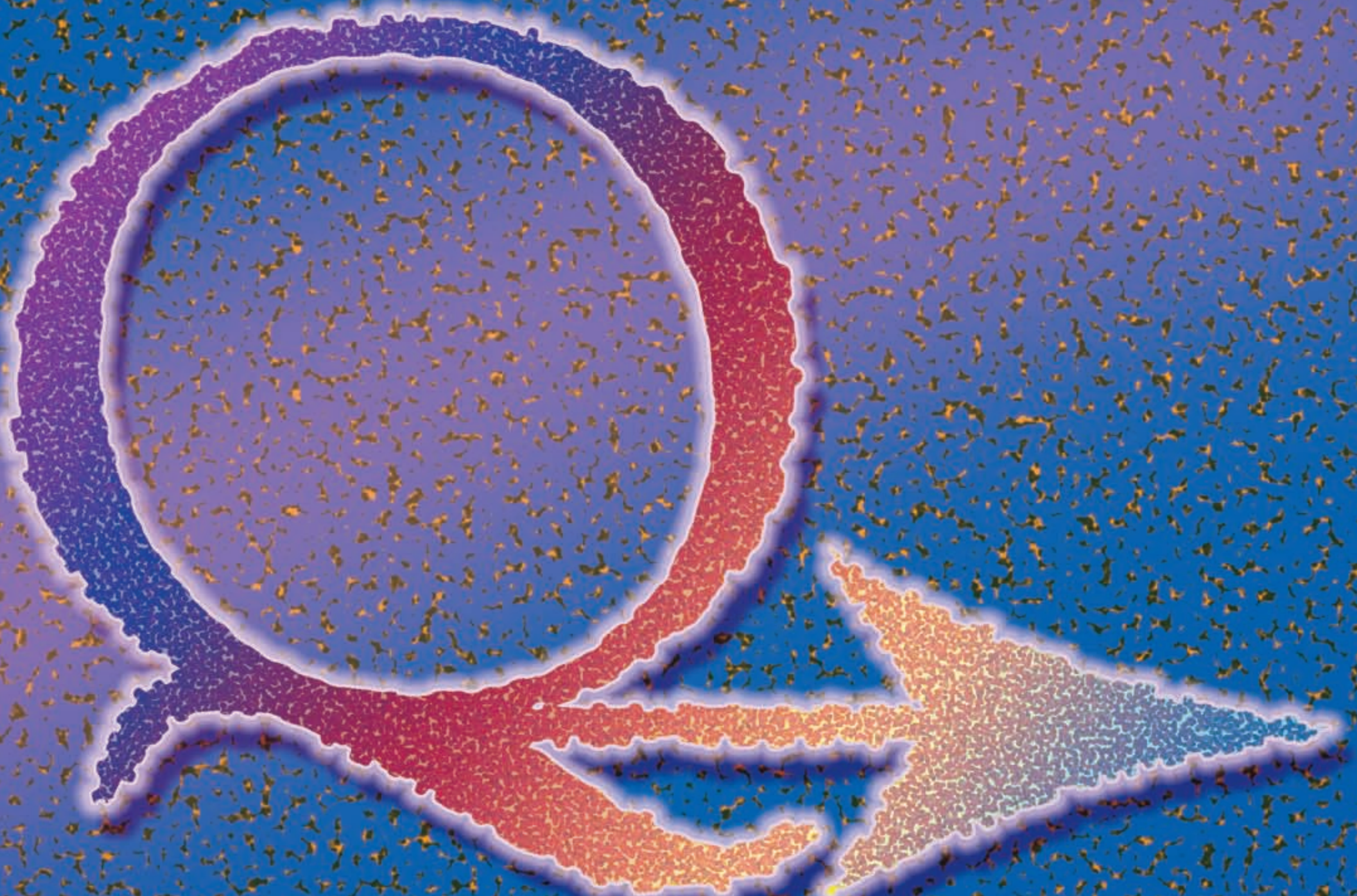
Quality

SIXTH EDITION



Donna C. S. Summers

Pearson

Formulas

Average and Range Charts

$\overline{X}$ chart:

$$\overline{\overline{X}} = \frac{\sum_{i=1}^{m} \overline{X}_i}{m}$$

$$UCL_{\overline{X}} = \overline{\overline{X}} + A_2\overline{R}$$

$$LCL_{\overline{X}} = \overline{\overline{X}} - A_2\overline{R}$$

R chart:

$$\overline{R} = \frac{\sum_{i=1}^{m} R_i}{m}$$

$$UCL_R = D_4\overline{R}$$

$$LCL_R = D_3\overline{R}$$

Revising the charts:

$$\overline{X} = \overline{\overline{X}}_{new} = \frac{\sum_{i=1}^{m} \overline{X} - \overline{X}_d}{m - m_d}$$

$$UCL_{\overline{X}} = \overline{X}_0 + A\sigma_0$$

$$LCL_{\overline{X}} = \overline{X}_0 - A\sigma_0$$

$$\sigma_0 = R_0/d_2$$

$$\overline{R}_{new} = \frac{\sum_{i=1}^{m} R - R_d}{m - m_d}$$

$$UCL_R = D_2\sigma_0$$

$$LCL_R = D_1\sigma_0$$

Average and Standard Deviation Charts

$\overline{X}$ chart:

