the percentage or probability represented by the shaded areas of Figure 6-5. For limits of ±3 standard deviations from the mean, the probability of a Type I error is .26% (100% − 99.74%), whereas for limits of ±2 standard deviations it is 4.56% (100% − 95.44%).

Types of Control Charts

Control charts are one of the most commonly used tools in statistical process control. They can be used to measure any characteristic of a product, such as the weight of a cereal box, the number of chocolates in a box, or the volume of bottled water. The different characteristics that can be measured by control charts can be divided into two groups: **variables** and **attributes.** A *control chart for variables* is used to monitor characteristics that can be measured and have a continuum of values, such as height, weight, or volume. A soft drink bottling operation is an example of a variable measure, since the amount of liquid in the bottles is measured and can take on a number of different values. Other examples are the weight of a bag of sugar, the temperature of a baking oven, or the diameter of plastic tubing.

▶ **Variable**
A product characteristic that can be measured and has a continuum of values (e.g., height, weight, or volume).

▶ **Attribute**
A product characteristic that has a discrete value and can be counted.

FIGURE 6-4 Percentage of values captured by different ranges of standard deviation

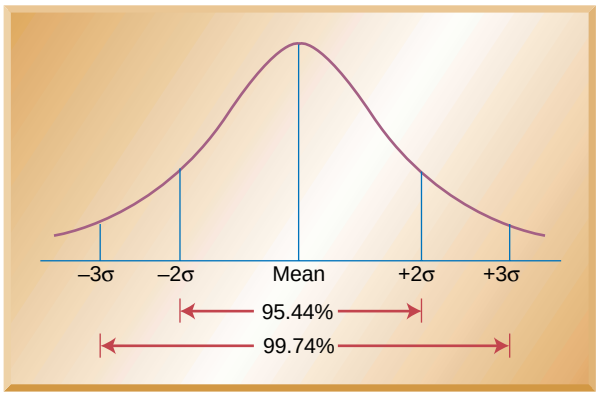
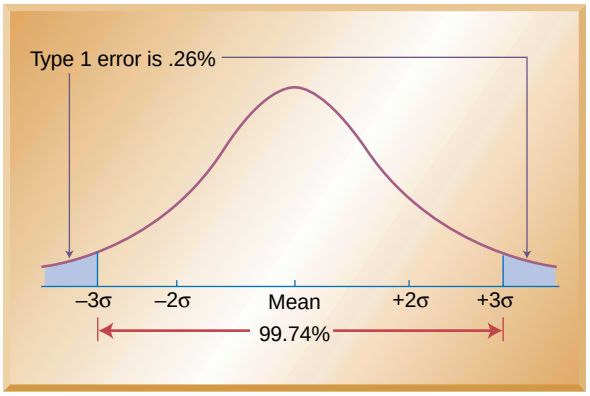


FIGURE 6-5 Chance of Type I error for ±3σ (sigma-standard deviations)



A *control chart for attributes*, on the other hand, is used to monitor characteristics that have discrete values and can be counted. Often they can be evaluated with a simple yes or no decision. Examples include color, taste, or smell. The monitoring of attributes usually takes less time than that of variables because a variable needs to be measured (e.g., the bottle of soft drink contains 15.9 ounces of liquid). An attribute requires only a single decision, such as yes or no, good or bad, acceptable or unacceptable (e.g., the apple is good or rotten, the meat is good or stale, the shoes have a defect or do not have a defect, the lightbulb works or it does not work) or counting the number of defects (e.g., the number of broken cookies in the box, the number of dents in the car, the number of barnacles on the bottom of a boat).

Statistical process control is used to monitor many different types of variables and attributes. In the next two sections we look at how to develop control charts for variables and control charts for attributes.

CONTROL CHARTS FOR VARIABLES

Control charts for variables monitor characteristics that can be measured and have a continuous scale, such as height, weight, volume, or width. When an item is inspected, the variable being monitored is measured and recorded. For example, if we were producing candles, height might be an important variable. We could take samples of candles and measure their heights. Two of the most commonly used control charts for variables monitor both the central tendency of the data (the mean) and the variability of the data (either the standard deviation or the range). Note that each chart monitors a different type of information. When observed values go outside the control limits, the process is assumed not to be in control. Production is stopped, and employees attempt to identify the cause of the problem and correct it. Next we look at how these charts are developed.

Mean (x-Bar) Charts

x-bar chart
A control chart used to monitor changes in the mean value of a process.

A mean control chart is often referred to as an ***x-bar chart.*** It is used to monitor changes in the mean of a process. To construct a mean chart we first need to construct the center line of the chart. To do this we take multiple samples and compute their means. Usually these samples are small, with about four or five observations. Each sample has its own mean, $\bar{x}$. The center line of the chart is then computed as the mean of all $\mathcal{K}$ sample means, where $\mathcal{K}$ is the number of samples:

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \cdots \bar{x}_{\mathcal{K}}}{\mathcal{K}}$$

To construct the upper and lower control limits of the chart, we use the following formulas:

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

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

where $\bar{\bar{x}}$ = the average of the sample means
z = standard normal variable (2 for 95.44% confidence, 3 for 99.74% confidence)
$\sigma_{\bar{x}}$ = standard deviation of the distribution of sample means, computed as $\sigma/\sqrt{n}$
σ = population (process) standard deviation
n = sample size (number of observations per sample)

Example 6.1 shows the construction of a mean (x-bar) chart.

EXAMPLE 6.1

Constructing a Mean (x-Bar) Chart

A quality control inspector at the Cocoa Fizz soft drink company has taken twenty-five samples with four observations each of the volume of bottles filled. The data and the computed means are shown in the table. If the standard deviation of the bottling operation is 0.14 ounces, use this information to develop control limits of three standard deviations for the bottling operation.

Sample Number	Observations (bottle volume in ounces) 1	2	3	4	Average $\bar{x}$	Range R
1	15.85	16.02	15.83	15.93	15.91	0.19
2	16.12	16.00	15.85	16.01	15.99	0.27
3	16.00	15.91	15.94	15.83	15.92	0.17
4	16.20	15.85	15.74	15.93	15.93	0.46
5	15.74	15.86	16.21	16.10	15.98	0.47
6	15.94	16.01	16.14	16.03	16.03	0.20
7	15.75	16.21	16.01	15.86	15.96	0.46
8	15.82	15.94	16.02	15.94	15.93	0.20
9	16.04	15.98	15.83	15.98	15.96	0.21
10	15.64	15.86	15.94	15.89	15.83	0.30
11	16.11	16.00	16.01	15.82	15.99	0.29
12	15.72	15.85	16.12	16.15	15.96	0.43
13	15.85	15.76	15.74	15.98	15.83	0.24
14	15.73	15.84	15.96	16.10	15.91	0.37
15	16.20	16.01	16.10	15.89	16.05	0.31
16	16.12	16.08	15.83	15.94	15.99	0.29
17	16.01	15.93	15.81	15.68	15.86	0.33
18	15.78	16.04	16.11	16.12	16.01	0.34
19	15.84	15.92	16.05	16.12	15.98	0.28
20	15.92	16.09	16.12	15.93	16.02	0.20
21	16.11	16.02	16.00	15.88	16.00	0.23
22	15.98	15.82	15.89	15.89	15.90	0.16
23	16.05	15.73	15.73	15.93	15.86	0.32
24	16.01	16.01	15.89	15.86	15.94	0.15
25	16.08	15.78	15.92	15.98	15.94	0.30
Total					398.75	7.17

• Solution

The center line of the control data is the average of the samples:

$$\bar{\bar{x}} = \frac{398.75}{25}$$

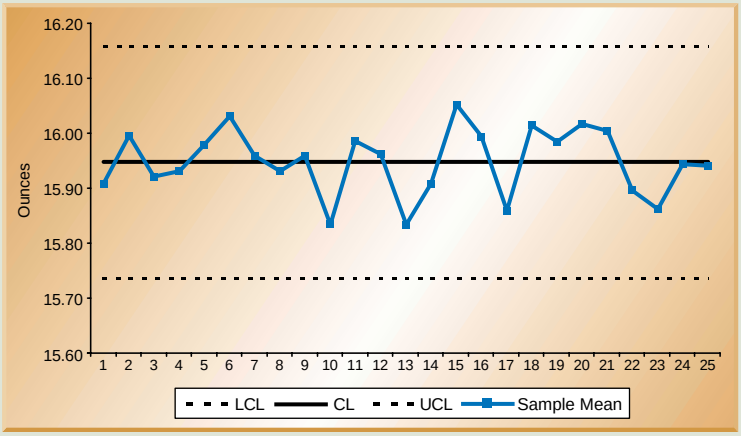
$$\bar{\bar{x}} = 15.95$$

The control limits are

$$\text{UCL} = \bar{\bar{x}} + z\sigma_{\bar{x}} = 15.95 + 3\left(\frac{.14}{\sqrt{4}}\right) = 16.16$$

$$\text{LCL} = \bar{\bar{x}} - z\sigma_{\bar{x}} = 15.95 - 3\left(\frac{.14}{\sqrt{4}}\right) = 15.74$$

The resulting control chart is:



This can also be computed using a spreadsheet as shown.

	A	B	C	D	E	F	G
1							
2	**X-Bar Chart: Cocoa Fizz**						
3							
4							
5		**Bottle Volume in Ounces**					
6	Sample Num	Obs 1	Obs 2	Obs 3	Obs 4	Average	Range
7	1	15.85	16.02	15.83	15.93	15.91	0.19
8	2	16.12	16.00	15.85	16.01	16.00	0.27
9	3	16.00	15.91	15.94	15.83	15.92	0.17
10	4	16.20	15.85	15.74	15.93	15.93	0.46
11	5	15.74	15.86	16.21	16.10	15.98	0.47
12	6	15.94	16.01	16.14	16.03	16.03	0.20
13	7	15.75	16.21	16.01	15.86	15.96	0.46
14	8	15.82	15.94	16.02	15.94	15.93	0.20
15	9	16.04	15.98	15.83	15.98	15.96	0.21
16	10	15.64	15.86	15.94	15.89	15.83	0.30
17	11	16.11	16.00	16.01	15.82	15.99	0.29
18	12	15.72	15.85	16.12	16.15	15.96	0.43
19	13	15.85	15.76	15.74	15.98	15.83	0.24
20	14	15.73	15.84	15.96	16.10	15.91	0.37
21	15	16.20	16.01	16.10	15.89	16.05	0.31
22	16	16.12	16.08	15.83	15.94	15.99	0.29
23	17	16.01	15.93	15.81	15.68	15.86	0.33
24	18	15.78	16.04	16.11	16.12	16.01	0.34
25	19	15.84	15.92	16.05	16.12	15.98	0.28
26	20	15.92	16.09	16.12	15.93	16.02	0.20
27	21	16.11	16.02	16.00	15.88	16.00	0.23
28	22	15.98	15.82	15.89	15.89	15.90	0.16
29	23	16.05	15.73	15.73	15.93	15.86	0.32
30	24	16.01	16.01	15.89	15.86	15.94	0.15
31	25	16.08	15.78	15.92	15.98	15.94	0.30
32						15.95	0.29
33		Number of Samples		25		Xbar-bar	R-bar
34	Number of Observations per Sample			4			
35							
36							

F7: =AVERAGE(B7:E7)

G7: =MAX(B7:E7)-MIN(B7:E7)

F32: =AVERAGE(F7:F31)

G32: =AVERAGE(G7:G31)

	A	B	C	D	E	F	G
39	**Computations for X-Bar Chart**						
40		Overall Mean (Xbar-bar) =		15.95			
41			Sigma for Process =	0.14	ounces		
42		Standard Error of the Mean =		0.07			
43		Z-value for control charts =		3			
44							
45		CL: Center Line =		**15.95**			
46		LCL: Lower Control Limit =		**15.74**			
47		UCL: Upper Control Limit =		**16.16**			

D40: =F32
D42: =D41/SQRT(D34)
D45: =D40
D46: =D40-D43*D42
D47: =D40+D43*D42

Another way to construct the control limits is to use the sample range as an estimate of the variability of the process. Remember that the range is simply the difference between the largest and smallest values in the sample. The spread of the range can tell us about the variability of the data. In this case control limits would be constructed as follows:

$$\text{Upper control limit (UCL)} = \bar{\bar{x}} + A_2\bar{R}$$

$$\text{Lower control limit (LCL)} = \bar{\bar{x}} - A_2\bar{R}$$

where $\bar{\bar{x}}$ = average of the sample means
$\bar{R}$ = average range of the samples
A_2 = factor obtained from Table 6-1.

Notice that A_2 is a factor that includes three standard deviations of ranges and is dependent on the sample size being considered.

EXAMPLE 6.2

Constructing a Mean (x-Bar) Chart from the Sample Range

A quality control inspector at Cocoa Fizz is using the data from Example 6.1 to develop control limits. If the average range ($\bar{R}$) for the twenty-five samples is .29 ounces (computed as $\frac{7.17}{25}$) and the average mean ($\bar{\bar{x}}$) of the observations is 15.95 ounces, develop three-sigma control limits for the bottling operation.

