

## **Chapter 1**

# ***Quality Improvement in the Modern Business Environment***

### **LEARNING OBJECTIVES**

After completing this chapter you should be able to:

1. Define and discuss quality and quality improvement
2. Discuss the different dimensions of quality
3. Discuss the evolution of modern quality improvement methods
4. Discuss the role that variability and statistical methods play in controlling and improving quality
5. Describe the quality management philosophies of W. Edwards Deming, Joseph M. Juran, and Armand V. Feigenbaum
6. Discuss total quality management, the Malcolm Baldrige National Quality Award, Six-Sigma, and quality systems and standards
7. Explain the links between quality and productivity and between quality and cost
8. Discuss product liability
9. Discuss the three functions: quality planning, quality assurance, and quality control and improvement

### **IMPORTANT TERMS AND CONCEPTS**

Acceptance sampling

Appraisal costs

Deming's 14 points

Designed experiments

Dimensions of quality

Fitness for use

Internal and External failure costs

ISO 9000:2005

Nonconforming product or service

Prevention costs

Product liability

Quality assurance

Quality characteristics

Quality control and improvement

Quality engineering

Quality of conformance

Quality of design

Quality planning

Quality systems and standards

Six-Sigma

Specifications

Statistical process control (SPC)

The Juran Trilogy

The Malcolm Baldrige National Quality Award

Total quality management (TQM)

Variability

## COMMENTS

The modern definition of quality, “Quality is inversely proportional to variability” (text p. 6), implies that product quality increases as variability in important product characteristics decreases. Quality improvement can then be defined as “... the reduction of variability in processes and products” (text p. 7). Since the early 1900’s, statistical methods have been used to control and improve quality. In the Introduction to Statistical Quality Control, 7th ed., by Douglas C. Montgomery, methods applicable in the key areas of process control, design of experiments, and acceptance sampling are presented.

To understand the potential for application of statistical methods, it may help to envision the system that creates a product as a “black box” (text Figure 1-3). The output of this black box is a product whose quality is defined by one or more quality characteristics that represent dimensions such as conformance to standards, performance, or reliability. Product quality can be evaluated with acceptance sampling plans. These plans are typically applied to either the output of a process or the input raw materials and components used in manufacturing. Application of process control techniques (such as control charts) or statistically designed experiments can achieve significant reduction in variability.

Black box inputs are categorized as “incoming raw materials and parts,” “controllable inputs,” and “uncontrollable inputs.”

The quality of incoming raw materials and parts is often assessed with acceptance sampling plans. As material is received from suppliers, incoming lots are inspected then dispositioned as either acceptable or unacceptable. Once a history of high quality material is established, a customer may accept the supplier’s process control data in lieu of incoming inspection results.

“Controllable” and “uncontrollable” inputs apply to incoming materials, process variables, and environmental factors. For example, it may be difficult to control the temperature in a heat-treating oven in the sense that some areas of the oven may be cooler while some areas may be warmer. Properties of incoming materials may be very difficult to control. For example, the moisture content and proportion of hardwood in trees used for papermaking have a significant impact on the quality characteristics of the finished paper. Environmental variables such as temperature and relative humidity are often hard to control precisely.

Whether or not controllable and uncontrollable inputs are significant can be determined through process characterization. Statistically designed experiments are extremely helpful in characterizing processes and optimizing the relationship between incoming materials, process variables, and product characteristics.

Although the initial tendency is to think of manufacturing processes and products, the statistical methods presented in this text can also be applied to business processes and products, such as financial transactions and services. In some organizations the opportunity to improve quality in three areas is even greater than it is in manufacturing.

Various quality philosophies and management systems are briefly described in the text; a common thread is the necessity for continuous improvement to increase productivity and reduce cost. The technical tools described in the text are essential for successful quality improvement. Quality management systems alone do not reduce variability and improve quality.