$$\overline{\overline{X}} = \frac{\sum_{i=1}^{m} \overline{X}_i}{m}$$

$$UCL_{\overline{X}} = \overline{\overline{X}} + A_3\overline{s}$$

$$LCL_{\overline{X}} = \overline{\overline{X}} - A_3\overline{s}$$

s chart:

$$\overline{s} = \frac{\sum_{i=1}^{m} s_i}{m}$$

$$UCL_s = B_4\overline{s}$$

$$LCL_s = B_3\overline{s}$$

Revising the charts:

$$X_0 = \overline{\overline{X}}_{new} = \frac{\sum_{i=1}^{m} \overline{X} - \overline{X}_d}{m - m_d}$$

$$s_0 = \overline{s}_{new} = \frac{\sum_{i=1}^{m} s - s_d}{m - m_d}$$

and

$$\sigma_0 = s_0/c_4$$

$$UCL_{\overline{X}} = \overline{X}_0 + A\sigma_0$$

$$LCL_{\overline{X}} = \overline{X}_0 - A\sigma_0$$

$$UCL_s = B_6\sigma_0$$

$$LCL_s = B_5\sigma_0$$

Fraction Nonconforming (p) Chart

$$p = \frac{np}{n}$$

$$\text{Centerline } \overline{p} = \frac{\sum_{i=1}^{n} np}{\sum_{i=1}^{n} n}$$

$$UCL_p = \overline{p} + 3\frac{\sqrt{\overline{p}(1 - \overline{p})}}{\sqrt{n}}$$

$$LCL_p = \overline{p} - 3\frac{\sqrt{\overline{p}(1 - \overline{p})}}{\sqrt{n}}$$

Revising:

$$\overline{p}_{new} = \frac{\sum_{i=1}^{n} np - np_d}{\sum_{i=1}^{n} n - n_d}$$

$$UCL_{p_{new}} = \overline{p}_{new} + 3\frac{\sqrt{\overline{p}_{new}(1 - \overline{p}_{new})}}{\sqrt{n}}$$

$$LCL_{p_{new}} = \overline{p}_{new} - 3\frac{\sqrt{\overline{p}_{new}(1 - \overline{p}_{new})}}{\sqrt{n}}$$

The process capability of the revised chart is the newly calculated p_{new}:

$$n_{ave} = \frac{\sum_{i=1}^{n} n}{m}$$

Number Nonconforming (np) Chart

$$\text{Centerline } n\overline{p} = \frac{\sum_{i=1}^{n} np}{m}$$

$$UCL_{np} = n\overline{p} + 3\sqrt{n\overline{p}(1 - \overline{p})}$$

$$LCL_{np} = n\overline{p} - 3\sqrt{n\overline{p}(1 - \overline{p})}$$

Percent Nonconforming (100p) Chart

The centerline for a percent nonconforming chart is $100\overline{p}$.

$$UCL_{100p} = 100\left[\overline{p} + \frac{3\sqrt{\overline{p}(1 - \overline{p})}}{\sqrt{n}}\right]$$

$$LCL_{100p} = 100\left[\overline{p} - \frac{3\sqrt{\overline{p}(1 - \overline{p})}}{\sqrt{n}}\right]$$

Count of Nonconformities (c) Chart

$$n = 1$$

$$\text{Centerline } \overline{c} = \frac{\sum_{i=1}^{n} c}{m}$$

$$UCL_c = \overline{c} + 3\sqrt{\overline{c}}$$

$$LCL_c = \overline{c} - 3\sqrt{\overline{c}}$$

Revising:

$$\text{Centerline } \overline{c}_{new} = \frac{\sum_{i=1}^{n} c - c_d}{m - m_d}$$

$$UCL_{c_{new}} = \overline{c}_{new} + 3\sqrt{\overline{c}_{new}}$$

$$LCL_{c_{new}} = \overline{c}_{new} - 3\sqrt{\overline{c}_{new}}$$

Nonconformities per Unit (u) Chart

$$n > 1$$

$$u = \frac{c}{n}$$

$$\text{Centerline } \overline{u} = \frac{\sum_{i=1}^{n} c}{\sum_{i=1}^{n} n}$$

$$UCL_u = \overline{u} + 3\frac{\sqrt{\overline{u}}}{\sqrt{n}}$$

$$LCL_u = \overline{u} - 3\frac{\sqrt{\overline{u}}}{\sqrt{n}}$$

Quality

Sixth Edition

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Pearson

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To Karl
with
gratitude and love

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PREFACE

While waiting my turn at the dentist's office, I busily marked up a copy of the fifth edition of this text in preparation for a new edition. Much to my surprise, a woman scolded me for writing in a book. To no avail, I tried to explain that it was my book, meaning not only did I own it but I wrote it. Instead she continued to lecture me on the perils of defacing a book. The experience caused me to think about quality improvement and how we relate to it. Quality improvement is a personal choice and requires commitment in the face of opposition. This book is designed to teach tools and techniques that can enhance your ability to do your job. So read the text, highlight it, circle key ideas, mark it up, make quality your own. Use it to make yourself a success. Can you think of a single organization that would not be interested in improving quality, productivity, financial results, and safety? It would be a rare company indeed that did not value these types of improvements. This text uses real-life examples to teach and explain a wide variety of improvement tools. Contributors have a variety of responsibilities and experiences: engineers, business managers, quality assurance professionals, program and project managers, distribution and warehousing managers, utility distribution managers, and safety professionals. The industries they represent are just as diverse: government, utilities, building trades, manufacturing, armed forces, hospitals, and even the ballet. Although the names have been changed, only minor modifications have been made to make it possible to use their experiences as teaching examples.