• Solution

$$\bar{\bar{x}} = 15.95 \text{ ounces} \qquad \bar{R} = .29$$

The value of A_2 is obtained from Table 6.1. For $n = 4$, $A_2 = .73$. This leads to the following limits:

$$\text{The center of the control chart} = \text{CL} = 15.95 \text{ ounces}$$

$$\text{UCL} = \bar{\bar{x}} + A_2\bar{R} = 15.95 + (.73)(.29) = 16.16$$

$$\text{LCL} = \bar{\bar{x}} - A_2\bar{R} = 15.95 - (.73)(.29) = 15.74$$

TABLE 6-1

Factors for three-sigma control limits of $\bar{x}$ and R-charts

Source: Factors adapted from the *ASTM Manual on Quality Control of Materials.*

Sample Size n	Factor for $\bar{x}$-Chart	Factors for R-Chart	
	A_2	D_3	D_4
2	1.88	0	3.27
3	1.02	0	2.57
4	0.73	0	2.28
5	0.58	0	2.11
6	0.48	0	2.00
7	0.42	0.08	1.92
8	0.37	0.14	1.86
9	0.34	0.18	1.82
10	0.31	0.22	1.78
11	0.29	0.26	1.74
12	0.27	0.28	1.72
13	0.25	0.31	1.69
14	0.24	0.33	1.67
15	0.22	0.35	1.65
16	0.21	0.36	1.64
17	0.20	0.38	1.62
18	0.19	0.39	1.61
19	0.19	0.40	1.60
20	0.18	0.41	1.59
21	0.17	0.43	1.58
22	0.17	0.43	1.57
23	0.16	0.44	1.56
24	0.16	0.45	1.55
25	0.15	0.46	1.54

Range (R) Charts

▶ **Range (R) chart**
A control chart that monitors changes in the dispersion or variability of process.

Range (R) charts are another type of control chart for variables. Whereas x-bar charts measure shift in the central tendency of the process, range charts monitor the dispersion or variability of the process. The method for developing and using R-charts is the same as that for x-bar charts. The center line of the control chart is the average range, and the upper and lower control limits are computed as follows:

$$\text{CL} = \bar{R}$$
$$\text{UCL} = D_4\,\bar{R}$$
$$\text{LCL} = D_3\,\bar{R}$$

where values for D_4 and D_3 are obtained from Table 6-1.

EXAMPLE 6.3

Constructing a Range (R) Chart

The quality control inspector at Cocoa Fizz would like to develop a range (R) chart in order to monitor volume dispersion in the bottling process. Use the data from Example 6.1 to develop control limits for the sample range.

• Solution

From the data in Example 6.1 you can see that the average sample range is:

$$\overline{R} = \frac{7.17}{25}$$

$$\overline{R} = 0.29$$

$$n = 4$$

From Table 6-1 for $n = 4$:

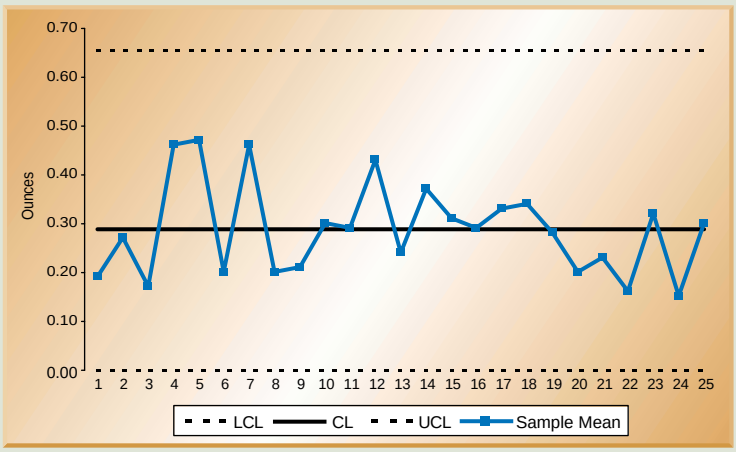
$$D_4 = 2.28$$

$$D_3 = 0$$

$$\text{UCL} = D_4 \overline{R} = 2.28\ (0.29) = 0.6612$$

$$\text{LCL} = D_3 \overline{R} = 0\ (0.29) = 0$$

The resulting control chart is:

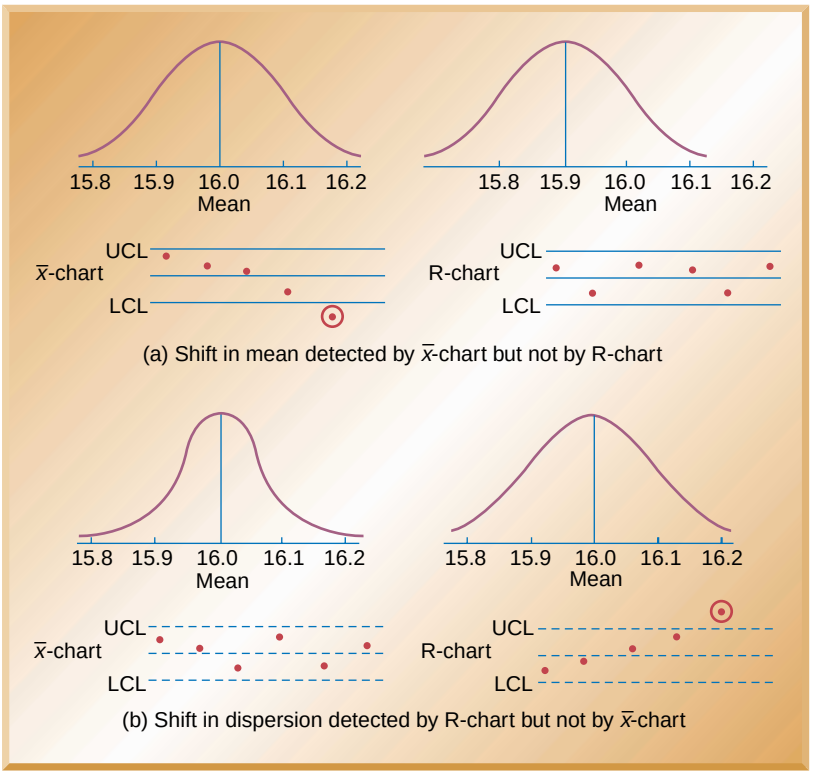


Using Mean and Range Charts Together

You can see that mean and range charts are used to monitor different variables. The mean or x-bar chart measures the central tendency of the process, whereas the range chart measures the dispersion or variance of the process. Since both variables are important, it makes sense to monitor a process using both mean and

FIGURE 6-6

Process shifts captured by $\bar{x}$-charts and R-charts



range charts. It is possible to have a shift in the mean of the product but not a change in the dispersion. For example, at the Cocoa Fizz bottling plant the machine setting can shift so that the average bottle filled contains not 16.0 ounces, but 15.9 ounces of liquid. The dispersion could be the same, and this shift would be detected by an x-bar chart but not by a range chart. This is shown in part (a) of Figure 6-6. On the other hand, there could be a shift in the dispersion of the product without a change in the mean. Cocoa Fizz may still be producing bottles with an average fill of 16.0 ounces. However, the dispersion of the product may have increased, as shown in part (b) of Figure 6-6. This condition would be detected by a range chart but not by an x-bar chart. Because a shift in either the mean or the range means that the process is out of control, it is important to use both charts to monitor the process.

CONTROL CHARTS FOR ATTRIBUTES

Control charts for attributes are used to measure quality characteristics that are counted rather than measured. Attributes are discrete in nature and entail simple yes-or-no decisions. For example, this could be the number of nonfunctioning lightbulbs, the proportion of broken eggs in a carton, the number of rotten apples, the number of scratches on a tile, or the number of complaints issued. Two

of the most common types of control charts for attributes are p-charts and c-charts.

P-charts are used to measure the proportion of items in a sample that are defective. Examples are the proportion of broken cookies in a batch and the proportion of cars produced with a misaligned fender. P-charts are appropriate when both the number of defectives measured and the size of the total sample can be counted. A proportion can then be computed and used as the statistic of measurement.

C-charts count the actual number of defects. For example, we can count the number of complaints from customers in a month, the number of bacteria on a petri dish, or the number of barnacles on the bottom of a boat. However, we *cannot* compute the proportion of complaints from customers, the proportion of bacteria on a petri dish, or the proportion of barnacles on the bottom of a boat.

Problem-Solving Tip: The primary difference between using a p-chart and a c-chart is as follows. A p-chart is used when both the total sample size and the number of defects can be computed. A c-chart is used when we can compute *only* the number of defects but cannot compute the proportion that is defective.

P-Charts

P-charts are used to measure the proportion that is defective in a sample. The computation of the center line as well as the upper and lower control limits is similar to the computation for the other kinds of control charts. The center line is computed as the average proportion defective in the population, $\bar{p}$. This is obtained by taking a number of samples of observations at random and computing the average value of p across all samples.

▶ **P-chart**
A control chart that monitors the *proportion* of defects in a sample.

To construct the upper and lower control limits for a p-chart, we use the following formulas:

$$\text{UCL} = \bar{p} + z\sigma_p$$
$$\text{LCL} = \bar{p} - z\sigma_p$$

where z = standard normal variable
$\bar{p}$ = the sample proportion defective
σ_p = the standard deviation of the average proportion defective

As with the other charts, z is selected to be either 2 or 3 standard deviations, depending on the amount of data we wish to capture in our control limits. Usually, however, they are set at 3.

The sample standard deviation is computed as follows:

$$\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

where n is the sample size.

EXAMPLE 6.4

Constructing a p-Chart

A production manager at a tire manufacturing plant has inspected the number of defective tires in twenty random samples with twenty observations each. Following are the number of defective tires found in each sample:

Sample Number	Number of Defective Tires	Number of Observations Sampled	Fraction Defective
1	3	20	.15
2	2	20	.10
3	1	20	.05
4	2	20	.10
5	1	20	.05
6	3	20	.15
7	3	20	.15
8	2	20	.10
9	1	20	.05
10	2	20	.10
11	3	20	.15
12	2	20	.10
13	2	20	.10
14	1	20	.05
15	1	20	.05
16	2	20	.10
17	4	20	.20
18	3	20	.15
19	1	20	.05
20	1	20	.05
Total	40	400	

Construct a three-sigma control chart ($z = 3$) with this information.

• Solution

The center line of the chart is

$$\text{CL} = \bar{p} = \frac{\text{total number of defective tires}}{\text{total number of observations}} = \frac{40}{400} = .10$$

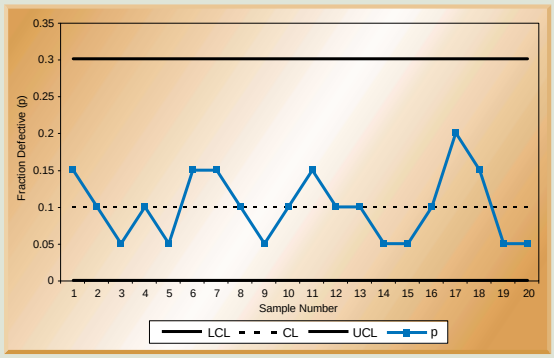
$$\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = \sqrt{\frac{(.10)(.90)}{20}} = .067$$

$$\text{UCL} = \bar{p} + z(\sigma_p) = .10 + 3(.067) = .301$$

$$\text{LCL} = \bar{p} - z(\sigma_p) = .10 - 3(.067) = -.101 \longrightarrow 0$$

In this example the lower control limit is negative, which sometimes occurs because the computation is an approximation of the binomial distribution. When this occurs, the LCL is rounded up to zero because we cannot have a negative control limit.

The resulting control chart is as follows:



This can also be computed using a spreadsheet as shown below.

	A	B	C	D
1				
2	**Constructing a p-Chart**			
3				
4	Size of Each Sample		20	
5	Number Samples		20	
6				
7	**Sample #**	**# Defective Tires**	**Fraction Defective**	C8: =B8/C$4
8	1	3	0.15	
9	2	2	0.10	
10	3	1	0.05	
11	4	2	0.10	
12	5	1	0.05	
13	6	3	0.15	
14	7	3	0.15	
15	8	2	0.10	
16	9	1	0.05	
17	10	2	0.10	
18	11	3	0.15	
19	12	2	0.10	
20	13	2	0.10	
21	14	1	0.05	
22	15	1	0.05	
23	16	2	0.10	
24	17	4	0.20	
25	18	3	0.15	
26	19	1	0.05	
27	20	1	0.05	

	A	B	C	D	E	F
29	**Computations for p-Chart**			C29: =SUM(B8:B27)/(C4*C5)		
30		p bar =	0.100	C30: =SQRT((C29*(1-C29))/C4)		
31		Sigma_p =	0.067			
32	Z-value for control charts =		3			
33						
34	CL: Center Line =		**0.100**	C33: =C29		
35	LCL: Lower Control Limit =		**0.000**	C34: =MAX(C$29-C$31*C$30,0)		
36	UCL: Upper Control Limit =		**0.301**	C35: =C$29+C$31*C$30		

C-CHARTS

C-chart
A control chart used to monitor the *number* of defects per unit.

C-charts are used to monitor the number of defects per unit. Examples are the number of returned meals in a restaurant, the number of trucks that exceed their weight limit in a month, the number of discolorations on a square foot of carpet, and the number of bacteria in a milliliter of water. Note that the types of units of measurement we are considering are a period of time, a surface area, or a volume of liquid.

The average number of defects, $\bar{c}$, is the center line of the control chart. The upper and lower control limits are computed as follows:

$$\text{UCL} = \bar{c} + z\sqrt{\bar{c}}$$
$$\text{LCL} = \bar{c} - z\sqrt{\bar{c}}$$

EXAMPLE 6.5

Computing a C-Chart

The number of weekly customer complaints are monitored at a large hotel using a c-chart. Complaints have been recorded over the past twenty weeks. Develop three-sigma control limits using the following data:

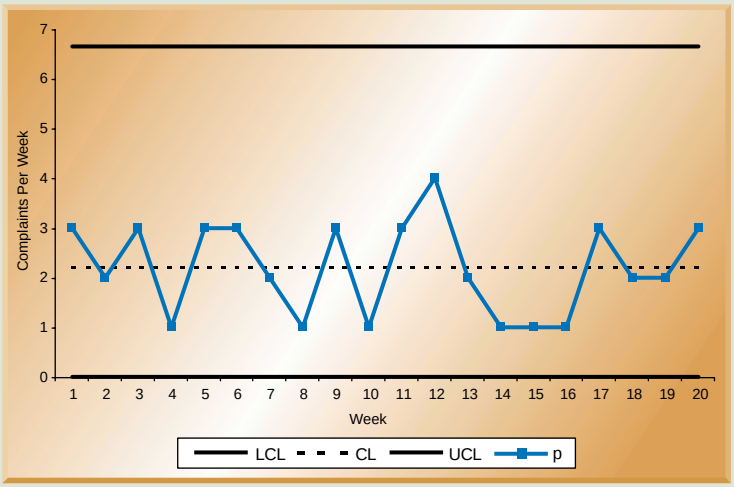
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Tota
No. of Complaints	3	2	3	1	3	3	2	1	3	1	3	4	2	1	1	1	3	2	2	3	**44**

• Solution

The average number of complaints per week is $\frac{44}{20} = 2.2$. Therefore, $\bar{c} = 2.2$.

$$\text{UCL} = \bar{c} + z\sqrt{\bar{c}} = 2.2 + 3\sqrt{2.2} = 6.65$$
$$\text{LCL} = \bar{c} - z\sqrt{\bar{c}} = 2.2 - 3\sqrt{2.2} = -2.25 \longrightarrow 0$$

As in the previous example, the LCL is negative and should be rounded up to zero. Following is the control chart for this example:



This can also be computed using a spreadsheet as shown below.

