FUNDAMENTALS OF QUALITY CONTROL AND IMPROVEMENT
To the memory of my parents,
who instilled the importance of
an incessant inquiry for knowledge —
and whose inspiration transcends mortality
# CONTENTS

## PREFACE

xix

## ABOUT THE COMPANION WEBSITE

xxiii

## PART I  PHILOSOPHY AND FUNDAMENTALS 1

1 Introduction to Quality Control and the Total Quality System 3

1-1 Introduction and Chapter Objectives, 3
1-2 Evolution of Quality Control, 4
1-3 Quality, 7
    Quality Characteristics, 8
    Variables and Attributes, 8
    Defects, 9
    Standard or Specification, 9
    Quality of Design, 10
    Quality of Conformance, 10
    Quality of Performance, 11
1-4 Quality Control, 12
    Off-Line Quality Control, 12
    Statistical Process Control, 12
    Acceptance Sampling Plans, 13
1-5 Quality Assurance, 13
1-6 Quality Circles and Quality Improvement Teams, 14
1-7 Customer Needs and Market Share, 15
    Kano Model, 15
1-8 Benefits of Quality Control and the Total Quality System, 16
    Total Quality System, 17
1-9 Quality and Reliability, 18
1-10 Quality Improvement, 18
1-11 Product and Service Costing, 19
    Activity-Based Costing, 20
1-12 Quality Costs, 23
  - Prevention Costs, 23
  - Appraisal Costs, 23
  - Internal Failure Costs, 24
  - External Failure Costs, 24
  - Hidden Failure Costs, 24
  - Quality Costs Data Requirements, 24
  - Process Cost Approach, 26
1-13 Measuring Quality Costs, 27
  - Impact of Quality Improvement on Quality Costs, 29
1-14 Management of Quality, 31
1-15 Quality and Productivity, 34
  - Effect on Cost, 34
  - Effect on Market, 34
1-16 Total Quality Environmental Management, 37
  - Green Supply Chain, 39
  - Summary, 40
  - Key Terms, 41
  - Exercises, 41
  - References, 46

2 Some Philosophies and Their Impact on Quality 47
  2-1 Introduction and Chapter Objectives, 47
  2-2 Service Industries and Their Characteristics, 47
    - Differences in the Manufacturing and Service Sectors, 49
    - Service Quality Characteristics, 50
    - Measuring Service Quality, 52
    - Techniques for Evaluating Service Quality, 52
  2-3 Model for Service Quality, 53
  2-4 W. Edwards Deming’s Philosophy, 56
    - Extended Process, 57
    - Deming’s 14 Points for Management, 58
    - Deming’s Deadly Diseases, 72
  2-5 Philip B. Crosby’s Philosophy, 75
    - Four Absolutes of Quality Management, 76
    - 14-Step Plan for Quality Improvement, 76
  2-6 Joseph M. Juran’s Philosophy, 78
    - Quality Trilogy Process, 79
    - Quality Planning, 79
    - Quality Control, 80
    - Quality Improvement, 81
  2-7 The Three Philosophies Compared, 82
    - Definition of Quality, 82
    - Management Commitment, 82
    - Strategic Approach to a Quality System, 83
Contents

Measurement of Quality, 83
Never-Ending Process of Improvement, 83
Education and Training, 83
Eliminating the Causes of Problems, 84
Goal Setting, 84
Structural Plan, 84
Summary, 85
Key Terms, 85
Exercises, 86
References, 88