HOW THIS BOOK DIFFERS FROM OTHERS ON THE MARKET

While no text can be all things to all readers, this text provides insightful case studies, clear explanations of popular quality tools and techniques, plentiful illustrations to support explanations, and subject matter relevant to the challenges faced by today's organizations. This text utilizes industry examples in each chapter to enhance readers' understanding of the mechanics of the tools. As a way of linking ideas and training, woven throughout the chapters are the adventures of JRPS.

Also included are example problems titled **Real Tools for Real Life**. Less mathematically detailed, yet more comprehensive, Real Tools for Real Life examples provide insight into how a combination of quality tools and techniques may be applied to resolve a customer issue. These examples complement the *learning through applications* theme of the text.

NEW TO THIS EDITION

The following is a list of key changes that have been made to this edition:

- Significantly Updated ISO 9000 material
- Increased focus on Six Sigma
- Expanded chapter topic coverage
- Reorganized chapters
- Updated examples
- Updated verbiage
- New chapter problems
- New PowerPoint presentations for each chapter

To ensure appropriate topic coverage, the material covered has been selected based on the Certified Quality Engineer certification available through the American Society for Quality. As an additional check, the material in this text has been reviewed by members of industry.

KEY FEATURES OF THE TEXT

The unique features of this text were designed to develop a greater understanding of the complexities of quality improvement efforts. The use of comprehensive examples and case studies continues to be the book's strongest feature. Taken from real-life situations, these examples and cases support learning by asking readers to consider the application and interpretation of the quality assurance techniques they have studied.

There are four key features of this text:

1. Emphasis is placed on the practical application of quality principles; process improvement and reduction of variation serve as the underlying themes.
2. Emphasis is also placed on the interpretation, understanding, and use of quality principles and concepts throughout the problem-solving process.
3. Detailed examples and case studies from a wide variety of industries, based on real-life situations, provide the student with an understanding of the knowledge and effort necessary to solve quality problems.
4. Within each chapter, continuity in student learning is maintained through the use of certain elements—a list of learning opportunities, italicized key words and concepts, integrated examples, a summary of lessons learned, formula summaries, and case studies.

ORGANIZATION OF THE TEXT

The text is divided into four parts: Setting the Stage, Control Charts for Variables, Control Charts for Attributes, and Expanding the Scope of Quality. The first part, Setting the Stage, includes Chapters 1, 2, 3, and 4. Chapter 1, Quality Basics, introduces quality definitions and concepts. Chapter 2, Quality Advocates, presents information about the individuals who shaped the quality movement in the United States and abroad. Chapter 3, Quality Systems, introduces ISO 9000, Six Sigma, and the Malcolm Baldrige National Quality Award. Chapter 4, Quality Improvement: Problem Solving, provides the student with a foundation in quality problem solving.

The second part, Control Charts for Variables, begins with Chapter 5, a review of statistics. This statistical background prepares readers for Chapters 6, 7, and 8 on control charts for variables, process capability, and other variable control charts.

The third part, Control Charts for Attributes, begins with Chapter 9, a review of probability. Chapter 10, Quality Control Charts for Attributes, presents p, c, and u charts.

Extending the discussion of basic quality concepts, the fourth part encourages the reader to examine other areas beyond traditional control charts. Expanding the Scope of Quality comprises Chapters 11 through 15. In these chapters, the concepts of reliability, design of experiments, quality function deployment, failure modes and effects analysis, quality costs, product liability, benchmarking, and auditing are all introduced.

The book concludes with six appendices—dealing with values for the area under the normal curve; factors for computing $\overline{X}$, s, and R charts; values of t distribution, binomial and Poisson probability distributions; and a list of helpful websites—a comprehensive glossary; and a bibliography.

SUPPLEMENTARY MATERIAL

Significantly updated, the **instructor's manual** is divided into three sections. The first includes solutions to selected end-of-chapter problems. The second section provides sample answers to the case studies. The third section provides sample test questions for each chapter as well as the answers to those questions.

The online instructor's manual and PowerPoint files are available to instructors at **http://www.pearsonhighered.com/irc**. Instructors can search for a text by author, title, ISBN, or by selecting the appropriate discipline from the pull-down menu at the top of the catalog home page. To access supplementary materials online, instructors need to request an instructor access code. Go to **http://www.pearsonhighered.com/irc** then click **Request access** for an instructor access code. Within 48 hours after registering you will receive a confirming e-mail including an instructor access code. Once you have received your code, go the site and log on for full instructions on downloading the materials you wish to use. One-time registration allows unlimited access to all instructor resource materials.

A **Student Solutions Manual** containing worked solutions to selected end-of-chapter problems is available at http://www.pearsonhighered.com/careersresources/

SOFTWARE AND THE USE OF COMPUTERS

In Chapters 4, 5, 6, 7, and 8, the creation of control charts and histograms is taught. To provide students with the opportunity to work realistic problems containing lots of data, purchasers of this text may want to use one of the many fine software programs on the market. Most companies offer free trial periods that will work well in a classroom setting. Software is not included with this text because most organizations will have their own software that employees will use. Also, each instructor will have their own software preferences.