	A	B
1		
2	**Computing a C-Chart**	
3		
4	**Week**	**Number of Complaints**
5	1	3
6	2	2
7	3	3
8	4	1
9	5	3
10	6	3
11	7	2
12	8	1
13	9	3
14	10	1
15	11	3
16	12	4
17	13	2
18	14	1
19	15	1
20	16	1
21	17	3
22	18	2
23	19	2
24	20	3

	A	B	C	D	E	F	G
26	**Computations for a C-Chart**			C27: =AVERAGE(B5:B24)			
27		c bar =	2.2				
28	Z-value for control charts =		3	C30: =SQRT(C27)			
29							
30		Sigma_c =	1.4832397	C31: =C26			
31				C32: =MAX(C$26-C$27*C$29,0)			
32		CL: Center Line =	**2.20**	C33: =C$26+C$27*C$29			
33	LCL: Lower Control Limit =		**0.00**				
34	UCL: Upper Control Limit =		**6.65**				

Before You Go On

We have discussed several types of statistical quality control (SQC) techniques. One category of SQC techniques consists of descriptive statistics tools such as the mean, range, and standard deviation. These tools are used to describe quality characteristics and relationships. Another category of SQC techniques consists of statistical process control (SPC) methods that are used to monitor changes in the production process. To understand SPC methods you must understand the differences between common and assignable causes of variation. Common

causes of variation are based on random causes that cannot be identified. A certain amount of common or normal variation occurs in every process due to differences in materials, workers, machines, and other factors. Assignable causes of variation, on the other hand, are variations that can be identified and eliminated. An important part of statistical process control (SPC) is monitoring the production process to make sure that the only variations in the process are those due to common or normal causes. Under these conditions we say that a production process is in a *state of control.*

You should also understand the different types of quality control charts that are used to monitor the production process: x-bar charts, R-range charts, p-charts, and c-charts.

PROCESS CAPABILITY

Process capability
The ability of a production process to meet or exceed preset specifications.

Product specifications
Preset ranges of acceptable quality characteristics.

So far we have discussed ways of monitoring the production process to ensure that it is in a *state of control* and that there are no assignable causes of variation. A critical aspect of statistical quality control is evaluating the ability of a production process to meet or exceed preset specifications. This is called **process capability.** To understand exactly what this means, let's look more closely at the term *specification.* **Product specifications,** often called *tolerances,* are preset ranges of acceptable quality characteristics, such as product dimensions. For a product to be considered acceptable, its characteristics must fall within this preset range. Otherwise, the product is not acceptable. Product specifications, or tolerance limits, are usually established by design engineers or product design specialists.

For example, the specifications for the width of a machine part may be specified as 15 inches $\pm .3$. This means that the width of the part should be 15 inches, though it is acceptable if it falls within the limits of 14.7 inches and 15.3 inches. Similarly, for Cocoa Fizz, the average bottle fill may be 16 ounces with tolerances of $\pm .2$ ounces. Although the bottles should be filled with 16 ounces of liquid, the amount can be as low as 15.8 or as high as 16.2 ounces.

Specifications for a product are preset on the basis of how the product is going to be used or what customer expectations are. As we have learned, any production process has a certain amount of natural variation associated with it. To be capable of producing an acceptable product, the process variation cannot exceed the preset specifications. Process capability thus involves evaluating process variability relative to preset product specifications in order to determine whether the process is capable of producing an acceptable product. In this section we will learn how to measure process capability.

Measuring Process Capability

Simply setting up control charts to monitor whether a process is in control does not guarantee process capability. To produce an acceptable product, the process must be *capable* and *in control* before production begins. Let's look at three examples of process variation relative to design specifications for the Cocoa Fizz soft drink company. Let's say that the specification for the acceptable volume of liquid is preset at 16 ounces $\pm .2$ ounces, which is 15.8 and 16.2 ounces. In part (a) of Figure 6-7 the process produces 99.74 percent (three sigma) of the product with volumes between 15.8 and 16.2 ounces. You can see that the process variability closely matches the preset specifications. Almost all the output falls within the preset specification range.

In part (b) of Figure 6-7, however, the process produces 99.74 percent (three sigma) of the product with volumes between 15.7 and 16.3 ounces. The process variability is outside the preset specifications. A large percentage of the product will fall outside the specified limits. This means that the process is *not capable* of producing the product within the preset specifications.

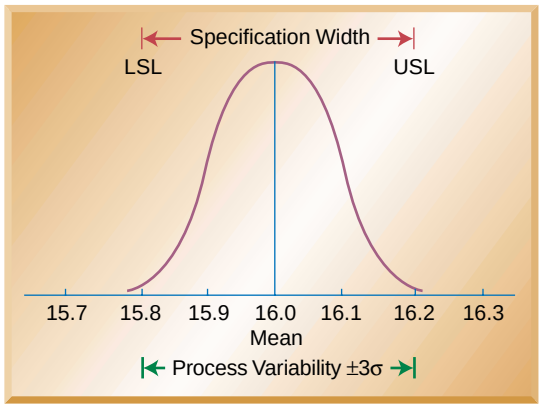
Part (c) of Figure 6-7 shows that the production process produces 99.74 percent (three sigma) of the product with volumes between 15.9 and 16.1 ounces. In this case the process variability is within specifications and the process exceeds the minimum capability.

Process capability is measured by the **process capability index,** C_p, which is computed as the ratio of the specification width to the width of the process variability:

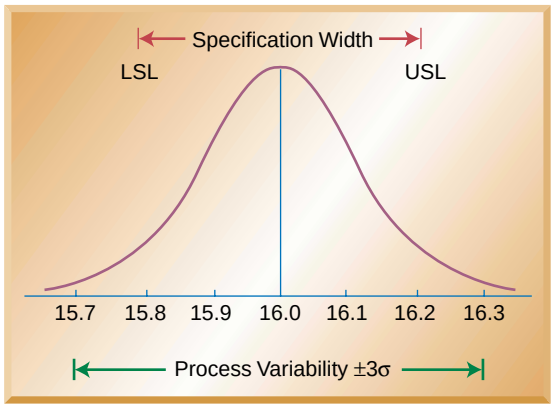
▶ **Process capability index** An index used to measure process capability.

$$C_p = \frac{\text{specification width}}{\text{process width}} = \frac{\text{USL} - \text{LSL}}{6\sigma}$$

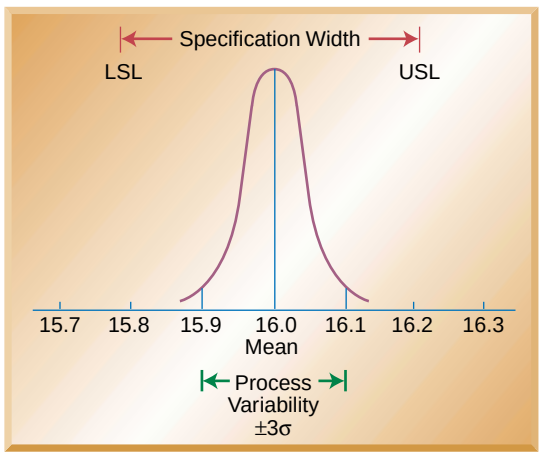
where the specification width is the difference between the upper specification limit (USL) and the lower specification limit (LSL) of the process. The process width is



(a) Process variability meets specification width



(b) Process variability outside specification width



(c) Process variability within specification width

FIGURE 6-7

Relationship between process variability and specification width

computed as 6 standard deviations (6σ) of the process being monitored. The reason we use 6σ is that most of the process measurement (99.74 percent) falls within ± 3 standard deviations, which is a total of 6 standard deviations.

There are three possible ranges of values for C_p that also help us interpret its value:

- $C_p = 1$: A value of C_p equal to 1 means that the process variability just meets specifications, as in Figure 6-7(a). We would then say that the process is minimally capable.
- $C_p \leq 1$: A value of C_p below 1 means that the process variability is outside the range of specification, as in Figure 6-7(b). This means that the process is not capable of producing within specification and the process must be improved.
- $C_p \geq 1$: A value of C_p above 1 means that the process variability is tighter than specifications and the process exceeds minimal capability, as in Figure 6-7(c).

A C_p value of 1 means that 99.74 percent of the products produced will fall within the specification limits. This also means that .26 percent (100% − 99.74%) of the products will not be acceptable. Although this percentage sounds very small, when we think of it in terms of parts per million (ppm) we can see that it can still result in a lot of defects. The number .26 percent corresponds to 2600 parts per million (ppm) defective ($0.0026 \times 1{,}000{,}000$). That number can seem very high if we think of it in terms of 2600 wrong prescriptions out of a million, or 2600 incorrect medical procedures out of a million, or even 2600 malfunctioning aircraft out of a million. You can see that this number of defects is still high. The way to reduce the ppm defective is to increase process capability.

EXAMPLE 6.6

Computing the C_p Value at Cocoa Fizz

Three bottling machines at Cocoa Fizz are being evaluated for their capability:

Bottling Machine	Standard Deviation
A	.05
B	.1
C	.2

If specifications are set between 15.8 and 16.2 ounces, determine which of the machines are capable of producing within specifications.

• Solution

To determine the capability of each machine we need to divide the specification width (USL − LSL = 16.2 − 15.8 = .4) by 6σ for each machine:

Bottling Machine	σ	USL−LSL	6σ	$C_p = \frac{\text{USL} - \text{LSL}}{6\sigma}$
A	.05	.4	.3	1.33
B	.1	.4	.6	.67
C	.2	.4	1.2	.33

Looking at the C_p values, only machine A is capable of filling bottles within specifications, because it is the only machine that has a C_p value at or above 1.

C_p is valuable in measuring process capability. However, it has one shortcoming: it assumes that process variability is centered on the specification range. Unfortunately, this is not always the case. Figure 6-8 shows data from the Cocoa Fizz example. In the figure the specification limits are set between 15.8 and 16.2 ounces, with a mean of 16.0 ounces. However, the process variation is not centered; it has a mean of 15.9 ounces. Because of this, a certain proportion of products will fall outside the specification range.

The problem illustrated in Figure 6-8 is not uncommon, but it can lead to mistakes in the computation of the C_p measure. Because of this, another measure for process capability is used more frequently:

$$C_{pk} = \min\left(\frac{\text{USL} - \mu}{3\sigma}, \frac{\mu - \text{LSL}}{3\sigma}\right)$$

where μ = the mean of the process
σ = the standard deviation of the process

This measure of process capability helps us address a possible lack of centering of the process over the specification range. To use this measure, the process capability of each half of the normal distribution is computed and the minimum of the two is used.

Looking at Figure 6-8, we can see that the computed C_p is 1:

Process mean: $\mu = 15.9$

Process standard deviation $\sigma = 0.067$

$\text{LSL} = 15.8$

$\text{USL} = 16.2$

$$C_p = \frac{0.4}{6(0.067)} = 1$$

The C_p value of 1.00 leads us to conclude that the process is capable. However, from the graph you can see that the process is *not* centered on the specification range

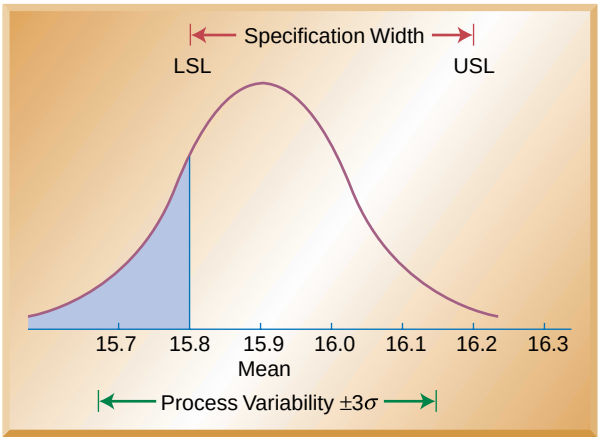


FIGURE 6-8

Process variability not centered across specification width

and is producing out-of-spec products. Using only the C_p measure would lead to an incorrect conclusion in this case. Computing C_{pk} gives us a different answer and leads us to a different conclusion:

$$C_{pk} = \min\left(\frac{\text{USL} - \mu}{3\sigma}, \frac{\mu - \text{LSL}}{3\sigma}\right)$$

$$C_{pk} = \min\left(\frac{16.2 - 15.9}{3(.1)}, \frac{15.9 - 15.8}{3(.1)}\right)$$

$$C_{pk} = \min\,(1.00, 0.33)$$

$$C_{pk} = \frac{.1}{.3} = .33$$

The computed C_{pk} value is less than 1, revealing that the process is not capable.

EXAMPLE 6.7

Computing the C_{pk} Value

Compute the C_{pk} measure of process capability for the following machine and interpret the findings. What value would you have obtained with the C_p measure?