3 Quality Management: Practices, Tools, and Standards 89

3-1 Introduction and Chapter Objectives, 89
3-2 Management Practices, 90
    Total Quality Management, 90
    Vision and Quality Policy, 92
    Balanced Scorecard, 94
    Performance Standards, 96
3-3 Quality Function Deployment, 99
    QFD Process, 100
3-4 Benchmarking and Performance Evaluation, 106
    Benchmarking, 107
    Quality Auditing, 110
    Vendor Selection and Certification Programs, 112
    Vendor Rating and Selection, 112
3-5 Health Care Analytics, 115
    Health Care Analytics and Big Data, 116
    Uniqueness of Health Care, 116
    Challenges in Health Care Quality, 121
3-6 Tools for Continuous Quality Improvement, 124
    Pareto Diagrams, 124
    Flowcharts, 124
    Cause-and-Effect Diagrams, 126
    Scatterplots, 126
    Multivariable Charts, 127
    Matrix and Three-Dimensional Plots, 129
    Failure Mode and Effects Criticality Analysis, 131
3-7 International Standards ISO 9000 and Other
    Derivatives, 137
    Features of ISO 9000, 137
    Other Industry Standards, 138
Summary, 139
Key Terms, 140
Exercises, 140
References, 144
## PART II  STATISTICAL FOUNDATIONS AND METHODS OF QUALITY IMPROVEMENT

### 4  Fundamentals of Statistical Concepts and Techniques in Quality Control and Improvement

**4-1** Introduction and Chapter Objectives, 150  
**4-2** Population and Sample, 150  
**4-3** Parameter and Statistic, 150  
**4-4** Probability, 151  
- Relative Frequency Definition of Probability, 151  
- Simple and Compound Events, 151  
- Complementary Events, 152  
- Additive Law, 153  
- Multiplicative Law, 154  
- Independence and Mutually Exclusive Events, 154  
**4-5** Descriptive Statistics: Describing Product or Process Characteristics, 156  
- Data Collection, 156  
- Measurement Scales, 158  
- Measures of Central Tendency, 159  
- Measures of Dispersion, 161  
- Measures of Skewness and Kurtosis, 166  
- Measures of Association, 169  
**4-6** Probability Distributions, 173  
- Cumulative Distribution Function, 175  
- Expected Value, 175  
- Discrete Distributions, 176  
- Continuous Distributions, 180  
**4-7** Inferential Statistics: Drawing Conclusions on Product and Process Quality, 189  
- Sampling Distributions, 189  
- Estimation of Product and Process Parameters, 190  
- Hypothesis Testing, 199  
**Summary**, 212  
**Appendix**: Approximations to Some Probability Distributions, 212  
- Binomial Approximation to the Hypergeometric, 212  
- Poisson Approximation to the Binomial, 212  
- Normal Approximation to the Binomial, 213  
- Normal Approximation to the Poisson, 214  
**Key Terms**, 215  
**Exercises**, 216  
**References**, 228

### 5  Data Analyses and Sampling

**5-1** Introduction and Chapter Objectives, 229  
**5-2** Empirical Distribution Plots, 230
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-3</td>
<td>Randomness of a Sequence, 235</td>
</tr>
<tr>
<td></td>
<td>Run Chart, 235</td>
</tr>
<tr>
<td>5-4</td>
<td>Validating Distributional Assumptions, 237</td>
</tr>
<tr>
<td></td>
<td>Probability Plotting, 237</td>
</tr>
<tr>
<td>5-5</td>
<td>Transformations to Achieve Normality, 240</td>
</tr>
<tr>
<td></td>
<td>Some Common Transformations, 240</td>
</tr>
<tr>
<td></td>
<td>Power Transformations, 240</td>
</tr>
<tr>
<td></td>
<td>Johnson Transformation, 241</td>
</tr>
<tr>
<td>5-6</td>
<td>Analysis of Count Data, 244</td>
</tr>
<tr>
<td></td>
<td>Hypothesis Test on Cell Probabilities, 244</td>
</tr>
<tr>
<td></td>
<td>Contingency Tables, 245</td>
</tr>
<tr>
<td></td>
<td>Measures of Association, 247</td>
</tr>
<tr>
<td>5-7</td>
<td>Analysis of Customer Satisfaction Data, 248</td>
</tr>
<tr>
<td></td>
<td>Customer Needs and Their Level of Satisfaction, 248</td>
</tr>
<tr>
<td></td>
<td>Displaying Survey Results, 253</td>
</tr>
<tr>
<td></td>
<td>Analysis of Survey Results, 255</td>
</tr>
<tr>
<td>5-8</td>
<td>Concepts in Sampling, 257</td>
</tr>
<tr>
<td></td>
<td>Sampling Designs and Schemes, 258</td>
</tr>
<tr>
<td></td>
<td>Sample Size Determination, 260</td>
</tr>
<tr>
<td></td>
<td>Bound on the Error of Estimation and Associated</td>
</tr>
<tr>
<td></td>
<td>Confidence Level, 260</td>
</tr>
<tr>
<td></td>
<td>Estimating the Difference of Two Population Means, 262</td>
</tr>
<tr>
<td></td>
<td>Estimating the Difference of Two Population</td>
</tr>
<tr>
<td></td>
<td>Proportions, 262</td>
</tr>
<tr>
<td></td>
<td>Controlling the Type I Error, Type II Error, and</td>
</tr>
<tr>
<td></td>
<td>Associated Parameter Shift, 263</td>
</tr>
<tr>
<td></td>
<td>Summary, 264</td>
</tr>
<tr>
<td></td>
<td>Key Terms, 265</td>
</tr>
<tr>
<td></td>
<td>Exercises, 266</td>
</tr>
<tr>
<td></td>
<td>References, 272</td>
</tr>
</tbody>
</table>