ACKNOWLEDGMENTS

Without the help and insight of my students and the people who hire them, this text would not have been possible. I would like to express my sincere appreciation to all. Their input has been invaluable. I would also like to give a very heartfelt thanks to the individuals who contributed to the examples, cases, and Real Tools for Real Life examples: Mary Beth Barrentine, Amy Brown, Erich Eggers, Holly Fabry, Chris Honious, and Mike Monnier. I am grateful for the support of Karl Summers, without you this text would not have been possible. I would also like to extend my thanks to my editors at Pearson and; finally, to the reviewers, Mahmoud AlOdeh, Bemidji State University; Gerald Cook, Deleware Technical Community College; Gary Maul, Otterbein University; Charles O'Lari, Quinebaug Valley Community College; and Christo Robberts, University of Minnesota Crookston.

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LIST OF CASE STUDIES

REAL TOOLS FOR REAL LIFE

A popular feature, Real Tools for Real Life, provides students with insight into how real people use the tools and concepts presented in this text.

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PART ONE

SETTING THE STAGE

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CHAPTER
ONE

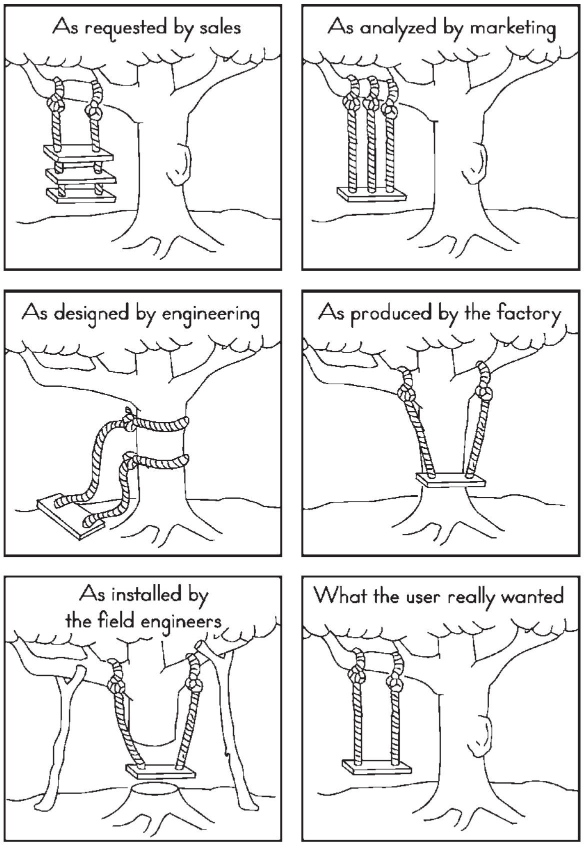
QUALITY BASICS

MAJOR TOPICS

- **Why Quality?**
- **Ingredients for Success**
- **The Evolution of Modern Quality**
- **The Future of Quality**
- **What Is the American Society for Quality?**
- **Summary**
- **Lessons Learned**
- **Chapter Problems**
- **Case Study 1.1 Quality Evolution: Where Are They Now?**

LEARNING OPPORTUNITIES

1. To develop a definition for quality
2. To understand the complexities of defining quality
3. To become familiar with differing definitions of quality from such sources as the American Society for Quality, Dr. W. Edwards Deming, Philip Crosby, and Armand Feigenbaum
4. To become familiar with the definitions of specifications, tolerance limits, inspection, prevention, quality, quality control, statistical quality control, statistical process control, total quality management, process improvement
5. To understand the differences between the philosophies of inspection, quality control, statistical quality control, statistical process control, total quality management, and continuous improvement, Six Sigma, and lean
6. To gain insight into the evolution of total quality management concepts
7. To understand the differences between actions necessary in inspection, quality control, statistical quality control, statistical process control, total quality management, and continuous improvement
8. To understand that a variety of different approaches to organizing for quality exist, including standards like ISO 9000 and methodologies like Six Sigma and lean



Based on Don Kite, *Parts Pups*, Nov. 1971, and *Reader's Digest*, October 1973.

The cartoon is meant to make us chuckle a little about the difficulties consumers can experience in communicating what they want. But when you take a closer look, it isn't so funny. How can a company expect to stay in business if no connection is made between what the customer wants and what the company provides? This chapter begins the exploration of using quality improvement concepts to fulfill customers' needs, requirements, and expectations.

WHY QUALITY?

Choices, choices, choices, today's consumer is inundated with choices. Don't like what you find in a brick and mortar store? Check on-line for a different style, size, or color. Need a doctor, lawyer, landscaper, electrician? Read reviews on-line before making your choice. Let's face it, customers have so many choices in today's marketplace, if they're not impressed, they'll go elsewhere. Given the myriad of choices available, companies and individuals providing products and services need to discover and implement methods that attract and retain customers. Picture an organization as a barrel that must be kept full of customers in order to stay in business. Each new customer is added into the top of the barrel. Unfortunately, for a variety of reasons, there are holes in the barrel through which customers escape, i.e., faulty construction, limited features, slow delivery, or poor value for the money. The organization has two choices, keep adding more customers to the top of the barrel or plug the holes. Wise companies find ways to retain their customers by plugging the holes.

Companies are always seeking an edge, something special that will set them apart from the competition. Finding an edge isn't easy; competition is present in every facet of providing a product or service. An organization's very survival is based on their ability to do what they said they would do faster, better, and cheaper than anyone else. Whether they try quality management, Six Sigma, just-in-time, lean, or other approaches, all organizations need individuals who have been taught a solid foundation in the fundamentals of improvement. The quality topics presented in this text comprise a set of statistical and problem-solving tools that are equal to more than the sum of their parts. They provide users with the ability to improve the way an organization works. Your success in your own job will be based on your ability to find ways to design and implement improvements that will enable your organization to do what they do faster, better, and cheaper. A tall order for most of us; fortunately, the tools and techniques taught in this text will help. Effective employees in effective organizations everywhere in the world are already using them. Steve Jobs, cofounder and CEO of Apple Computer, once said "Be a yardstick of quality. Some people aren't used to an environment where excellence is expected."