Machine Data: USL = 110
LSL = 50
Process σ = 10
Process μ = 70

• Solution

To compute the C_{pk} measure of process capability:

$$C_{pk} = \min\left(\frac{\text{USL} - \mu}{3\sigma}, \frac{\mu - \text{LSL}}{3\sigma}\right)$$

$$= \min\left(\frac{110 - 60}{3(10)}, \frac{60 - 50}{3(10)}\right)$$

$$= \min\,(1.67, 0.33)$$

$$= 0.33$$

This means that the process is not capable. The C_p measure of process capability gives us the following measure,

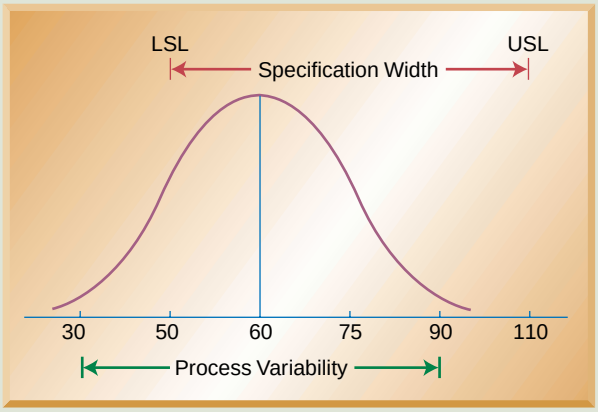
$$C_p = \frac{60}{6(10)} = 1$$

leading us to believe that the process is capable. The reason for the difference in the measures is that the process is not centered on the specification range, as shown in Figure 6-9.

Process capability of machines is a critical element of statistical process control.

FIGURE 6-9

Process variability not centered across specification width for Example 6.7



Six Sigma Quality

The term **Six Sigma®** was coined by the Motorola Corporation in the 1980s to describe the high level of quality the company was striving to achieve. Sigma (σ) stands for the number of standard deviations of the process. Recall that ± 3 sigma (σ) means that 2600 ppm are defective. The level of defects associated with Six Sigma is approximately 3.4 ppm. Figure 6-10 shows a process distribution with quality levels of ± 3 sigma (σ) and ± 6 sigma (σ). You can see the difference in the number of defects produced.

▶ **Six sigma quality** A high level of quality associated with approximately 3.4 defective parts per million.

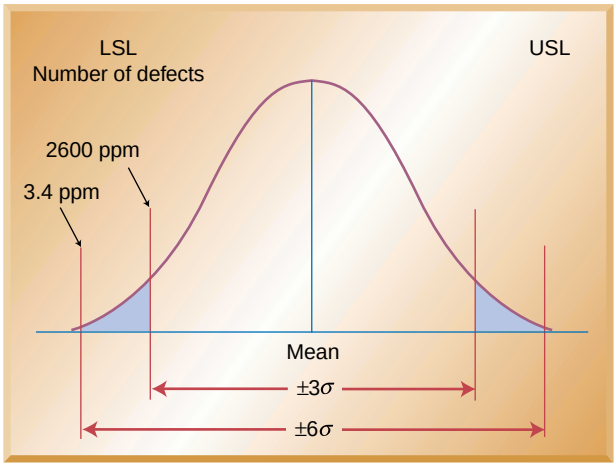


FIGURE 6-10

PPM defective for $\pm 3\sigma$ versus $\pm 6\sigma$ quality *(not to scale)*

LINKS TO PRACTICE

Motorola, Inc.
www.motorola.com

To achieve the goal of Six Sigma, Motorola has instituted a quality focus in every aspect of its organization. Before a product is designed, marketing ensures that product characteristics are exactly what customers want. Operations ensures that exact product characteristics can be achieved through product design, the manufacturing process, and the materials used. The Six Sigma concept is an integral part of other functions as well. It is used in the finance and accounting departments to reduce costing errors and the time required to close the books at the end of the month. Numerous other companies, such as General Electric and Texas Instruments, have followed Motorola's leadership and have also instituted the Six Sigma concept. In fact, the Six Sigma quality standard has become a benchmark in many industries.

There are two aspects to implementing the Six Sigma concept. The first is the use of technical tools to identify and eliminate causes of quality problems. These technical tools include the statistical quality control tools discussed in this chapter. They also include the problem-solving tools discussed in Chapter 5, such as cause-and-effect diagrams, flow charts, and Pareto analysis. In Six Sigma programs the use of these technical tools is integrated throughout the entire organizational system.

The second aspect of Six Sigma implementation is people involvement. In Six Sigma all employees have the training to use technical tools and are responsible for rooting out quality problems. Employees are given martial arts titles that reflect their skills in the Six Sigma process. *Black belts* and *master black belts* are individuals who have extensive training in the use of technical tools and are responsible for carrying out the implementation of Six Sigma. They are experienced individuals who oversee the measuring, analyzing, process controlling, and improving. They achieve this by acting as coaches, team leaders, and facilitators of the process of continuous improvement. *Green belts* are individuals who have sufficient training in technical tools to serve on teams or on small individual projects.

Successful Six Sigma implementation requires commitment from top company leaders. These individuals must promote the process, eliminate barriers to implementation, and ensure that proper resources are available. A key individual is a *champion* of Six Sigma. This is a person who comes from the top ranks of the organization and is responsible for providing direction and overseeing all aspects of the process.

ACCEPTANCE SAMPLING

Acceptance sampling, the third branch of statistical quality control, refers to the process of randomly inspecting a certain number of items from a lot or batch in order to decide whether to accept or reject the entire batch. What makes acceptance

sampling different from statistical process control is that acceptance sampling is performed either *before* or *after* the process, rather than during the process. Acceptance sampling *before* the process involves sampling materials received from a supplier, such as randomly inspecting crates of fruit that will be used in a restaurant, boxes of glass dishes that will be sold in a department store, or metal castings that will be used in a machine shop. Sampling *after* the process involves sampling finished items that are to be shipped either to a customer or to a distribution center. Examples include randomly testing a certain number of computers from a batch to make sure they meet operational requirements, and randomly inspecting snowboards to make sure that they are not defective.

You may be wondering why we would only inspect some items in the lot and not the entire lot. Acceptance sampling is used when inspecting every item is not physically possible or would be overly expensive, or when inspecting a large number of items would lead to errors due to worker fatigue. This last concern is especially important when a large number of items are processed in a short period of time. Another example of when acceptance sampling would be used is in destructive testing, such as testing eggs for salmonella or vehicles for crash testing. Obviously, in these cases it would not be helpful to test every item! However, 100 percent inspection does make sense if the cost of inspecting an item is less than the cost of passing on a defective item.

As you will see in this section, the goal of acceptance sampling is to determine the criteria for acceptance or rejection based on the size of the lot, the size of the sample, and the level of confidence we wish to attain. Acceptance sampling can be used for both attribute and variable measures, though it is most commonly used for attributes. In this section we will look at the different types of sampling plans and at ways to evaluate how well sampling plans discriminate between good and bad lots.

Sampling involves randomly inspecting items from a lot.

Sampling Plans

A **sampling plan** is a plan for acceptance sampling that precisely specifies the parameters of the sampling process and the acceptance/rejection criteria. The variables to be specified include the size of the lot (N), the size of the sample inspected from the lot (n), the number of defects above which a lot is rejected (c), and the number of samples that will be taken.

▶ **Sampling plan**
A plan for acceptance sampling that precisely specifies the parameters of the sampling process and the acceptance/rejection criteria.

There are different types of sampling plans. Some call for *single sampling*, in which a random sample is drawn from every lot. Each item in the sample is examined and is labeled as either "good" or "bad." Depending on the number of defects or "bad" items found, the entire lot is either accepted or rejected. For example, a lot size of 50 cookies is evaluated for acceptance by randomly inspecting 10 cookies from the lot. The cookies may be inspected to make sure they are not broken or burned. If 4 or more of the 10 cookies inspected are bad, the entire lot is rejected. In this example, the lot size $N = 50$, the sample size $n = 10$, and the maximum number of defects at which a lot is accepted is $c = 4$. These parameters define the acceptance sampling plan.

Another type of acceptance sampling is called *double sampling*. This provides an opportunity to sample the lot a second time if the results of the first sample are inconclusive. In double sampling we first sample a lot of goods according to preset criteria for definite acceptance or rejection. However, if the results fall in the middle range,

they are considered inconclusive and a second sample is taken. For example, a water treatment plant may sample the quality of the water ten times in random intervals throughout the day. Criteria may be set for acceptable or unacceptable water quality, such as .05 percent chlorine and .1 percent chlorine. However, a sample of water containing between .05 percent and .1 percent chlorine is inconclusive and calls for a second sample of water.

In addition to single and double-sampling plans, there are *multiple sampling plans.* Multiple sampling plans are similar to double sampling plans except that criteria are set for more than two samples. The decision as to which sampling plan to select has a great deal to do with the cost involved in sampling, the time consumed by sampling, and the cost of passing on a defective item. In general, if the cost of collecting a sample is relatively high, single sampling is preferred. An extreme example is collecting a biopsy from a hospital patient. Because the actual cost of getting the sample is high, we want to get a large sample and sample only once. The opposite is true when the cost of collecting the sample is low but the actual cost of testing is high. This may be the case with a water treatment plant, where collecting the water is inexpensive but the chemical analysis is costly. In this section we focus primarily on single sampling plans.

Operating Characteristic (OC) Curves

As we have seen, different sampling plans have different capabilities for discriminating between good and bad lots. At one extreme is 100 percent inspection, which has perfect discriminating power. However, as the size of the sample inspected decreases, so does the chance of accepting a defective lot. We can show the discriminating power of a sampling plan on a graph by means of an **operating characteristic (OC) curve.** This curve shows the probability or chance of accepting a lot given various proportions of defects in the lot.

▶ **Operating characteristic (OC) curve**
A graph that shows the probability or chance of accepting a lot given various proportions of defects in the lot.

Figure 6-11 shows a typical OC curve. The *x* axis shows the percentage of items that are defective in a lot. This is called "lot quality." The *y* axis shows the probability or chance of accepting a lot. You can see that if we use 100 percent inspection we are certain of accepting only lots with zero defects. However, as the proportion of defects in the lot increases, our chance of accepting the lot decreases. For example, we have a 90 percent probability of accepting a lot with 5 percent defects and an 80 percent probability of accepting a lot with 8 percent defects.

Regardless of which sampling plan we have selected, the plan is not perfect. That is, there is still a chance of accepting lots that are "bad" and rejecting "good" lots. The steeper the OC curve, the better our sampling plan is for discriminating between "good" and "bad." Figure 6-12 shows three different OC curves, A, B, and C. Curve A is the most discriminating and curve C the least. You can see that the steeper the slope of the curve, the more discriminating is the sampling plan. When 100 percent inspection is not possible, there is a certain amount of risk for consumers in accepting defective lots and a certain amount of risk for producers in rejecting good lots.

▶ **Acceptable quality level (AQL)**
The small percentage of defects that consumers are willing to accept.

▶ **Lot tolerance percent defective (LTPD)**
The upper limit of the percentage of defective items consumers are willing to tolerate.

There is a small percentage of defects that consumers are willing to accept. This is called the **acceptable quality level (AQL)** and is generally in the order of 1–2 percent. However, sometimes the percentage of defects that passes through is higher than the AQL. Consumers will usually tolerate a few more defects, but at some point the number of defects reaches a threshold level beyond which consumers will not tolerate them. This threshold level is called the **lot tolerance percent defective (LTPD).** The

FIGURE 6-11

Example of an operating characteristic (OC) curve

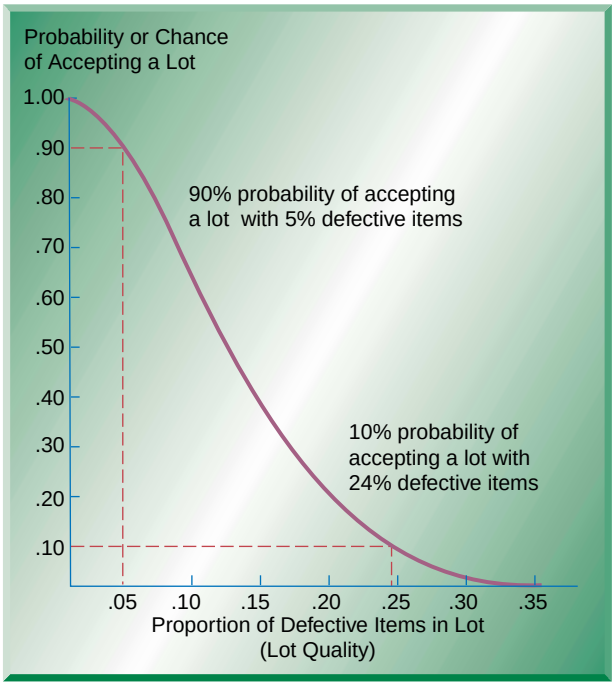
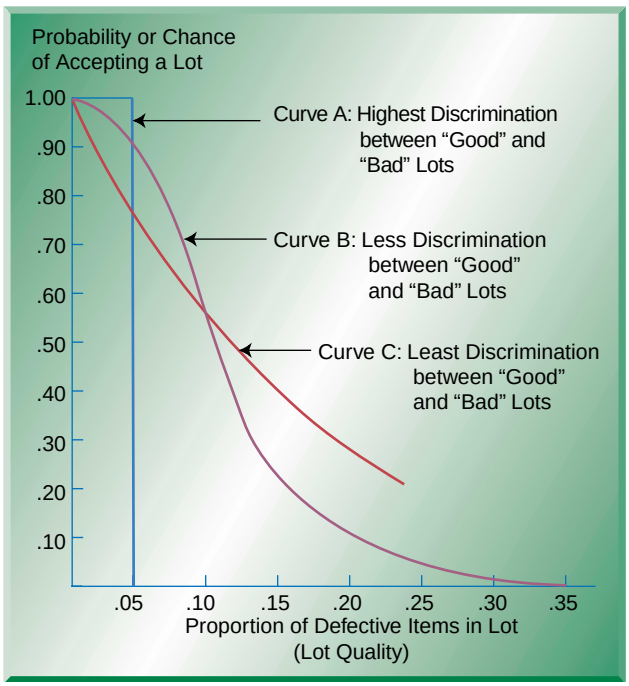


FIGURE 6-12

OC curves with different steepness levels and different levels of discrimination



LTPD is the upper limit of the percentage of defective items consumers are willing to tolerate.