# Chapter 2

## The DMAIC Process

### LEARNING OBJECTIVES

After completing this chapter you should be able to:

- 1. Understand the importance of selecting good projects for improvement activities
- 2. Explain the five steps of DMAIC: Define, Measure, Analyze, Improve, and Control
- 3. Explain the purpose of tollgate reviews
- 4. Understand the decision-making requirements of the tollgate review for each DMAIC step
- 5. Know when and when not to use DMAIC
- 6. Understand how DMAIC fits into the framework of the Six Sigma philosophy

### IMPORTANT TERMS AND CONCEPTS

Analyze step	Key process input variables (KPIV)
Control step	Key process output variables (KPOV)
Define step	Measure step
Design for Six Sigma (DFSS)	Project charter
DMAIC	SIPOC diagram
Failure modes and effects analysis (FMEA)	Six Sigma
Improve step	Tollgate

## 2-2 CHAPTER 2 THE DMAIC PROCESS

### EXERCISES

**2.7.** Explain the importance of tollgates in the DMAIC process.

At a tollgate, a project team presents its work to managers and “owners” of the process. In a six-sigma organization, the tollgate participants also would include the project champion, master black belts, and other black belts not working directly on the project. Tollgates are where the project is reviewed to ensure that it is on track and they provide a continuing opportunity to evaluate whether the team can successfully complete the project on schedule. Tollgates also present an opportunity to provide guidance regarding the use of specific technical tools and other information about the problem. Organization problems and other barriers to success—and strategies for dealing with them—also often are identified during tollgate reviews. Tollgates are critical to the overall problem-solving process; It is important that these reviews be conducted very soon after the team completes each step.

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**2.11.** Suppose that your business is operating at the three-sigma quality level. If projects have an average improvement rate of 50% annually, how many years will it take to achieve Six Sigma quality?

$$3.4 = 66,810(1 - 0.5)^x$$

$$3.4 / 66,810 = 0.5^x$$

$$\ln(3.4 / 66,810) = x \ln 0.5$$

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$$x = \frac{\ln(3.4 / 66,810)}{\ln 0.5} = 14.26 \text{ years} \approx 14 \text{ years, 3 months}$$

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**2.12.** Suppose that your business is operating at the 5-sigma quality level. If projects have an average improvement rate of 50% annually, how many years will it take to achieve Six Sigma quality?

5 sigma quality is approximately 233 ppm defective, assuming the customary  $1.5\sigma$  shift in mean (Figure 1.2(b)).

$$3.4 = 233(1 - 0.5)^x$$

$$3.4 / 233 = 0.5^x$$

$$\ln(3.4 / 233) = x \ln 0.5$$

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$$x = \frac{\ln(3.4 / 233)}{\ln 0.5} = 6.2 \text{ years} \approx 6 \text{ years, 1 month}$$

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**2.13.** Explain why it is important to separate sources of variability into special or assignable causes and common or chance causes.

Common or chance causes are due to the inherent variability in the system and cannot generally be controlled. Special or assignable causes can be discovered and removed, thus reducing the variability in the overall system. It is important to distinguish between the two types of variability, because the strategy to reduce variability depends on the source. Chance cause variability can only be removed by changing the system, while assignable cause variability can be addressed by finding and eliminating the assignable causes.

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**2.15.** Suppose that during the analyze phase an obvious solution is discovered. Should that solution be immediately implemented and the remaining steps of DMAIC abandoned? Discuss your answer.

Generally, no. The advantage of completing the rest of the DMAIC process is that the solution will be documented, tested, and its applicability to other parts of the business will be evaluated. An immediate implementation of an “obvious” solution may not lead to an appropriate control plan. Completing the rest of DMAIC can also lead to further refinements and improvements to the solution.

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**2.18.** It has been estimated that safe aircraft carrier landings operate at about the  $5\sigma$  level. What level of ppm defective does this imply?

If the operating limits are around the  $5\sigma$  level, and we assume the  $1.5\sigma$  shift in the mean customary for Six Sigma applications, then the probability of a safe landing is the area under the normal curve that is within  $5\sigma$  of the target mean, given that the true mean is  $1.5\sigma$  off of the target mean. Thus, the probability of a safe landing is 0.999767 and the corresponding ppm defective is  $(1 - 0.999767) \times 1,000,000 = 233$ .

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# Chapter 3

## Modeling Process Quality

### LEARNING OBJECTIVES

After completing this chapter you should be able to:

1. Construct and interpret visual data displays, including the stem-and-leaf plot, the histogram, and the box plot
2. Compute and interpret the sample mean, the sample variance, the sample standard deviation, and the sample range
3. Explain the concepts of a random variable and a probability distribution
4. Understand and interpret the mean, variance, and standard deviation of a probability distribution
5. Determine probabilities from probability distributions
6. Understand the assumptions for each of the discrete probability distributions presented
7. Understand the assumptions for each of the continuous probability distributions presented
8. Select an appropriate probability distribution
9. Use probability plots
10. Use approximations for some hypergeometric and binomial distributions

### IMPORTANT TERMS AND CONCEPTS

Approximations to probability distributions	Percentile
Binomial distribution	Poisson distribution
Box plot	Population
Central limit theorem	Probability distribution
Continuous distribution	Probability plotting
Descriptive statistics	Quartile
Discrete distribution	Random variable
Exponential distribution	Run chart
Gamma distribution	Sample
Geometric distribution	Sample average
Histogram	Sample standard deviation
Hypergeometric probability distribution	Sample variance
Interquartile range	Standard deviation

Variable	Maximum
Ex3-1	16.070



3.2.