**PART III  STATISTICAL PROCESS CONTROL**

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Statistical Process Control Using Control Charts, 275</td>
</tr>
<tr>
<td>6-1</td>
<td>Introduction and Chapter Objectives, 275</td>
</tr>
<tr>
<td>6-2</td>
<td>Causes of Variation, 277</td>
</tr>
<tr>
<td></td>
<td>Special Causes, 277</td>
</tr>
<tr>
<td></td>
<td>Common Causes, 277</td>
</tr>
<tr>
<td>6-3</td>
<td>Statistical Basis for Control Charts, 277</td>
</tr>
<tr>
<td></td>
<td>Basic Principles, 277</td>
</tr>
<tr>
<td></td>
<td>Selection of Control Limits, 279</td>
</tr>
</tbody>
</table>
CONTENTS

Errors in Making Inferences from Control Charts, 281
Effect of Control Limits on Errors in Inference Making, 285
Warning Limits, 286
Effect of Sample Size on Control Limits, 286
Average Run Length, 287

6-4 Selection of Rational Samples, 289
Sample Size, 289
Frequency of Sampling, 289

6-5 Analysis of Patterns in Control Charts, 290
Some Rules for Identifying an Out-of-Control Process, 290
Interpretation of Plots, 292
Determination of Causes of Out-of-Control Points, 294

6-6 Maintenance of Control Charts, 294
Summary, 295
Key Terms, 295
Exercises, 295
References, 298

7 Control Charts for Variables

7-1 Introduction and Chapter Objectives, 300
7-2 Selection of Characteristics for Investigation, 301
7-3 Preliminary Decisions, 302
Selection of Rational Samples, 302
Sample Size, 303
Frequency of Sampling, 303
Choice of Measuring Instruments, 303
Design of Data Recording Forms, 303

7-4 Control Charts for the Mean and Range, 303
Development of the Charts, 303
Variable Sample Size, 309
Standardized Control Charts, 309
Control Limits for a Given Target or Standard, 310
Interpretation and Inferences from the Charts, 313
Control Chart Patterns and Corrective Actions, 315

7-5 Control Charts for the Mean and Standard Deviation, 321
No Given Standards, 322
Given Standard, 323

7-6 Control Charts for Individual Units, 326
No Given Standards, 327
Given Standard, 328

7-7 Control Charts for Short Production Runs, 330
\( \bar{X} \)- and \( R \)-Charts for Short Production Runs, 330
Z-MR Chart, 330

7-8 Other Control Charts, 332
Cumulative Sum Control Chart for the Process Mean, 332
Tabular Method, 333
V-Mask Method, 336
Cumulative Sum for Monitoring Process Variability, 340
Moving-Average Control Chart, 341
Exponentially Weighted Moving-Average or Geometric Moving-Average Control Chart, 343
Modified Control Chart, 347
Acceptance Control Chart, 350