Consumer's risk is the chance or probability that a lot will be accepted that contains a greater number of defects than the LTPD limit. This is the probability of making a Type II error—that is, accepting a lot that is truly "bad." Consumer's risk or Type II error is generally denoted by beta (β). The relationships among AQL, LTPD, and β are shown in Figure 6-13. **Producer's risk** is the chance or probability that a lot containing an acceptable quality level will be rejected. This is the probability of making a Type I error—that is, rejecting a lot that is "good." It is generally denoted by alpha (α). Producer's risk is also shown in Figure 6-13.

We can determine from an OC curve what the consumer's and producer's risks are. However, these values should not be left to chance. Rather, sampling plans are usually designed to meet specific levels of consumer's and producer's risk. For example, one common combination is to have a consumer's risk (β) of 10 percent and a producer's risk (α) of 5 percent, though many other combinations are possible.

▶ **Consumer's risk**
The chance of accepting a lot that contains a greater number of defects than the LTPD limit.

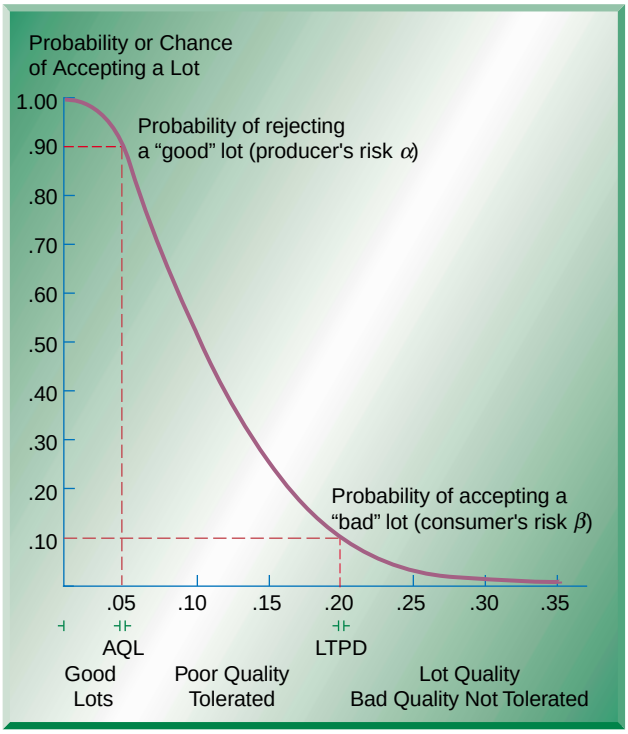
▶ **Producer's risk**
The chance that a lot containing an acceptable quality level will be rejected.

Developing OC Curves

An OC curve graphically depicts the discriminating power of a sampling plan. To draw an OC curve, we typically use a cumulative binomial distribution to obtain

FIGURE 6-13

An OC curve showing producer's risk (α) and consumer's risk (β)



probabilities of accepting a lot given varying levels of lot defects.[1] The cumulative binomial table is found in Appendix C. A small part of this table is reproduced in Table 6-2. The top of the table shows values of *p*, which represents the proportion of defective items in a lot (5 percent, 10 percent, 20 percent, etc.). The left-hand column shows values of *n*, which represent the sample size being considered, and *x* represents the cumulative number of defects found. Let's use an example to illustrate how to develop an OC curve for a specific sampling plan using the information from Table 6-2.

TABLE 6-2

Partial Cumulative Binomial Probability Table

		Proportion of Items Defective (*p*)									
		.05	.10	.15	.20	.25	.30	.35	.40	.45	.50
n	*x*										
5	0	.7738	.5905	.4437	.3277	.2373	.1681	.1160	.0778	.0503	.0313
	1	.9974	.9185	.8352	.7373	.6328	.5282	.4284	.3370	.2562	.1875
	2	.9988	.9914	.9734	.9421	.8965	.8369	.7648	.6826	.5931	.5000

[1]For $n \geq 20$ and $p \leq .05$ a Poisson distribution is generally used.

EXAMPLE 6.8

Constructing an OC Curve

Let's say that we want to develop an OC curve for a sampling plan in which a sample of $n = 5$ items is drawn from lots of $N = 1000$ items. The accept/reject criteria are set up in such a way that we accept a lot if *no more than* one defect ($c = 1$) is found.

• Solution

Let's look at the partial binomial distribution in Table 6-2. Since our criteria require us to sample $n = 5$, we will go to the row where n equals 5 in the left-hand column. The "x" column tells us the cumulative number of defects found at which we reject the lot. Since we are not allowing more than one defect, we look for an x value that corresponds to 1. The row corresponding to $n = 5$ and $x = 1$ tells us our chance or probability of accepting lots with various proportions of defects using this sampling plan. For example, with this sampling plan we have a 99.74% chance of accepting a lot with 5% defects. If we move down the row, we can see that we have a 91.85% chance of accepting a lot with 10% defects, a 83.52% chance of accepting a lot with 15% defects, and a 73.73% chance of accepting a lot with 20% defects. Using these values and those remaining in the row, we can construct an OC chart for $n = 5$ and $c = 1$. This is shown in Figure 6-14.

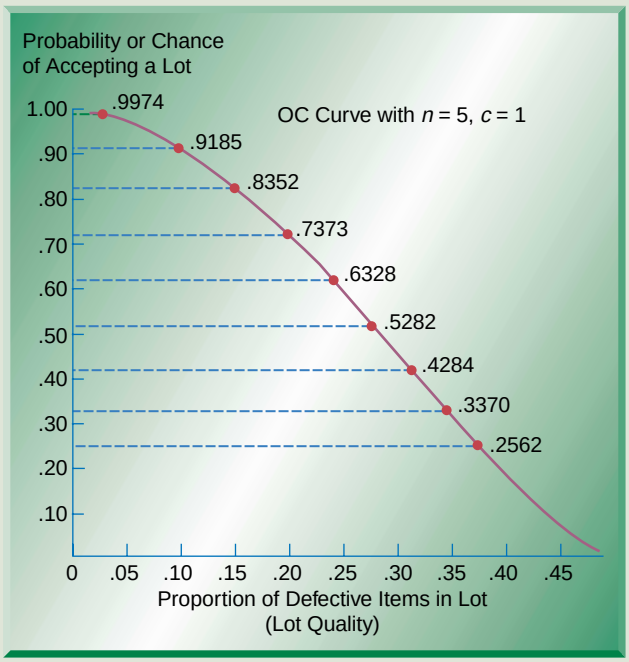


FIGURE 6-14

OC curve with $n = 5$ and $c = 1$

Average Outgoing Quality

As we observed with the OC curves, the higher the quality of the lot, the higher is the chance that it will be accepted. Conversely, the lower the quality of the lot, the greater is the chance that it will be rejected. Given that some lots are accepted and some rejected, it is useful to compute the **average outgoing quality (AOQ)** of lots to get a sense of the overall outgoing quality of the product. Assuming that all lots have the

▶ **Average outgoing quality (AOQ)**
The expected proportion of defective items that will be passed to the customer under the sampling plan.

same proportion of defective items, the average outgoing quality can be computed as follows:

$$\text{AOQ} = (P_{ac})p\left(\frac{N-n}{N}\right)$$

where P_{ac} = probability of accepting a given lot
p = proportion of defective items in a lot
N = the size of the lot
n = the sample size chosen for inspection

Usually we assume the fraction in the previous equation to equal 1 and simplify the equation to the following form:

$$\text{AOQ} = (P_{ac})p$$

We can then use the information from Figure 6-14 to construct an AOQ curve for different levels of probabilities of acceptance and different proportions of defects in a lot. As we will see, an AOQ curve is similar to an OC curve.

EXAMPLE 6.9

Constructing an AOQ Curve

Let's go back to our initial example, in which we sampled 5 items ($n = 5$) from a lot of 1000 ($N = 1000$) with an acceptance range of no more than 1($c = 1$) defect. Here we will construct an AOQ curve for this sampling plan and interpret its meaning.

• **Solution**

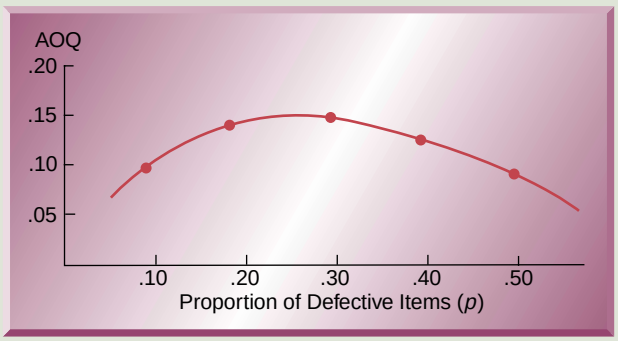
For the parameters $N = 1000$, $n = 5$, and $c = 1$, we can read the probabilities of P_{ac} from Figure 6-14. Then we can compute the value of AOQ as AOQ $= (P_{ac})\,p$.

p	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50
P_{ac}	.9974	.9185	.8352	.7373	.6328	.5282	.4284	.3370	.2562	.1875
AOQ	.0499	.0919	.1253	.1475	.1582	.1585	.1499	.1348	.1153	.0938

Figure 6–15 shows a graphical representation of the AOQ values. The AOQ varies, depending on the proportion of defective items in the lot. The largest value of AOQ, called the average outgoing quality limit (AOQL), is around 15.85%. You can see from Figure 6-15 that the average outgoing quality

FIGURE 6-15

The AOQ for $n = 5$ and $c = 1$



will be high for lots that are either very good or very bad. For lots that have close to 30% of defective items, the AOQ is the highest. Managers can use this information to compute the worst possible value of their average outgoing quality given the proportion of defective items (p). Then this information can be used to develop a sampling plan with appropriate levels of discrimination.

IMPLICATIONS FOR MANAGERS

In this chapter we have learned about a variety of different statistical quality control (SQC) tools that help managers make decisions about product and process quality. However, to use these tools properly managers must make a number of decisions. In this section we discuss some of the most important decisions that must be made when implementing SPC.

How Much and How Often to Inspect

Consider Product Cost and Product Volume As you know, 100 percent inspection is rarely possible. The question then becomes one of how often to inspect in order to minimize the chances of passing on defects and still keep inspection costs manageable. This decision should be related to the *product cost* and *product volume* of what is being produced. At one extreme are high-volume, low-cost items, such as paper, pencils, nuts and bolts, for which 100 percent inspection would not be cost justified. Also, with such a large volume 100 percent inspection would not be possible because worker fatigue sets in and defects are often passed on. At the other extreme are low-volume, high-cost items, such as parts that will go into a space shuttle or be used in a medical procedure, that require 100 percent inspection.

Most items fall somewhere between the two extremes just described. For these items, frequency of inspection should be designed to consider the trade-off between the cost of inspection and the cost of passing on a defective item. Historically, inspections were set up to minimize these two costs. Today, it is believed that defects of any type should not be tolerated and that eliminating them helps reduce organizational costs. Still, the inspection process should be set up to consider issues of product cost and volume. For example, one company will probably have different frequencies of inspection for different products.

Consider Process Stability Another issue to consider when deciding how much to inspect is the stability of the process. Stable processes that do not change frequently do not need to be inspected often. On the other hand, processes that are unstable and change often should be inspected frequently. For example, if it has been observed that a particular type of drilling machine in a machine shop often goes out of tolerance, that machine should be inspected frequently. Obviously, such decisions cannot be made without historical data on process stability.

Consider Lot Size The size of the lot or batch being produced is another factor to consider in determining the amount of inspection. A company that produces a small number of large lots will have a smaller number of inspections than a company that produces a large number of small lots. The reason is that every lot should have some inspection, and when lots are large, there are fewer lots to inspect.

Where to Inspect

Since we cannot inspect every aspect of a process all the time, another important decision is to decide where to inspect. Some areas are less critical than others. Following are some points that are typically considered most important for inspection.

Inbound Materials Materials that are coming into a facility from a supplier or distribution center should be inspected before they enter the production process. It is important to check the quality of materials before labor is added to it. For example, it would be wasteful for a seafood restaurant not to inspect the quality of incoming lobsters only to later discover that its lobster bisque is bad. Another reason for checking inbound materials is to check the quality of sources of supply. Consistently poor quality in materials from a particular supplier indicates a problem that needs to be addressed.

Finished Products Products that have been completed and are ready for shipment to customers should also be inspected. This is the last point at which the product is in the production facility. The quality of the product represents the company's overall quality. The final quality level is what will be experienced by the customer, and an inspection at this point is necessary to ensure high quality in such aspects as fitness for use, packaging, and presentation.

Prior to Costly Processing During the production process it makes sense to check quality before performing a costly process on the product. If quality is poor at that point and the product will ultimately be discarded, adding a costly process will simply lead to waste. For example, in the production of leather armchairs in a furniture factory, chair frames should be inspected for cracks before the leather covering is added. Otherwise, if the frame is defective the cost of the leather upholstery and workmanship may be wasted.

Which Tools to Use

In addition to where and how much to inspect, managers must decide which tools to use in the process of inspection. As we have seen, tools such as control charts are best used at various points in the production process. Acceptance sampling is best used for inbound and outbound materials. It is also the easiest method to use for attribute measures, whereas control charts are easier to use for variable measures. Surveys of industry practices show that most companies use control charts, especially x-bar and R-charts, because they require less data collection than p-charts.