The bore diameters of eight randomly selected bearings are shown here (in mm): 50.001, 50.002, 49.998, 49.997, 50.000, 49.996, 50.003, 50.004

(a) Calculate the sample average.

$$\bar{x} = \sum_{i=1}^n x_i / n = (50.001 + 49.998 + \cdots + 50.004) / 8 = 50.000 \text{ mm}$$

(b) Calculate the sample standard deviation.

$$s = \sqrt{\frac{\sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i\right)^2 / n}{n-1}} = \sqrt{\frac{(50.001^2 + \cdots + 50.004^2) - (50.001 + \cdots + 50.004)^2 / 8}{8-1}} = 0.0029 \text{ mm}$$

MTB > Stat > Basic Statistics > Display Descriptive Statistics									
Descriptive Statistics: Ex3-2									
Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3
Ex3-2	8	0	50.000	0.00103	0.00290	49.996	49.997	50.001	50.003
Variable	Maximum								
Ex3-2	50.004								

3.3. ☺

The service time in minutes from admit to discharge for ten patients seeking care in a hospital emergency department are 21, 136, 185, 156, 3, 16, 48, 28, 100, and 12. Calculate the mean and standard deviation of the service time.

MTB > Stat > Basic Statistics > Display Descriptive Statistics										
Descriptive Statistics: Ex3-3										
Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Ex3-3	10	0	70.5	21.4	67.7	3.0	15.0	38.0	141.0	185.0

Variable	Maximum
Ex3-5	959.00

[illegible]

3-6 CHAPTER 3 MODELING PROCESS QUALITY

3.8.

The time to failure in hours of an electronic component subjected to an accelerated life test is shown in Table 3E.1. To accelerate the failure test, the units were tested at an elevated temperature (read down, then across).

TABLE 3E.1			
Electronic Component Failure Time			
127	124	121	117
125	123	136	131
132	120	140	125
124	119	137	133
129	128	125	141
121	133	124	125
142	137	128	140
151	124	129	131
161	143	130	129
125	123	123	126

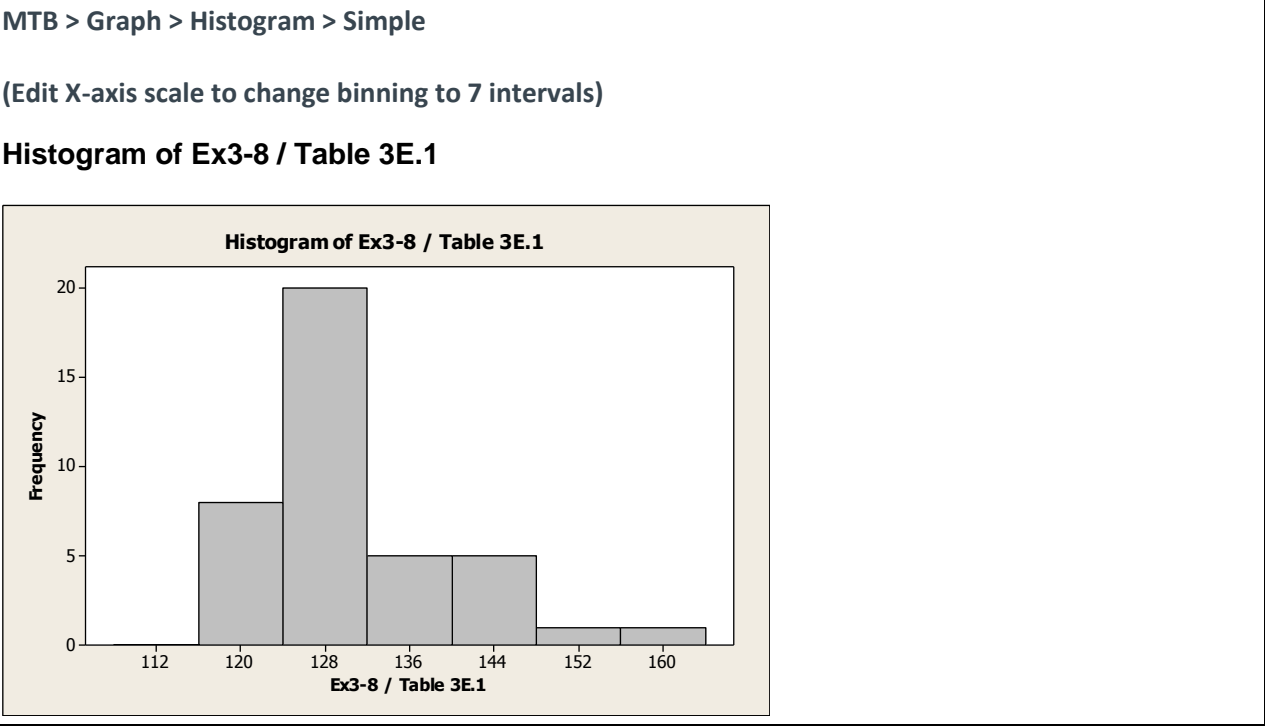
- (a) Calculate the sample average and standard deviation.
- (d) Find the sample median and the lower and upper quartiles.