7-9 Risk-Adjusted Control Charts, 352
Risk-Adjusted Cumulative Sum (RACUSUM) Chart, 353
Risk-Adjusted Sequential Probability Ratio Test (RASPRT), 354
Risk-Adjusted Exponentially Weighted Moving-Average (RAEWMA) Chart, 355
Variable Life-Adjusted Display (VLAD) Chart, 356

7-10 Multivariate Control Charts, 359
Controlling Several Related Quality Characteristics, 359
Hotelling’s $T^2$ Control Chart and Its Variations, 362
Phase 1 and Phase 2 Charts, 363
Usage and Interpretations, 365
Individual Observations with Unknown Process Parameters, 366
Generalized Variance Chart, 367

Summary, 372
Key Terms, 373
Exercises, 374
References, 387

8 Control Charts for Attributes

8-1 Introduction and Chapter Objectives, 390
8-2 Advantages and Disadvantages of Attribute Charts, 390
Advantages, 390
Disadvantages, 391
8-3 Preliminary Decisions, 392
8-4 Chart for Proportion Nonconforming: $p$-Chart, 392
Construction and Interpretation, 393
Variable Sample Size, 400
Risk-Adjusted $p$-Charts in Health Care, 404
Special Considerations for $p$-Charts, 408
8-5 Chart for Number of Nonconforming Items: $np$-Chart, 409
No Standard Given, 409
Standard Given, 410
8-6 Chart for Number of Nonconformities: $c$-Chart, 411
No Standard Given, 412
Standard Given, 412
Probability Limits, 414
Applications in Health Care When Nonoccurrence of Nonconformities Are Not Observable, 415
CONTENTS

8-7 Chart for Number of Nonconformities Per Unit: $u$-Chart, 417
  Variable Sample Size and No Specified Standard, 417
  Risk-Adjusted $u$–Charts in Health Care, 420
8-8 Chart for Demerits Per Unit: $u$-Chart, 423
  Classification of Nonconformities, 423
  Construction of a $U$-Chart, 423
8-9 Charts for Highly Conforming Processes, 426
  Transformation to Normality, 426
  Use of Exponential Distribution for Continuous Variables, 426
  Use of Geometric Distribution for Discrete Variables, 427
  Probability Limits, 427
  Applications in Health Care of Low-Occurrence Nonconformities, 429
8-10 Operating Characteristic Curves for Attribute Control Charts, 431
  Summary, 434
  Key Terms, 435
  Exercises, 435
  References, 448

9 Process Capability Analysis 449

9-1 Introduction and Chapter Objectives, 449
9-2 Specification Limits and Control Limits, 450
9-3 Process Capability Analysis, 451
  Process Capability, 452
9-4 Natural Tolerance Limits, 453
  Statistical Tolerance Limits, 454
9-5 Specifications and Process Capability, 454
9-6 Process Capability Indices, 457
  $C_p$ Index, 457
  Upper and Lower Capability Indices, 458
  $C_{pk}$ Index, 459
  Capability Ratio, 461
  Taguchi Capability Index, $C_{pm}$, 462
  $C_{pmk}$ Index, 462
  Confidence Intervals and Hypothesis Testing
  on Capability Indices, 463
  Comparison of Capability Indices, 464
  Effect of Measurement Error on Capability Indices, 468
  Gage Repeatability and Reproducibility, 470
  Evaluation of Measurement Systems, 471
  Metrics for Evaluation of Measurement Systems, 471
  Preparation for a Gage Repeatability
  and Reproducibility Study, 472
  $C_p$ Index and the Nonconformance Rate, 475
9-7 Process Capability Analysis Procedures, 476
  Estimating Process Mean and Standard Deviation, 477
PART IV ACCEPTANCE SAMPLING 501