STATISTICAL QUALITY CONTROL IN SERVICES

Statistical quality control (SQC) tools have been widely used in manufacturing organizations for quite some time. Manufacturers such as Motorola, General Electric, Toyota, and others have shown leadership in SQC for many years. Unfortunately, service organizations have lagged behind manufacturing firms in their use of SQC. The primary reason is that statistical quality control requires measurement, and it is difficult to measure the quality of a service. Remember that services often provide an intangible product and that perceptions of quality are often highly subjective. For example, the quality of a service is often judged by such factors as friendliness and courtesy of the staff and promptness in resolving complaints.

A way to measure the quality of services is to devise quantifiable measurements of the important dimensions of a particular service. For example, the number of complaints received per month, the number of telephone rings after which a response is received, or customer waiting time can be quantified. These types of measurements are not subjective or subject to interpretation. Rather, they can be measured and recorded. As in manufacturing, acceptable control limits should be developed and the variable in question should be measured periodically.

Another issue that complicates quality control in service organizations is that the service is often consumed during the production process. The customer is often present during service delivery, and there is little time to improve quality. The workforce that interfaces with customers is part of the service delivery. The way to manage this issue is to provide a high level of workforce training and to empower workers to make decisions that will satisfy customers.

LINKS TO PRACTICE

The Ritz-Carlton Hotel Company, L.L.C.
www.ritzcarlton.com

Nordstrom, Inc.
www.nordstrom.com

One service organization that has demonstrated quality leadership is The Ritz-Carlton Hotel Company. This luxury hotel chain caters to travelers who seek high levels of customer service. The goal of the chain is to be recognized for outstanding service quality. To this end, computer records are kept of regular clients' preferences. To keep customers happy, employees are empowered to spend up to $2,000 on the spot to correct any customer complaint. Consequently, The Ritz-Carlton has received a number of quality awards including winning the Malcolm Baldrige National Quality Award twice. It is the only company in the service category to do so.

Another leader in service quality that uses the strategy of high levels of employee training and empowerment is Nordstrom Department Stores. Outstanding customer service is the goal of this department store chain. Its organizational chart places the customer at the head of the organization. Records are kept of regular clients' preferences, and employees are empowered to make decisions on the spot to satisfy customer wants. The customer is considered to always be right.

LINKS TO PRACTICE

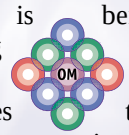
Marriott International, Inc.
www.marriott.com

Service organizations, must also use statistical tools to measure their processes and monitor performance. For example, the Marriott is known for regularly collecting data in the form of guest surveys. The company randomly surveys as many as a million guests each year. The collected data is stored in a large database and continually examined for patterns, such as trends and changes in customer preferences. Statistical techniques are used to analyze the data and provide important information, such as identifying areas that have the highest impact on performance, and those areas that need improvement. This information allows Marriott to provide a superior level of customer service, anticipate customer demands, and put resources in service features most important to customers.

OM ACROSS THE ORGANIZATION

It is easy to see how operations managers can use the tools of SQC to monitor product and process quality. However, you may not readily see how these statistical techniques affect other functions of the organization. In fact, SQC tools require input from other functions, influence their success, and are actually used by other organizational functions in designing and evaluating their tasks.

Marketing plays a critical role in setting up product and service quality standards. It is up to marketing to provide information on current and future quality standards required by customers and those being offered by competitors. Operations managers can incorporate this information into product and process design. Consultation with marketing managers is essential to ensure that quality standards are being met. At the same time, meeting quality standards is essential to the marketing department, since sales of products are dependent on the standards being met.



Finance is an integral part of the statistical quality control process, because it is responsible for placing financial values on SQC efforts. For example, the finance department evaluates the dollar costs of defects, measures financial improvements that result from tightening of quality standards, and is actively involved in approving investments in quality improvement efforts.

Human resources becomes even more important with the implementation of TQM and SQC methods, as the role of workers changes. To understand and utilize SQC tools, workers need ongoing training and the ability to work in teams, take pride in their work, and assume higher levels of responsibility. The human resources department is responsible for hiring workers with the right skills and setting proper compensation levels.

Information systems is a function that makes much of the information needed for SQC accessible to all who need it. Information systems managers need to work closely with other functions during the implementation of SQC so that they understand exactly what types of information are needed and in what form. As we have seen, SQC tools are dependent on information, and it is up to information systems managers to make that information available. As a company develops ways of using TQM and SQC tools, information systems managers must be part of this ongoing evolution to ensure that the company's information needs are being met.

All functions need to work closely together in the implementation of statistical process control. Everyone benefits from this collaborative relationship: operations is able to produce the right product efficiently; marketing has the exact product customers are looking for; and finance can boast of an improved financial picture for the organization.

SQC also affects various organizational functions through its direct application in evaluating quality performance in all areas of the organization. SQC tools are not used only to monitor the production process and ensure that the product being produced is within specifications. As we have seen in the Motorola Six Sigma example, these tools can be used to monitor both quality levels and defects in accounting procedures, financial record keeping, sales and marketing, office administration, and other functions. Having high quality standards in operations does not guarantee high quality in the organization as a whole. The same stringent standards and quality evaluation procedures should be used in setting standards and evaluating the performance of all organizational functions.

INSIDE OM

The decision to increase the level of quality standard and reduce the number of product defects requires support from every function within operations management. Two areas of operations management that are particularly affected are product and process design. Process design needs to be modified to incorporate customer-defined quality and simplification of design. Processes need to be continuously monitored and changed to build quality into the process and reduce variation. Other areas that are affected are job design,

as we expand the role of employees to become responsible for monitoring quality levels and to use statistical quality control tools. Supply chain management and inventory control are also affected as we increase quality standard requirements from our suppliers and change the materials we use. All areas of operations management are involved when increasing the quality standard of a firm.

Chapter Highlights

1. Statistical quality control (SQC) refers to statistical tools that can be used by quality professionals. Statistical quality control can be divided into three broad categories: descriptive statistics, acceptance sampling, and statistical process control (SPC).
2. Descriptive statistics are used to describe quality characteristics, such as the mean, range, and variance. Acceptance sampling is the process of randomly inspecting a sample of goods and deciding whether to accept or reject the entire lot. Statistical process control (SPC) involves inspecting a random sample of output from a process and deciding whether the process is producing products with characteristics that fall within preset specifications.
3. There are two causes of variation in the quality of a product or process: common causes and assignable causes. Common causes of variation are random causes that we cannot identify. Assignable causes of variation are those that can be identified and eliminated.
4. A control chart is a graph used in statistical process control that shows whether a sample of data falls within the normal range of variation. A control chart has upper and lower control limits that separate common from assignable causes of variation. Control charts for variables monitor characteristics that can be measured and have a continuum of values, such as height, weight, or volume. Control charts for attributes are used to monitor characteristics that have discrete values and can be counted.
5. Control charts for variables include x-bar charts and R-charts. X-bar charts monitor the mean or average value of a product characteristic. R-charts monitor the range or dispersion of the values of a product characteristic. Control charts for attributes include p-charts and c-charts. P-charts are used to monitor the proportion of defects in a sample. C-charts are used to monitor the actual number of defects in a sample.
6. Process capability is the ability of the production process to meet or exceed preset specifications. It is measured by the process capability index, C_p, which is computed as the ratio of the specification width to the width of the process variability.
7. The term *Six Sigma* indicates a level of quality in which the number of defects is no more than 3.4 parts per million.
8. The goal of acceptance sampling is to determine criteria for acceptance or rejection based on lot size, sample size, and the desired level of confidence. Operating characteristic (OC) curves are graphs that show the discriminating power of a sampling plan.
9. It is more difficult to measure quality in services than in manufacturing. The key is to devise quantifiable measurements for important service dimensions.

Key Terms

statistical quality control (SQC) 172
descriptive statistics 172
statistical process control (SPC) 173
acceptance sampling 173
common causes of variation 174
assignable causes of variation 174
mean (average) 174
range 175
standard deviation 175
control chart 176
out of control 176
variable 177
attribute 177
x-bar chart 178
R-chart 182
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process capability 190
product specifications 190
process capability index 191
Six Sigma quality 195
sampling plan 197
operating characteristic (OC) curve 198
acceptable quality level (AQL) 198
lot tolerance percent defective (LTPD) 198
consumer's risk 199
producer's risk 199
average outgoing quality (AOQ) 201

Formula Review

1. Mean $\bar{x} = \dfrac{\sum_{i=1}^{n} \bar{x}_i}{n}$

2. Standard Deviation $\sigma = \sqrt{\dfrac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$

3. Control Limits for x-Bar Charts

Upper control limit (UCL) $= \bar{\bar{x}} + z\sigma_{\bar{x}}$

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

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

4. Control Limits for x-Bar Charts Using Sample Range as an Estimate of Variability

Upper control limit (UCL) $= \bar{\bar{x}} + A_2 \bar{R}$

Lower control limit (LCL) $= \bar{\bar{x}} - A_2 \bar{R}$

5. Control Limits for R-Charts $\text{UCL} = D_4 \bar{R}$, $\text{LCL} = D_3 \bar{R}$

6. Control Limits for p-Charts $\text{UCL} = \bar{p} + z(\sigma_p)$, $\text{LCL} = \bar{p} - z(\sigma_p)$

7. Control Limits for c-Charts $\text{UCL} = \bar{c} + z\sqrt{\bar{c}}$, $\text{LCL} = \bar{c} + z\sqrt{\bar{c}}$

8. Measures for Process Capability

$$C_p = \frac{\text{specification width}}{\text{process width}} = \frac{\text{USL} - \text{LSL}}{6\sigma}$$

$$C_{pk} = \min\left(\frac{\text{USL} - \mu}{3\sigma}, \frac{\mu - \text{LSL}}{3\sigma}\right)$$

9. Average Outgoing Quality $\text{AOQ} = (P_{ac})p$

Solved Problems

• Problem 1

A quality control inspector at the Crunchy Potato Chip Company has taken 3 samples with 4 observations each of the volume of bags filled. The data and the computed means are shown in the following table:

Sample of Potato Chip Bag Volume in Ounces

Sample Number	Observations 1	2	3	4
1	12.5	12.3	12.6	12.7
2	12.8	12.4	12.4	12.8
3	12.1	12.6	12.5	12.4
4	12.2	12.6	12.5	12.3
5	12.4	12.5	12.5	12.5
6	12.3	12.4	12.6	12.6
7	12.6	12.7	12.5	12.8
8	12.4	12.3	l2.6	12.5
9	12.6	12.5	l2.3	12.6
10	12.1	12.7	12.5	12.8
Mean $\bar{x}$	12.4	12.5	12.5	12.6

If the standard deviation of the bagging operation is 0.2 ounces, use the information in the table to develop control limits of 3 standard deviations for the bottling operation.

• *Solution*

The center line of the control data is the average of the samples:

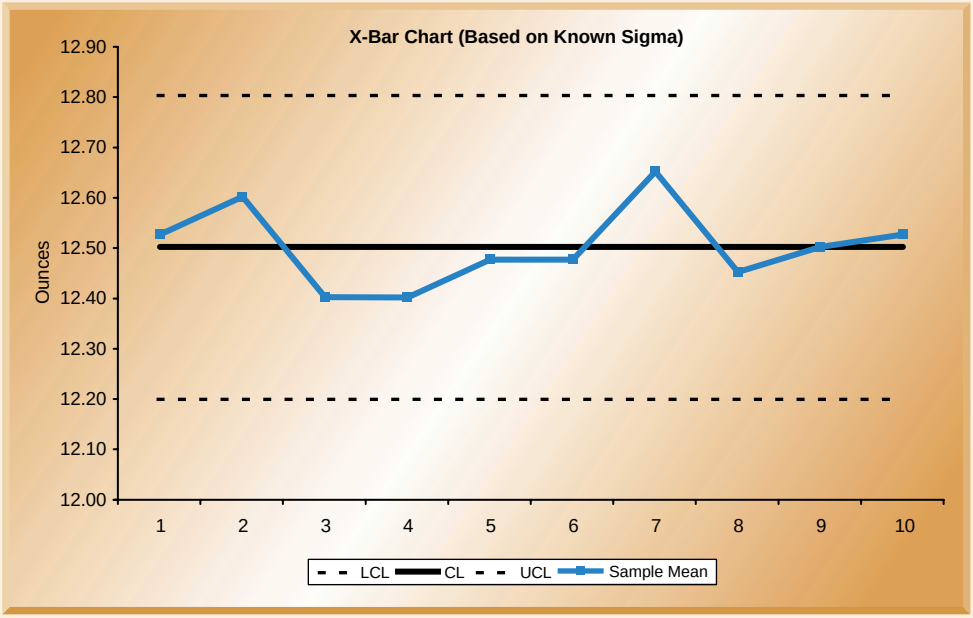
$$\bar{\bar{x}} = \frac{12.4 + 12.5 + 12.5 + 12.6}{4} = 12.5 \text{ ounces}$$

The control limits are:

$$\text{UCL} = \bar{\bar{x}} + z\sigma_{\bar{x}} = 12.5 + 3\left(\frac{.2}{\sqrt{4}}\right) = 12.80$$

$$\text{LCL} = \bar{\bar{x}} - z\sigma_{\bar{x}} = 12.5 - 3\left(\frac{.2}{\sqrt{4}}\right) = 12.20$$

Following is the associated control chart:



The problem can also be solved using a spreadsheet.