Henry Ford, American industrialist and founder of the Ford Motor Company, once said that "Quality means doing it right when no one is looking." But what is quality? Can it be defined or is it a matter of knowing it when we see it?

The American Society for Quality defines ***quality*** as *a subjective term for which each person has his or her own definition. In technical usage, quality can have two meanings:* (1) *the characteristics of a product or service that bear on its ability to satisfy stated or implied needs and* (2) *a product or service free of deficiencies.*

Many prominent professionals in the field have developed definitions of quality. Dr. W. Edwards Deming, well-known consultant and author on the subject of quality, describes quality as *nonfaulty systems.* To Dr. Deming, nonfaulty systems are error-free systems that have the ability to provide the consumer with a product or service as specified. Dr. Joseph M. Juran, in his book *Juran's Quality Control Handbook,* describes quality as *fitness for use.* In his text, *Quality Is Free,* Philip Crosby discusses quality as *conformance to requirements* and nonquality as *nonconformance.*

Quality can take many forms. The above definitions mention three types: quality of design, quality of conformance, and quality of performance. *Quality of design* means that the product or service has been designed to successfully fill a consumer need, real or perceived. *Quality of conformance*—conformance to requirements—refers to the manufacture of the product or the provision of the service that meets the specific requirements set by the consumer. *Quality of performance* means that the product or service performs its intended function as identified by the consumer. Perhaps the most complete definition is that by Armand Feigenbaum, author of *Total Quality Control.* He states that *quality is a customer determination which is based on the customer's actual experience with the product or service, measured against his or her requirements—stated or unstated, conscious or merely sensed, technically operational or entirely subjective—and always representing a moving target in a competitive market.** Several key words stand out in this definition:

- Customer determination: Only a customer can decide if and how well a product or service meets his or her needs, requirements, and expectations.
- Actual experience: The customer will judge the quality of a product or service not only at the time of purchase but throughout usage of the product or service.
- Requirements: Necessary aspects of a product or service called for or demanded by the customer may be stated or unstated, conscious or merely sensed.
- Technically operational: Aspects of a product or service may be clearly identified in words by the consumer.
- Entirely subjective: Aspects of a product or service may only be conjured in a consumer's personal feelings.

Feigenbaum's definition shows how difficult it is to define quality for a particular product or service. Quality definitions are as different as people. In many cases, no two customers will have exactly the same expectations for the same product or service. Notice that Feigenbaum's definition also recognizes that a consumer's needs, requirements, and expectations change over time and with different situations. Under some circumstances customer expectations will not remain the same from purchase to purchase or encounter to encounter. To produce or supply a quality product or service, a company must be able to define and meet the customer's reasonable needs, requirements, and expectations, even as they change over time. This is true whether the product is tangible (automobiles, cell phones, or computers) or intangible (airplane schedules, hospital

*From Total Quality Control, 04e by Armand V. Feigenbaum. Published by McGraw Hill, © 2005.

care, or repair service). It is also true for service industry transactions, even when the customer participates by supplying information or materials. Because of Feigenbaum's broad emphasis on customer requirements, this text will use his description of quality as its guide.

INGREDIENTS FOR SUCCESS

Corporate Culture

Companies seeking to remain competitive in today's global markets must integrate quality into all aspects of their organization. Successful companies *focus on customers* and their needs, requirements, and expectations. The *voice of the customer* serves as a significant source of information for making improvements to a company's products and services. A successful enterprise has a **vision statement** of how it sees itself in the future. This vision serves as a guide, enabling company leaders to create strategic plans supporting the organization's objectives. A clear vision helps create an atmosphere within an organization that is cohesive, with its members sharing a common culture and value system focused on the customer. Teamwork and a results-oriented, problem-solving approach are often mainstays in this type of environment.

Every organization has "the way we do things": tried-and-true activities and methods developed to support the functioning of the company, but what happens when things change and a new competitor or new technology or new owner shakes up the status quo? How the organization adapts is crucial to its survival. Throughout this text, you'll be reading about an organization called JR Precision Shafts (JRPS). JRPS manufactures large precision shafts for pumps, motors, and generators. In later examples, you will see how they apply the tools and techniques taught in this text to improve the way they do business.

First, some background about the company. Three years ago this company experienced a significant change in leadership when it was purchased by three partners. These three enterprising individuals honed their knowledge of quality tools and techniques at their former companies. The culture at JRPS has changed as the people in the organization buy into the "Grow the Business" vision of the new owners. To support their vision, the new owners have implemented a strategic plan that integrates a two-pronged approach: growth by enhancing their current specialties and acquisition growth by branching out into other manufacturing areas. Objectives to support these goals include utilizing quality and lean manufacturing methods, improving and standardizing processes, creating formal hiring and training systems, instituting a productive maintenance program, partnering with vendors, and enhancing technology usage.