10 Acceptance Sampling Plans for Attributes and Variables 503

10-1 Introduction and Chapter Objectives, 504
10-2 Advantages and Disadvantages of Sampling, 504
10-3 Producer and Consumer Risks, 505
10-4 Operating Characteristic Curve, 505
   Effect of the Sample Size and the Acceptance Number, 508
10-5 Types of Sampling Plans, 509
   Advantages and Disadvantages, 510
10-6 Evaluating Sampling Plans, 511
   Average Outgoing Quality, 511
   Average Total Inspection, 513
   Average Sample Number, 514
10-7 Bayes Rule and Decision Making Based on Samples, 516
10-8 Lot-by-Lot Attribute Sampling Plans, 519
   Single Sampling Plans, 519
   Double Sampling Plans, 526
   Multiple Sampling Plans, 532
   Standard Sampling Plans, 533
10-9 Other Attribute Sampling Plans, 537
   Chain Sampling Plan, 537
   Sequential Sampling Plan, 539
10-10 Deming’s kp Rule, 540
   Critique of the kp Rule, 542
10-11 Sampling Plans for Variables, 543
    Advantages and Disadvantages of Variable Plans, 543
10-12 Variable Sampling Plans for a Process Parameter, 544
    and Known Process Standard Deviation, 544
    Estimating Process Average: Double Specification Limits
    and Known Process Standard Deviation, 546
    and Unknown Process Standard Deviation, 549
10-13 Variable Sampling Plans for Estimating the Lot Proportion
    Nonconforming, 550
    Derivation of a Variable Sampling Plan with a Single
    Specification Limit and Known Process
    Standard Deviation, 551
    Standardized Plans: ANSI/ISO/ASQ Z1.9
    and MIL-STD-414, 554
Summary, 555
Key Terms, 556
Exercises, 556
References, 562

PART V PRODUCT AND PROCESS DESIGN 563

11 Reliability 565

11-1 Introduction and Chapter Objectives, 565
11-2 Reliability, 566
11-3 Life-Cycle Curve and Probability Distributions in Modeling
    Reliability, 566
    Probability Distributions to Model Failure Rate, 567
    Availability, 570
11-4 System Reliability, 570
    Systems with Components in Series, 571
    Systems with Components in Parallel, 573
    Systems with Components in Series and in Parallel, 575
    Systems with Standby Components, 576
11-5 Operating Characteristic Curves, 578
11-6 Reliability and Life Testing Plans, 580
    Types of Tests, 580
    Life Testing Plans Using the Exponential Distribution, 582
    Standard Life Testing Plans Using Handbook H-108, 584
11-7 Survival Analysis, 588
    Estimation of the Survival Function, 588
    Confidence Intervals for the Survival Function, 593
    Comparison of Survival Functions of Two Groups, 595
Summary, 599
12 Experimental Design and the Taguchi Method

12-1 Introduction and Chapter Objectives, 606
12-2 Experimental Design Fundamentals, 606
   Features of Experimentation, 610
12-3 Some Experimental Designs, 611
   Completely Randomized Design, 612
   Randomized Block Design, 618
   Latin Square Design, 623
12-4 Factorial Experiments, 631
   Two-Factor Factorial Experiment Using a Completely
   Randomized Design, 632
   Two-Factor Factorial Experiment Using a
   Randomized Block Design, 636
   Role of Contrasts, 642
   The $2^k$ Factorial Experiment, 648
   Confounding in $2^k$ Factorial Experiments, 652
   Fractional Replication in $2^k$ Experiments, 653
12-5 The Taguchi Method, 659
12-6 The Taguchi Philosophy, 660
12-7 Loss Functions, 663
   Target Is Best, 664
   Smaller Is Better, 667
   Larger Is Better, 668
12-8 Signal-to-Noise Ratio and Performance Measures, 670
   Target Is Best, 670
   Smaller Is Better, 673
   Larger Is Better, 673
12-9 Critique of S/N Ratios, 673
12-10 Experimental Design in the Taguchi Method, 674
   Orthogonal Arrays and Linear Graphs, 675
   Estimation of Effects, 685
12-11 Parameter Design in the Taguchi Method, 690
   Application to Attribute Data, 692
12-12 Critique of Experimental Design and the Taguchi Method, 694
   Summary, 696
   Key Terms, 697
   Exercises, 698
   References, 708

13 Process Modeling Through Regression Analysis

13-1 Introduction and Chapter Objectives, 711
13-2 Deterministic and Probabilistic Models, 712
## CONTENTS