	A	B	C	D	E	F	G
1							
2	**Crunchy Potato Chips Company**						
3							
4		F7: =AVERAGE(B7:E7)					
5				**Bottle Volume in Ounces**			
6	Sample Num	Obs 1	Obs 2	Obs 3	Obs 4	Average	
7	1	12.50	12.30	12.60	12.70	12.53	
8	2	12.80	12.40	12.40	12.80	12.60	
9	3	12.10	12.60	12.50	12.40	12.40	
10	4	12.20	12.60	12.50	12.30	12.40	
11	5	12.40	12.50	12.50	12.50	12.48	
12	6	12.30	12.40	12.60	12.60	12.48	
13	7	12.60	12.70	12.50	12.80	12.65	
14	8	12.40	12.30	12.60	12.50	12.45	
15	9	12.60	12.50	12.30	12.60	12.50	
16	10	12.10	12.70	12.50	12.80	12.53	
17						12.50	
18		Number of Samples		10		Xbar-bar	
19	Number of Observations per Sample			4			
20			F17: =AVERAGE(F7:F16)				
21							
22	**Computations for X-Bar Chart**				D23: =F17		
23	Overall Mean (Xbar-bar) =			12.50			
24	Sigma for Process =			0.2	ounces	D25: =D24/SQRT(D19)	
25	Standard Error of the Mean =			0.1			
26	Z-value for control charts =			3			
27					D28: =D23		
28	CL: Center Line =			**12.50**	D29: =D23-D26*D25		
29	LCL: Lower Control Limit =			**12.20**	D30: =D23+D26*D25		
30	UCL: Upper Control Limit =			**12.80**			

• Problem 2

Use of the sample range to estimate variability can also be applied to the Crunchy Potato Chip operation. A quality control inspector has taken 4 samples with 5 observations each, measuring the volume of chips per bag. If the average range for the 4 samples is .2 ounces and the average mean of the observations is 12.5 ounces, develop three-sigma control limits for the bottling operation.

• Solution

$$\bar{\bar{x}} = 12.5 \text{ ounces}$$

$$\bar{R} = .2$$

The value of A_2 is obtained from Table 6-1. For $n = 5$, $A_2 = .58$. This leads to the following limits:

The center of the control chart is CL = 12.5 ounces

$$\text{UCL} = \bar{\bar{x}} + A_2\bar{R} = 12.5 + (.58)(.2) = 12.62$$

$$\text{LCL} = \bar{\bar{x}} - A_2\bar{R} = 12.5 - (.58)(.2) = 12.38$$

• Problem 3

Ten samples with 5 observations each have been taken from the Crunchy Potato Chip Company plant in order to test for volume dispersion in the bagging process. The average sample range was found to be .3 ounces. Develop control limits for the sample range.

• Solution

$$\bar{R} = .3 \text{ ounces}$$

$$n = 5$$

From Table 6-1 for $n = 5$:

$$D_4 = 2.11$$

$$D_3 = 0$$

Therefore,

$$\text{UCL} = D_4\bar{R} = 2.11(.3) = .633$$

$$\text{LCL} = D_3\bar{R} = 0(.3) = 0$$

• Problem 4

A production manager at a light bulb plant has inspected the number of defective light bulbs in 10 random samples with 30 observations each. Following are the numbers of defective light bulbs found:

Sample	Number Defective	Number of Observations in Sample
1	1	30
2	3	30
3	3	30
4	1	30
5	0	30
6	5	30
7	1	30
8	1	30
9	1	30
10	1	30
Total	17	300

Construct a three-sigma control chart ($z = 3$) with this information.

• Solution

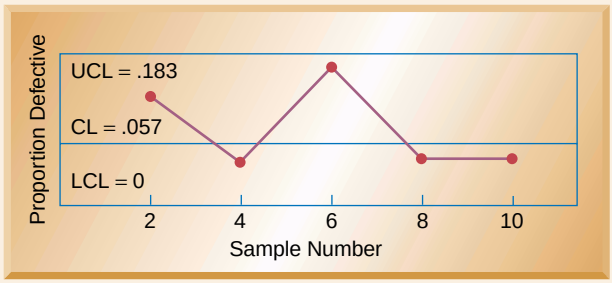
The center line of the chart is:

$$\text{CL} = \bar{p} = \frac{\text{number defective}}{\text{number of observations}} = \frac{17}{300} = .057$$

$$\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = \sqrt{\frac{(.057)(.943)}{30}} = .042$$

$$\text{UCL} = \bar{p} + z(\sigma_p) = .057 + 3(.042) = .183$$

$$\text{LCL} = \bar{p} - z(\sigma_p) = .057 - 3(.042) = -.069 \longrightarrow 0$$



This is also solved using a spreadsheet.

	A	B	C	D	E	F	G
1							
2	**p-Chart for Light Bulb Quality**						
3							
4		Sample Size	30				
5		Number Samples	10				
6							
7	**Sample #**	**# Defectives**	**p**	C8: =B8/C$4			
8	1	1	0.03333333				
9	2	3	0.1				
10	3	3	0.1				
11	4	1	0.03333333				
12	5	0	0				
13	6	5	0.16666667				
14	7	1	0.03333333				
15	8	1	0.03333333				
16	9	1	0.03333333				
17	10	1	0.03333333				
18				C19: =SUM(B8:B17)/(C4*C5)			
19		p bar =	0.05666667	C20: =SQRT((C19*(1-C19))/C4)			
20		Sigma_p =	0.04221199				
21	Z-value for control charts =		3				
22				C23: =C19			
23	CL: Center Line =		**0.05666667**	C24: =MAX(C$19-C$21*C$20,0)			
24	LCL: Lower Control Limit =		**0**	C25: =C$19+C$21*C$20			
25	UCL: Upper Control Limit =		**0.18330263**				

• Problem 5

Kinder Land Child Care uses a c-chart to monitor the number of customer complaints per week. Complaints have been recorded over the past 20 weeks. Develop a control chart with three-sigma control limits using the following data:

Week	Number of Complaints	Week	Number of Complaints
1	0	11	4
2	3	12	3
3	4	13	1
4	1	14	1
5	0	15	1
6	0	16	0
7	3	17	2
8	1	18	1
9	1	19	2
10	0	20	2
		Total	30

• *Solution*

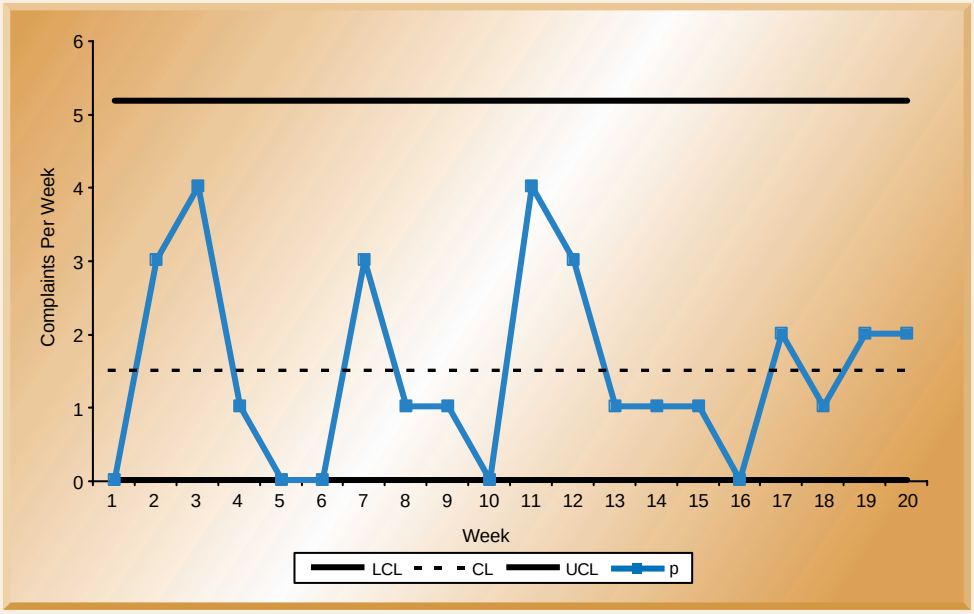
The average weekly number of complaints is $\frac{30}{20} = 1.5$

Therefore,

$$\text{UCL} = \bar{c} + z\sqrt{\bar{c}} = 1.5 + 3\sqrt{1.5} = 5.17$$

$$\text{LCL} = \bar{c} - z\sqrt{\bar{c}} = 1.5 - 3\sqrt{1.5} = -2.17 \longrightarrow 0$$

The resulting control chart is:



• Problem 6

Three bagging machines at the Crunchy Potato Chip Company are being evaluated for their capability. The following data are recorded:

Bagging Machine	Standard Deviation
A	.2
B	.3
C	.05

If specifications are set between 12.35 and 12.65 ounces, determine which of the machines are capable of producing within specification.

• Solution

To determine the capability of each machine we need to divide the specification width (USL − LSL = 12.65 − 12.35 = .3) by 6σ for each machine:

Bagging Machine	σ	USL − LSL	6σ	$C_p = \frac{\text{USL} - \text{LSL}}{6\sigma}$
A	.2	.3	1.2	0.25
B	.3	.3	1.8	0.17
C	.05	.3	.3	1.00

Looking at the C_p values, only machine C is capable of bagging the potato chips within specifications, because it is the only machine that has a C_p value at or above 1.

• Problem 7

Compute the C_{pk} measure of process capability for the following machine and interpret the findings. What value would you have obtained with the C_p measure?

Machine Data: USL = 80
LSL = 50
Process σ = 5
Process μ = 60

• Solution

To compute the C_{pk} measure of process capability:

$$C_{pk} = \min\left(\frac{\text{USL} - \mu}{3\sigma}, \frac{\mu - \text{LSL}}{3\sigma}\right)$$

$$= \min\left(\frac{80 - 60}{3(5)}, \frac{60 - 50}{3(5)}\right)$$

$$= \min(1.33, 0.67)$$

$$= 0.67$$

This means that the process is not capable. The C_p measure of process capability gives us the following measure:

$$C_p = \frac{30}{6(5)} = 1.0$$

which leads us to believe that the process is capable.

Discussion Questions

1. Explain the three categories of statistical quality control (SQC). How are they different, what different information do they provide, and how can they be used together?

2. Describe three recent situations in which you were directly affected by poor product or service quality.

3. Discuss the key differences between common and assignable causes of variation. Give examples.

4. Describe a quality control chart and how it can be used. What are upper and lower control limits? What does it mean if an observation falls outside the control limits?

5. Explain the differences between x-bar and R-charts. How can they be used together and why would it be important to use them together?

6. Explain the use of p-charts and c-charts. When would you use one rather than the other? Give examples of measurements for both p-charts and c-charts.

7. Explain what is meant by process capability. Why is it important? What does it tell us? How can it be measured?

8. Describe the process of acceptance sampling. What types of sampling plans are there? What is acceptance sampling used for?

9. Describe the concept of Six Sigma quality. Why is such a high quality level important?

Problems

1. A quality control manager at a manufacturing facility has taken 4 samples with 4 observations each of the diameter of a part.
   (a) Compute the mean of each sample.
   (b) Compute an estimate of the mean and standard deviation of the sampling distribution.
   (c) Develop control limits for 3 standard deviations of the product diameter.

Samples of Part Diameter in Inches

1	2	3	4
5.8	6.2	6.1	6.0
5.9	6.0	5.9	5.9
6.0	5.9	6.0	5.9
6.1	5.9	5.8	6.1

2. A quality control inspector at the Beautiful Shampoo Company has taken 3 samples with 4 observations each of the volume of shampoo bottles filled. The data collected by the inspector and the computed means are shown here:

Samples of Shampoo Bottle Volume in Ounces

Observation	1	2	3
1	19.7	19.7	19.7
2	20.6	20.2	18.7
3	18.9	18.9	21.6
4	20.8	20.7	20.0
Mean	20.0	19.875	20.0

If the standard deviation of the shampoo bottle filling operation is .2 ounces, use the information in the table to develop control limits of 3 standard deviations for the operation.

3. A quality control inspector has taken 4 samples with 5 observations each at the Beautiful Shampoo Company, measuring the volume of shampoo per bottle. If the average range for the 4 samples is .4 ounces and the average mean of the observations is 19.8 ounces, develop three sigma control limits for the bottling operation.

4. A production manager at Ultra Clean Dishwashing company is monitoring the quality of the company's production process. There has been concern relative to the quality of the operation to accurately fill the 16 ounces of dishwashing liquid. The product is designed for a fill level of 16.00 ± 0.30. The company collected the following sample data on the production process:

	Observations			
Sample	1	2	3	4
1	16.40	16.11	15.90	15.78
2	15.97	16.10	16.20	15.81
3	15.91	16.00	16.04	15.92
4	16.20	16.21	15.93	15.95
5	15.87	16.21	16.34	16.43
6	15.43	15.49	15.55	15.92
7	16.43	16.21	15.99	16.00
8	15.50	15.92	l6.12	16.02
9	16.13	16.21	16.05	16.01
10	15.68	16.43	16.20	15.97

   (a) Are the process mean and range in statistical control?
   (b) Do you think this process is capable of meeting the design standard?

5. Ten samples with 5 observations each have been taken from the Beautiful Shampoo Company plant in order to test for volume dispersion in the shampoo bottle filling process. The average sample range was found to be .3 ounces. Develop control limits for the sample range.

6. The Awake Coffee Company produces gourmet instant coffee. The company wants to be sure that the average fill of coffee containers is 12.0 ounces. To make sure the process is in control, a worker periodically selects at random a box containing 6 containers of coffee and measures their weight. When the process is in control, the range of the weight of coffee samples averages .6 ounces.
   (a) Develop an R-chart and an $\bar{x}$-chart for this process.
   (b) The measurements of weight from the last five samples taken of the 6 containers are shown below:

Is the process in control? Explain your answer.

Sample	$\bar{x}$	R
1	12.1	.7
2	11.8	.4
3	12.3	.6
4	11.5	.4
5	11.6	.9

7. A production manager at a Contour Manufacturing plant has inspected the number of defective plastic molds in 5 random samples of 20 observations each. Following are the number of defective molds found in each sample:

Sample	Number of Defects	Number of Observations in Sample
1	1	20
2	2	20
3	2	20
4	1	20
5	0	20
Total	6	100

Construct a three-sigma control chart ($z = 3$) with this information.

8. A tire manufacturer has been concerned about the number of defective tires found recently. In order to evaluate the true magnitude of the problem, a production manager selected ten random samples of 20 units each for inspection. The number of defective tires found in each sample are as follows:

(a) Develop a p-chart with a $z = 3$.