Processes and Process Improvement

A ***process** takes inputs and performs value-added activities on those inputs to create an output* (Figure 1.1). To put it another way, processes are made up of interrelated activities that interact with each other. If you think about it, any work being done is a process. Most of us do not realize how many processes we perform on a day-to-day basis. For instance, you go through a process when you select a movie to see. The input is the information about show times and places, whom you are going with, and what criteria you have for choosing a movie. The value-added activities are driving to the movie theater, buying a ticket, and watching the movie. And the output is the result, the entertainment value of the movie.

Industries have innumerable processes that enable them to provide products or services for customers. Typical processes include: design, delivery, development, manufacturing, training, assembly, marketing, evaluation, information management, and customer communication. Though no company has the same set of processes, the list is endless. Process outputs include services, products, decisions, directions, proposals, solutions, recommendations, reports, information, and so on. Inputs to processes are often the outputs of a previous process. Think about the number of processes necessary to provide a shirt by mail order over the Internet. The company must have a catalog website preparation process, a website distribution process, a process for obtaining the goods it plans to sell, an ordering process, a credit-check process, a packaging process, a mailing process, and a billing process, to name a few. Other processes typically found in organizations include financial management; customer service; equipment maintenance and installation; production and inventory control; employee hiring, training, reviewing, firing, and payroll; software development; and product or service design, creation, inspection, packaging, delivery, and improvement.

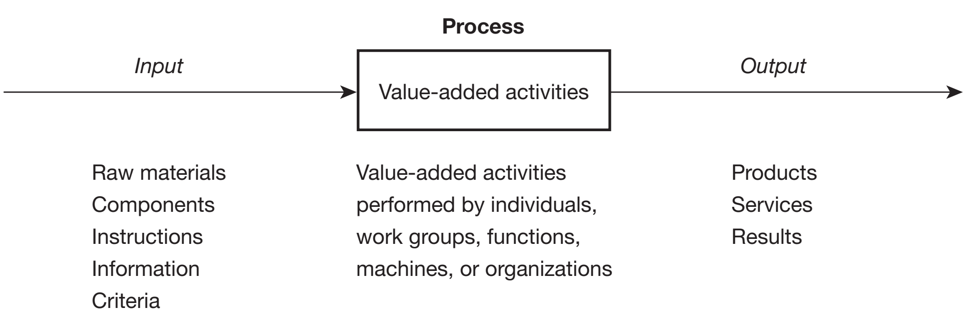


FIGURE 1.1 Processes

The Quoting Process at JRPS

REAL TOOLS for REAL LIFE

Prior to new leadership at JRPS, the activity of turning a quote into a finished part had no uniform process. Since no one really knew exactly what needed to be done there were many incorrect quotes, lost quotes, missing or past due orders, incorrect or improperly priced orders, and other problems. Knowing that standardized processes reduce the chances of errors, the new owners formed a team with the objective of defining order processing. The boundaries of the process were set at "customer requests a quote" to end at "customer receives parts." As the team analyzed the existing methods, they realized that a better order processing method was needed. The team readily considered computerizing the process; however, they recognized that computerizing a nonfunctional process wouldn't help company performance. A further example will show you the tools they used to redesign the process. With their new process, errors have decreased significantly while customer satisfaction has increased dramatically.

Many processes develop over time, with little concern for whether it is the most effective manner in which to provide a product or service. To remain competitive in the world marketplace, companies must seek out wasteful processes and use quality techniques to improve them. The processes providing the products and services will need to be quality-engineered, with the aim of preventing defects and increasing productivity by reducing process cycle times and eliminating waste.

The topics in this text comprise a set of statistical tools that provides users with the power to understand process behavior. With this knowledge, users can find ways to improve the way their organization provides its products and services. These tools can be applied to all sorts of processes including manufacturing, services, and government. Together, they provide a means of reducing process variation. The tools themselves are fundamental to good process management. Applying them is fundamental to good management, period.

Variation

In any process that produces a product or provides a service, rarely are two products or service experiences exactly alike. Even identical twins have their differences. ***Variation****, to be different from one instance to the next, is present in any natural process, meaning that no two products or occurrences are exactly alike.* In manufacturing, variation is often identified as the difference between the specified target dimension and the actual part dimension. In service industries, variation may be the difference between the type of service received and the type of service expected. Companies interested in providing a quality product or service use statistical process control techniques to carefully study the variation present in their processes. To more consistently provide a high-quality product or service, a company must determine why differences exist between similar products or services and then remove the causes of these differences from the processes that produce them. Think of it this way: If you are carpooling with an individual who is sometimes late, sometimes early, and sometimes on time, it is difficult to plan when you should be ready to leave. If, however, the person is always five minutes late, you may not like it, but you can plan around it. The first person exhibits a lot of variation; you never know when to expect him or her. The second person, although late, has very little variation in his or her process; hence you know that if you need to leave at exactly 5 P.M., you had better tell that person to be ready at 4:55 P.M.. The best situation would be to be on time every time. It is this best situation at which companies are aiming when they seek to eliminate or reduce the variation present in a process. Methods of improving processes by removing variation are the focus of this text.