MTB > Stat > Basic Statistics > Display Descriptive Statistics									
Descriptive Statistics: Ex3-8_Table 3E.1									
Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	
Ex3-8_Table 3E.1	40	0	130.05	1.43	9.06	117.00	124.00	128.00	
Variable		Q3	Maximum						
Ex3-8_Table 3E.1		135.25	161.00						

3.8. continued

(b) Construct a histogram.

Use  $\sqrt{n} = \sqrt{40} \cong 7$  bins



Note that the histogram has 6 bins. The number of bins can be changed by editing the X scale. However, when 7 bins are specified, Minitab generates a 6-bin histogram. Constructing a 7-bin histogram requires manual specification of the bin cut points. Recall that this formula is an approximation, and therefore either 6 or 8 bins should suffice for assessing the distribution of the data.

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**3.8. continued**

(c) Construct a stem-and-leaf plot.



3.9.

The data shown in Table 3E.2 are chemical process yield readings on successive days (read down, then across). Construct a histogram for these data. Comment on the shape of the histogram. Does it resemble any of the distributions that we have discussed in this chapter?

■ TABLE 3E.2  
Process Yield

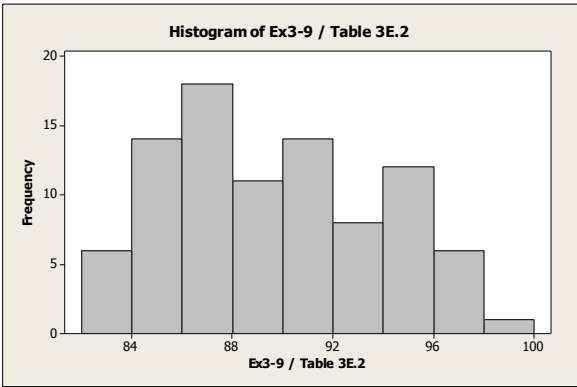
94.1	87.3	94.1	92.4	84.6	85.4
93.2	84.1	92.1	90.6	83.6	86.6
90.6	90.1	96.4	89.1	85.4	91.7
91.4	95.2	88.2	88.8	89.7	87.5
88.2	86.1	86.4	86.4	87.6	84.2
86.1	94.3	85.0	85.1	85.1	85.1
95.1	93.2	84.9	84.0	89.6	90.5
90.0	86.7	87.3	93.7	90.0	95.6
92.4	83.0	89.6	87.7	90.1	88.3
87.3	95.3	90.3	90.6	94.3	84.1
86.6	94.1	93.1	89.4	97.3	83.7
91.2	97.8	94.6	88.6	96.8	82.9
86.1	93.1	96.3	84.1	94.4	87.3
90.4	86.4	94.7	82.6	96.1	86.4
89.1	87.6	91.1	83.1	98.0	84.5

Use  $\sqrt{n} = \sqrt{90} \cong 9$  bins

MTB > Graph > Histogram > Simple

(Edit X-axis scale to change binning to 9 intervals)

Histogram of Ex3-9 / Table 3E.2



The distribution appears to have two “peaks” or central tendencies, at about 88 and 94. This is also referred to as a **bimodal** distribution. It does not resemble any of the continuous distributions discussed in this chapter (normal, lognormal, exponential, gamma, or Weibull).