(b) Suppose that the next 4 samples selected had 6, 3, 3, and 4 defects. What conclusion can you make?

Sample	Number Defective
1	1
2	3
3	2
4	1
5	4
6	1
7	2
8	0
9	3
10	1

9. U-learn University uses a c-chart to monitor student complaints per week. Complaints have been recorded over the past 10 weeks. Develop three-sigma control limits using the following data:

Week	Number of Complaints
1	0
2	3
3	1
4	1
5	0
6	0
7	3
8	1
9	1
10	2

10. University Hospital has been concerned with the number of errors found in its billing statements to patients. An audit of 100 bills per week over the past 12 weeks revealed the following number of errors:

Week	Number of Errors
1	4
2	5
3	6
4	6
5	3
6	2
7	6
8	7
9	3
10	4
11	4
12	4

(a) Develop control charts with $z = 3$.

(b) Is the process in control?

11. Three ice cream packing machines at the Creamy Treat Company are being evaluated for their capability. The following data are recorded:

Packing Machine	Standard Deviation
A	.2
B	.3
C	.05

If specifications are set between 15.8 and 16.2 ounces, determine which of the machines are capable of producing within specifications.

12. Compute the C_{pk} measure of process capability for the following machine and interpret the findings. What value would you have obtained with the C_p measure?

Machine Data: USL = 100
LSL = 70
Process $\sigma = 5$
Process $\mu = 80$

13. Develop an OC curve for a sampling plan in which a sample of $n = 5$ items is drawn from lots of $N = 1000$ items. The accept/reject criteria are set up in such a way that we accept a lot if no more than one defect ($c = 1$) is found.

14. Quality Style manufactures self-assembling furniture. To reduce the cost of returned orders, the manager of its quality control department inspects the final packages each day using randomly selected samples. The defects include wrong parts, missing connection parts, parts with apparent painting problems, and parts with rough surfaces. The average defect rate is three per day.

(a) Which type of control chart should be used? Construct a control chart with three-sigma control limits.

(b) Today the manager discovered nine defects. What does this mean?

15. Develop an OC curve for a sampling plan in which a sample of $n = 10$ items is drawn from lots of $N = 1000$. The accept/reject criteria is set up in such a way that we accept a lot if no more than one defect ($c = 1$) is found.

16. The Fresh Pie Company purchases apples from a local farm to be used in preparing the filling for their apple pies. Sometimes the apples are fresh and ripe. Other times they can be spoiled or not ripe enough. The company has decided that they need an acceptance sampling plan for the purchased apples. Fresh Pie has decided that the acceptable quality level is 5 defective apples per 100, and the lot tolerance proportion defective is 5%. Producer's risk should be no more than 5% and consumer's risk 10% or less.

(a) Develop a plan that satisfies the above requirements.

(b) Determine the AOQL for your plan, assuming that the lot size is 1000 apples.

17. A computer manufacturer purchases microchips from a world-class supplier. The buyer has a lot tolerance proportion defective of 10 parts in 5000, with a consumer's risk of 15%. If the computer manufacturer decides to sample 2000 of the microchips received in each shipment, what acceptance number, c, would they want?

18. Joshua Simms has recently been placed in charge of purchasing at the Med-Tech Labs, a medical testing laboratory. His job is to purchase testing equipment and supplies. Med-Tech currently has a contract with a reputable supplier in the industry. Joshua's job is to design an appropriate acceptance sampling plan for Med-Tech. The contract with the supplier states that the acceptable quality level is 1% defective. Also, the lot tolerance proportion defective is 4%, the producer's risk is 5%, and the consumer's risk is 10%.

(a) Develop an acceptance sampling plan for Joshua that meets the stated criteria.

(b) Draw the OC curve for the plan you developed.

(c) What is the AOQL of your plan, assuming a lot size of 1000?

19. Breeze Toothpaste Company makes tubes of toothpaste. The product is produced and then pumped into tubes and capped. The production manager is concerned whether the filling process for the tubes of toothpaste is in statistical control. The process should be centered on 6 ounces per tube. Six samples of 5 tubes were taken and each tube was weighed. The weights are:

	Ounces of Toothpaste per Tube				
Sample	1	2	3	4	5
1	5.78	6.34	6.24	5.23	6.12
2	5.89	5.87	6.12	6.21	5.99
3	6.22	5.78	5.76	6.02	6.10
4	6.02	5.56	6.21	6.23	6.00
5	5.77	5.76	5.87	5.78	6.03
6	6.00	5.89	6.02	5.98	5.78

(a) Develop a control chart for the mean and range for the available toothpaste data.

(b) Plot the observations on the control chart and comment on your findings.

20. Breeze Toothpaste Company has been having a problem with some of the tubes of toothpaste leaking. The tubes are packed in containers with 100 tubes each. Ten containers of toothpaste have been sampled. The following number of toothpaste tubes were found to have leaks:

Sample	Number of Leaky Tubes	Sample	Number of Leaky Tubes
1	4	6	6
2	8	7	10
3	12	8	9
4	11	9	5
5	12	10	8
		Total	85

Develop a p-chart with three-sigma control limits and evaluate whether the process is in statistical control.

21. The Crunchy Potato Chip Company packages potato chips in a process designed for 10.0 ounces of chips with an upper specification limit of 10.5 ounces and a lower specification limit of 9.5 ounces. The packaging process results in bags with an average net weight of 9.8 ounces and a standard deviation of 0.12 ounces. The company wants to determine if the process is capable of meeting design specifications.

22. The Crunchy Potato Chip Company sells chips in boxes with a net weight of 30 ounces per box (850 grams). Each box contains 10 individual 3-ounce packets of chips. Product design specifications call for the packet-filling process average to be set at 86.0 grams so that the average net weight per box will be 860 grams. Specification width is set for the box to weigh 850 ± 12 grams. The standard deviation of the packet-filling process is 8.0 grams. The target process capability ratio is 1.33. The production manager has just learned that the packet-filling process average weight has dropped down to 85.0 grams. Is the packaging process capable? Is an adjustment needed?

CASE: Scharadin Hotels

Scharadin Hotels are a national hotel chain started in 1957 by Milo Scharadin. What started as one upscale hotel in New York City turned into a highly reputable national hotel chain. Today Scharadin Hotels serve over 100 1ocations and are recognized for their customer service and quality. Scharadin Hotels are typically located in large metropolitan areas close to convention centers and centers of commerce. They cater to both business and nonbusiness customers and offer a wide array of services. Maintaining high customer service has been considered a priority for the hotel chain.

A Problem with Quality

The Scharadin Hotel in San Antonio, Texas, had recently been experiencing a large number of guest complaints due to billing errors. The complaints seem to center around guests disputing charges on their final hotel bill. Guest complaints ranged from extra charges, such as meals or services that were not purchased, to confusion for not being charged at all. Most hotel guests use express checkout on their day of departure. With express checkout the hotel bill is left under the guest's door in the early morning hours and, if all is in order, does not require any additional action on the guest's part. Express checkout is a welcome service by busy travelers who are free to depart the hotel at their convenience. However, the increased number of billing errors began creating unnecessary delays and frustration for the guests who unexpectedly needed to settle their bill with the front desk. The hotel staff often had to calm frustrated guests who were rushing to the airport and were aggravated that they were getting charged for items they had not purchased.

Identifying the Source of the Problem

Larraine Scharadin, Milo Scharadin's niece, had recently been appointed to run the San Antonio hotel. A recent business school graduate, Larraine had grown up in the hotel business. She was poised and confident, and understood the importance of high quality for the hotel. When she became aware of the billing problem, she immediately called a staff meeting to uncover the source of the problem.

During the staff meeting discussion quickly turned to problems with the new computer system and software that had been put in place. Tim Coleman, head of MIS, defended the system, stating that the system was sound and the problems were exaggerated. Tim claimed that a few hotel guests made an issue of a few random problems. Scott Schultz, head of operations, was not so sure. Scott said that he noticed that the number of complaints seem to have significantly increased since the new system was installed. He said that he had asked his team to perform an audit of 50 random bills per day over the past 30 days. Scott showed the following numbers to Larraine, Tim, and the other staff members.

Day	Number of Incorrect Bills	Day	Number of Incorrect Bills	Day	Number of Incorrect Bills
1	2	11	1	21	3
2	2	12	2	22	3
3	1	13	3	23	3
4	2	14	3	24	4
5	2	15	2	25	5
6	3	16	3	26	5
7	2	17	2	27	6
8	2	18	2	28	5
9	1	19	1	29	5
10	2	20	3	30	5

Everyone looked at the data that had been presented. Then Tim exclaimed: "Notice that the number of errors increases in the last third of the month. The computer system had been in place for the entire month so that can't be the problem. Scott, it is probably the new employees you have on staff that are not entering the data properly." Scott quickly retaliated: "The employees are trained properly! Everyone knows the problem is the computer system!"

The argument between Tim and Scott become heated, and Larraine decided to step in. She said, "Scott, I think it is best if you perform some statistical analysis of that data and send us your findings. You know that we want a high-quality standard. We can't be Motorola with six-sigma quantity, but let's try for three-sigma. Would you develop some control charts with the data and let us know if you think the process is in control?"

Case Questions

1. Set up three-sigma control limits with the given data.
2. Is the process in control? Why?
3. Based on your analysis do you think the problem is the new computer system or something else?
4. What advice would you give to Larraine based on the information that you have?

CASE: Delta Plastics, Inc. (B)

Jose De Costa, Director of Manufacturing at Delta Plastics, sat at his desk looking at the latest production quality report, showing the number and type of product defects per week (see the quality report in Delta Plastics, Inc. Case A, Chapter 5). He was faced with the task of evaluating production quality for products made with two different materials. One of the materials was new and called "super plastic" due to its ability to sustain large temperature changes. The other material was the standard plastic that had been successfully used by Delta for many years.

The company had started producing products with the new "super plastic" material only a month earlier. Jose suspected that the new material could result in more defects during the production process than the standard material they had been using. Jose was opposed to starting production until R&D had fully completed testing and refining the new material. However, the CEO of Delta ordered production despite objections from manufacturing and R&D. Jose carefully looked at the report in front of him and prepared to analyze the results.

Case Questions

1. Prepare a three-sigma control chart for both production processes, using the new and standard material (use the quality report in Delta Plastics, Inc. Case A, Chapter 5). Are both processes in control? What can you conclude?
2. Are both materials equally subject to the defects?
3. Given your findings, what advice would you give Jose?

Interactive Learning

Enhance and test your knowledge of Chapter 6. Use the CD and visit our Web site, www.wiley.com/college/reid, for additional resources and information.

1. **Spreadsheets** *Solved Problems 1 and 4*
2. **Company Tours**
   Rickenbacker International Corporation
   Genesis Technologies, Inc.
   Canadian Springs Water Company
3. **Additional Web Resources**
   American Society for Quality Control, www.asqc.org
   Australian Quality Council, www.aqc.org.au
4. **Internet Challenge** *Safe-Air*

To gain business experience, you have volunteered to work at Safe-Air, a nonprofit agency that monitors airline safety records and customer service. Your first assignment is to compare three airlines based on their on-time arrivals and departures. Your manager has asked you to get your information from the Internet. Select any three airlines. For an entire week check the daily arrival and departure schedules of the three airlines from your city or closest airport. Remember that it is important to compare the arrivals and departures from the same location and during the same time period to account for factors such as the weather. Record the data that you collect for each airline. Then decide which types of statistical quality control tools you are going to use to evaluate the airlines' performances. Based on your findings, draw a conclusion regarding the on-time arrivals and departures of each of the airlines. Which is best and which is worst? Are there large differences in performance among the airlines? Also describe the statistical quality control tools you have decided to use to monitor performance. If you have chosen to use more than one tool, are you finding the tools equally useful or is one better at capturing differences in performance? Finally, based on what you have learned so far, how would you perform this analysis differently in the future?

Virtual Company: Valley Memorial Hospital

Assignment: *Statistical Quality Control* This assignment involves controlling nursing hours at Valley Memorial Hospital. Lee Jordan, director of the hospital's Medical/Surgical Nursing Unit, has already told you that VMH employs more than 500 nurses, with an annual nursing budget of $5,000,000. "We're trying for a five

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percent reduction in nursing FTEs—full-time equivalents," he says. "I've been personally recording the nursing hours per patient per day for over three months in Med/Surg. I would like you to look at the numbers and see if you can tell me how to meet our goals.

To complete this assignment, go to **www.wiley.com/college/reid** to get more details on the following projects:

1. Develop upper and lower limits for FTEs within which the Medical/Surgical Nursing Unit will be efficient and will maintain quality at least 95 percent of the time.
2. Look at the data and determine whether Jordan is really in control of nursing hours. If he isn't, tell him why.
3. Determine how the Medical/Surgical Nursing Unit can bring nursing hours per patient day (NHPPD) down to 8.00. Also, provide some advice on how Jordan can get his staff to buy into the concept of an NHPPD target of 8.00.
4. Jot down your thoughts on the three statistical problems, which are contained in memos Jordan received from other VMH staff:

   - Will Hartmann, in the Business Office has kept track of billing errors for the past 21 weeks. Based on this data, determine control limits for billing errors. Also, is the percentage of defective bills a valid measure for this analysis?
   - Analyze trends in patient surveys about the meals served at VMH. Doug Jennings, in Dietary, thinks the number of OUTSTANDING responses has been declining, but he's not sure if that decline is statistically significant.
   - Margot Hamilton, in Housekeeping, has been keeping track of defects in room cleaning. Based on her data, develop some recommendations on how she can get better results.

To access the Web site:

- Go to **www.wiley.com/college/reid**
- Click **Student Companion Site**
- Click **Virtual Company**
- Click **Kaizen Consulting, Inc.**
- Click **Consulting Assignments**
- Click **Statistical Quality Control**

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