Product and service designers translate customer needs, requirements, and expectations into tangible requirements called specifications. ***Specifications*** *state product or service characteristics in terms of a desired design target value or dimension.* In service industries, specifications may take the form of descriptions of the types of services that are expected to be performed (Table 1.1). In manufacturing, specifications may be given as nominal target dimensions (Table 1.2), or they may take the form of tolerance limits (Table 1.3). ***Tolerance limits*** *show the permissible changes in the dimension of a quality characteristic.*

TABLE 1.1 Specifications for Banking Transactions at Teller Windows Serving 10,000 Customers Monthly

Item	Specification
Customer Perception of Service/Quality	2 or Fewer Complaints per Month
Downtime of Teller Window Due to Teller Absence	Not to Exceed 5 Min per Day
Deposits Not Credited	1 or Fewer per Month
Accounts Not Debited	1 or Fewer per Month
Errors on Cash In and Out Tickets	1 or Fewer per Month
Missing and Illegible Entries	2 or Fewer per Month
Inadequate Cash Reserves	2 or Fewer Occurrences per Month

Specifications and Tolerance Limits at JRPS

REAL TOOLS for REAL LIFE

Electric motors (Figure 1.2) work by converting electrical energy to mechanical energy. To do this, electricity flows through a copper wire winding contained in a housing. The current sets up a rotating magnetic field. The stator, the metal surrounding a central shaft, becomes polarized and rotates on its axis. The shaft transfers the energy created to other devices either by direct drive or through the use of gears. The shafts made at JRPS are made to order for specific customers. Engineers at JRPS work with customers to properly prepare drawings showing the specifications and tolerance limits for the custom shafts (Figure 1.3).

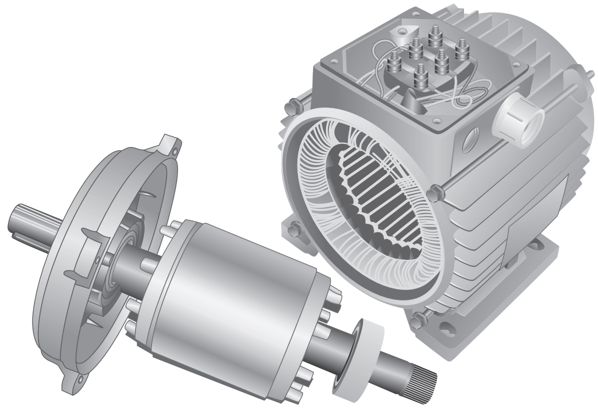


FIGURE 1.2 Electric Motor

PART *Rocker Arm Shaft*	APPROVED: AS IS / AS REVISED		PAGE 1
OPER / DATE ISSUED / DATE REVISED	TOLERANCES UNLESS OTHERWISE SPECIFIED *7.65 ± 0.02*	NOTES *Key Dimension Noted With **	**INSP.FREQ.** ALL DIAMETERS, CHAMFERS, RUNOUT, PERPENDICULARITY 1/5 ALL LENGTHS, RADII. CENTERS, THREADS 1/10

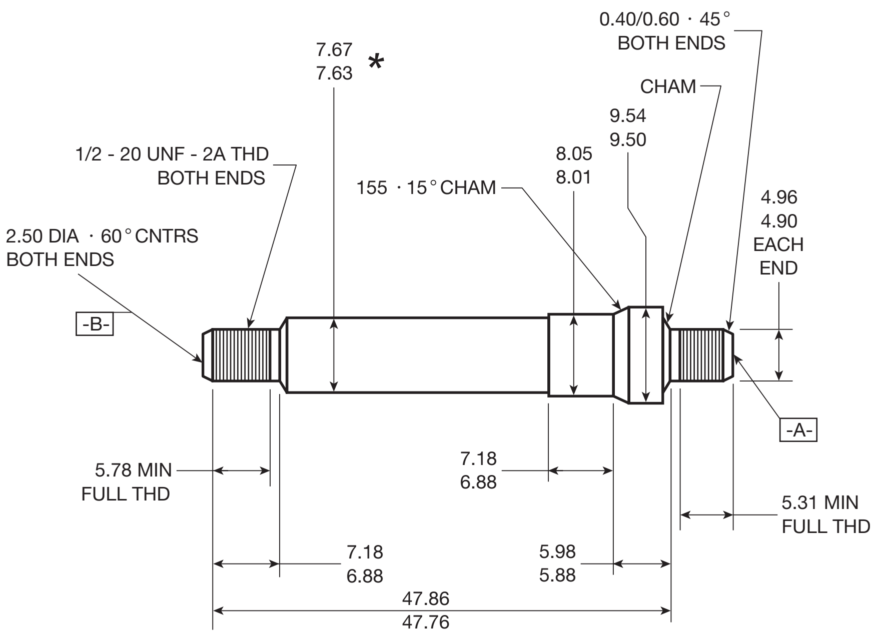


FIGURE 1.3 Custom Shaft Specifications

TABLE 1.2 Specifications for Nominal Dimensions

Item	Nominal Dimension
Door Height	6 ft 6 inch
Theater Performance Start Time	8:00 P.M.
Wheelbase Length of a Car (in Catalog Shown to Customer)	110 inch
Frequency for a Radio Station	102.6 Hz
Calories in a Serving	100
Servings in a Package	8

TABLE 1.3 Specifications for Tolerance Limits

Item	Specifications
Priority Overnight Delivery Time	Before 10:00 A.M.
Metal Hardness	R_c-44–48
Car Tire Pressure	30–35 psi
Heat-Treat Oven Temperature	1300–1400°C
Wheelbase Length of a Car	110 $\pm$ 0.10 in.
Household Water Pressure	550 $\pm$ 5 psi
Diameter of a Bolt	10.52–10.55 mm

Parts manufactured between the tolerance, or specification, limits are considered acceptable. Designers should seek input from the customer, from engineering and manufacturing professionals, and from any others who can assist in determining the appropriate specifications and tolerances for a given item.