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3.10.

An article in *Quality Engineering* (Vol. 4, 1992, pp. 487–495) presents viscosity data from a batch chemical process. A sample of these data is presented in Table 3E.3 (read down, then across).

■ TABLE 3E.3

Viscosity			
13.3	14.9	15.8	16.0
14.5	13.7	13.7	14.9
15.3	15.2	15.1	13.6
15.3	14.5	13.4	15.3
14.3	15.3	14.1	14.3
14.8	15.6	14.8	15.6
15.2	15.8	14.3	16.1
14.5	13.3	14.3	13.9
14.6	14.1	16.4	15.2
14.1	15.4	16.9	14.4
14.3	15.2	14.2	14.0
16.1	15.2	16.9	14.4
13.1	15.9	14.9	13.7
15.5	16.5	15.2	13.8
12.6	14.8	14.4	15.6
14.6	15.1	15.2	14.5
14.3	17.0	14.6	12.8
15.4	14.9	16.4	16.1
15.2	14.8	14.2	16.6
16.8	14.0	15.7	15.6

(a) Construct a stem-and-leaf display for the viscosity data.

Stem-and-Leaf Plot (Unordered)	
2	12o 68
6	13* 3134
12	13o 776978
28	14* 3133101332423404
(15)	14o 585669589889695
37	15* 3324223422112232
21	15o 568987666
12	16* 144011
6	16o 85996
1	17* 0
Stem	Freq Leaf



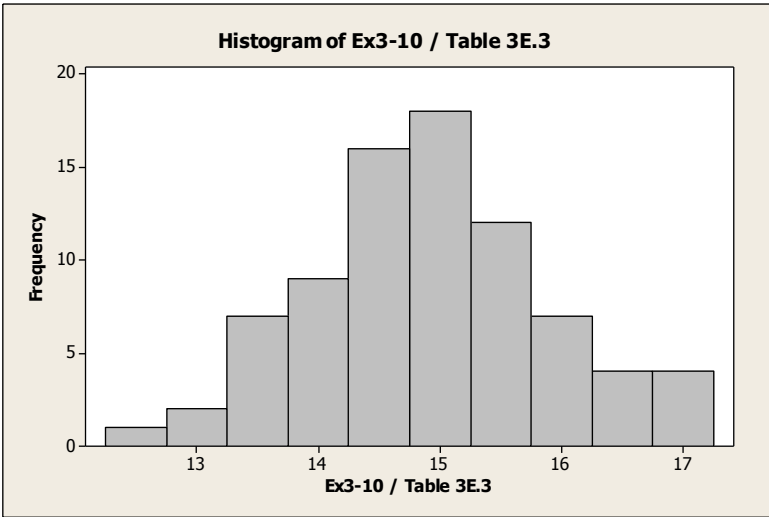
3.10. continued

(b) Construct a frequency distribution and histogram.

Use  $\sqrt{n} = \sqrt{80} \cong 9$  bins

MTB > Graph > Histogram > Simple

Histogram of Ex3-10 / Table 3E.3



(c) Convert the stem-and-leaf plot in part (a) into an ordered stem-and-leaf plot. Use this graph to assist in locating the median and the upper and lower quartiles of the viscosity data.

MTB > Graph > Stem-and-Leaf

Stem-and-Leaf Display: Ex3-10 / Table 3E.3

Stem-and-leaf of Ex3-10 / Table 3E.3 N = 80  
Leaf Unit = 0.10

```
2      12      68
6      13     1334
12     13     677789
28     14     0011122333333444
(15)   14     5555666888899999
37     15     1122222222333344
21     15     566667889
12     16     011144
6      16     56899
1      17      0
```

**3-12** CHAPTER 3 MODELING PROCESS QUALITY

**3.10.(c) continued**

median observation rank is  $(0.5)(80) + 0.5 = 40.5$

$$x_{0.50} = (14.9 + 14.9)/2 = 14.9$$

Q1 observation rank is  $(0.25)(80) + 0.5 = 20.5$

$$Q1 = (14.3 + 14.3)/2 = 14.3$$

Q3 observation rank is  $(0.75)(80) + 0.5 = 60.5$

$$Q3 = (15.6 + 15.5)/2 = 15.55$$

(d) What are the tenth and ninetieth percentiles of viscosity?