To manufacture products within specifications, the processes producing the parts need to be stable and predictable. *A process is considered to be under control when the variability (variation) from one part to another or from one service to another is stable and predictable*. Just as in the carpooling example, predictability enables those studying the process to make decisions concerning the product or service. When a process is predictable, very little variation is present. Statistical process control practitioners use a variety of techniques to locate the sources of variation in a process. Once these sources are located, process improvements should be made to eliminate or reduce the amount of variation present.

Example 1.1 Reducing Variation

At Makepiece Fabrics Inc., fabric printing is serious business. There are two key ways to achieve a patterned fabric: use colored threads to weave the pattern directly into the fabric during fabrication or use inks to print onto a plain fabric. Printing multicolored fabrics, which have a pattern only on one side, is tricky business. Rolls of white fabric pass through printing presses containing plates etched with designs. For multicolored fabrics, eight printing plates, each inked with a different color, are etched with only the items that will appear in that particular color. In many cases, the items are interrelated, such as when one color is overlaid on top of another. If the printing plates are not aligned properly with each other and with the fabric, the colors may be offset, resulting in a blurry, unreadable design.

Makepiece's process engineers have worked diligently to reduce or eliminate variation from the fabric-printing process. Sources of variation include the printing plates, the inks, the fabric, and the presses containing the plates. The engineers have improved the devices that hold the plates in place, eliminating plate movement during press cycles. They have developed an inventory-control system to monitor ink freshness in order to ensure a clean print. They have tested different fabrics to determine which ones hold the best impressions. These improvements have been instrumental in removing variation from the fabric-printing process.

With a stable printing process that exhibits little variation, process managers at Makepiece can predict future production rates and costs. They can respond knowledgeably to customer inquiries concerning fabric costs and delivery dates. If the fabric-production process were unstable, exhibiting unpredictable variation and producing both good and bad fabrics, then the process managers could only guess at what the future would bring (Figure 1.4).

Productivity

At first glance, quality and productivity may seem the same or very similar. Actually, there is a difference between the two. To be productive, one must work efficiently and operate in a manner that best utilizes the available resources. Productivity's principal focus is on doing

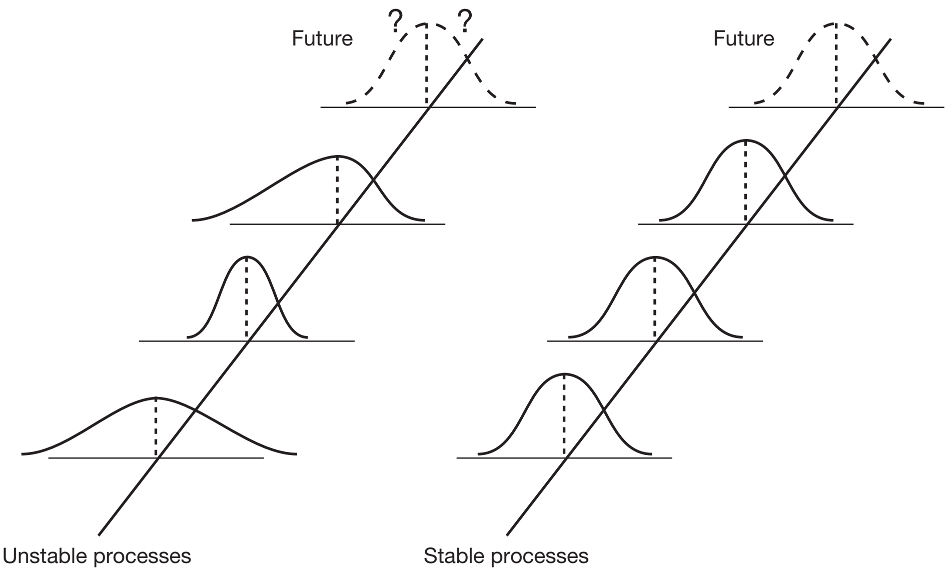


FIGURE 1.4 Predictions Based on Stable and Unstable Processes

something more efficiently. Quality, on the other hand, focuses on being effective. Being effective means achieving the intended results or goals while meeting the customer's requirements. So quality concentrates not only on doing things right (being productive), but also on doing the right things right (being effective). In manufacturing terms, if a company can produce 10,000 table lamps in 13 hours instead of in 23 hours, this is a dramatic increase in productivity. However, if customers are not purchasing these table lamps because they are ugly, then the company is not effective, and the increased productivity is meaningless. To remain competitive, companies must focus on effectively meeting the reasonable needs and expectations of their customers. Productivity and quality improvements come from managing work activities as processes. As process performance is measured and sources of variation are removed, the effectiveness of the process increases.

THE EVOLUTION OF MODERN QUALITY

Many people believe that quality efforts began during the Industrial Revolution. Actually, an emphasis on quality has existed for thousands of years. Consider the large round stones shown in Figure 1.5. These 10,000-year-old stones uncovered during an archeological dig at the Tarxien Temple in Malta are uniformly 15 inches in diameter, nearly perfectly round, and created using only stone implements. For all of the stones to be so uniform, a design standard had to be in place. These round stones were used to roll large slabs of stones used in the construction of temples, like the Hagar Qim, that still stand today (Figure 1.6). Note the square lines of the 10,000-year-old temple—another example of quality at work.

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FIGURE 1.5 Tarxien Temple Stones

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FIGURE 1.6 Hagar Qim Temple, Malta