10<sup>th</sup> percentile observation rank =  $(0.10)(80) + 0.5 = 8.5$

$$x_{0.10} = (13.7 + 13.7)/2 = 13.7$$

90<sup>th</sup> percentile observation rank is  $(0.90)(80) + 0.5 = 72.5$

$$x_{0.90} = (16.4 + 16.1)/2 = 16.25$$

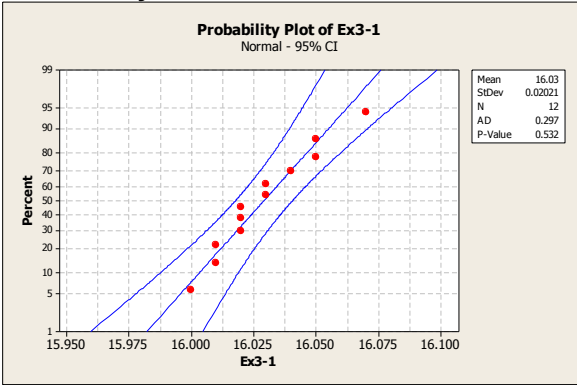
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3.11.

Construct and interpret a normal probability plot of the volumes of the liquid detergent bottles in Exercise 3.1.

MTB > Graph > Probability Plot > Simple and select Normal Distribution

Probability Plot of Ex3-1



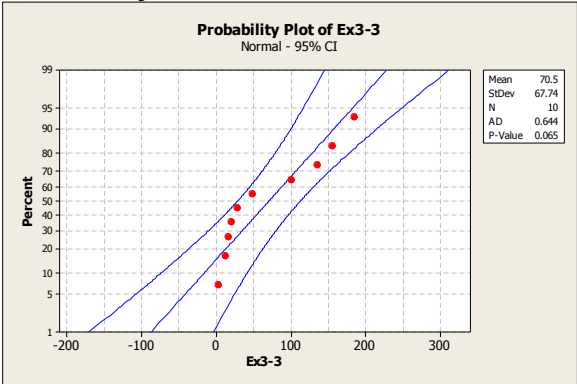
When plotted on a normal probability plot, the data points tend to fall along a straight line, indicating that a normal distribution adequately describes the volume of detergent.

3.12.

Construct and interpret a normal probability plot of the nine furnace temperature measurements in Exercise 3.5.

MTB > Graph > Probability Plot > Simple and select Normal Distribution

Probability Plot of Ex3-3



When plotted on a normal probability plot, the data points tend to fall along a straight line, indicating a normal distribution adequately describes the furnace temperatures.

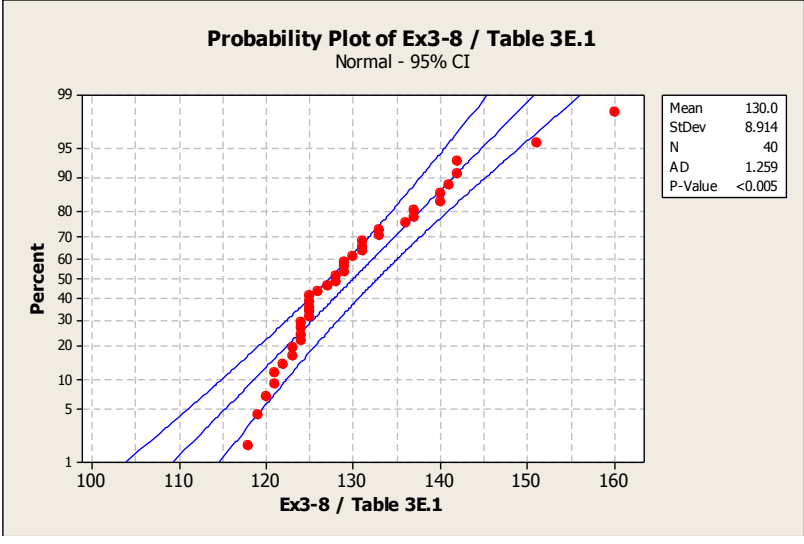
3-14 CHAPTER 3 MODELING PROCESS QUALITY

3.13.

Construct a normal probability plot of the failure time data in Exercise 3.8. Does the assumption that failure time for this component is well modeled by a normal distribution seem reasonable?

MTB > Graph > Probability Plot > Simple and select Normal Distribution

Probability Plot of Ex3-8 / Table 3E.1



When plotted on a normal probability plot, the data points do not fall along a straight line, indicating that the normal distribution does not reasonably describe the failure times.