13-3 Model Assumptions, 714  
13-4 Least Squares Method for Parameter Estimation, 716  
    Performance Measures of a Regression Model, 719  
13-5 Model Validation and Remedial Measures, 722  
    Linearity of Regression Function, 722  
    Constancy of Error Variance, 723  
    Normality of Error Component, 725  
    Independence of Error Components, 725  
13-6 Estimation and Inferences from a Regression Model, 726  
    Inferences on Individual $\beta_i$ Parameters, 727  
    Inferences on All $\beta_i$, $i = 1, 2, \ldots, p - 1$ Parameters, 727  
    Simultaneous Inferences on Some $\beta_i$, $i = 1, 2, \ldots, p - 1$, 727  
    Hypothesis Tests on a Subset of $\beta_i$ Parameters, 728  
    Estimation of Mean Response, 728  
    Simultaneous Confidence Intervals for Several Mean Responses, 729  
    Prediction of Individual Observations, 729  
    Simultaneous Prediction Intervals for Several New Observations, 729  
13-7 Qualitative Independent Variables, 732  
    Additive Model, 732  
    Interaction Model, 733  
13-8 Issues in Multiple Regression, 738  
    Data from a Retrospective Versus Designed Experiment, 738  
    Outliers in the Space of the Independent Variables, 739  
    Outliers for the Dependent Variable, 740  
    Influential Observations, 741  
13-9 Logistic Regression, 742  
    Binary Response Variable, 742  
    Assumptions in Regression, 744  
    Summary, 746  
    Key Terms, 747  
    Exercises, 748  
    References, 752

### Appendixes

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>Cumulative Binomial Distribution, 753</td>
</tr>
<tr>
<td>A-2</td>
<td>Cumulative Poisson Distribution, 758</td>
</tr>
<tr>
<td>A-3</td>
<td>Cumulative Standard Normal Distribution, 760</td>
</tr>
<tr>
<td>A-4</td>
<td>Values of $t$ for a Specified Right-Tail Area, 763</td>
</tr>
<tr>
<td>A-5</td>
<td>Chi-Squared Values for a Specified Right-Tail Area, 765</td>
</tr>
<tr>
<td>A-6</td>
<td>Values of $F$ for a Specified Right-Tail Area, 767</td>
</tr>
<tr>
<td>A-7</td>
<td>Factors for Computing Centerline and Three-Sigma Control Limits, 773</td>
</tr>
<tr>
<td>A-8</td>
<td>Uniform Random Numbers, 774</td>
</tr>
</tbody>
</table>

### Index

<table>
<thead>
<tr>
<th>Index</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>775</td>
</tr>
</tbody>
</table>
PREFACE

This book covers the foundations of modern methods of quality control and improvement that are used in the manufacturing and service industries. Quality is key to surviving tough competition. Consequently, business needs technically competent people who are well-versed in statistical quality control and improvement. This book should serve the needs of students in business and management and students in engineering, technology, and related disciplines. Professionals will find this book to be a valuable reference in the field.

An outgrowth of many years of teaching, research, and consulting in the field of quality assurance and statistical process control, the methods discussed in this book apply statistical foundations to real-world situations. Mathematical derivations and proofs are kept to a minimum to allow a better flow of material. Although an introductory course in statistics would be useful to a reader, the foundations of statistical tools and techniques discussed in Chapter 4 should enable students without a statistical background to understand the material.

Prominently featured are many real-world examples. For each major concept, at least one example demonstrates its application. The field of health care within the service sector is of immense importance. From an individual or a population perspective, creating processes that provide quality health care are desirable. Additionally, the growing escalation of the cost of providing quality care raises the question of improving the effectiveness and efficiency of all processes associated with the delivery of such services. For this reason, issues related to health care quality have been addressed in several chapters, for example, Chapters 3, 5, 7, 8, 11, and 13.

The book is divided into five parts. Part I, which deals with the philosophy and fundamentals of quality control, consists of three chapters. Chapter 1 is an introduction to quality control and the total quality system. In addition to introducing the reader to the nomenclature associated with quality control and improvement, it provides a framework for the systems approach to quality. Discussions of quality costs and their measurement, along with activity-based costing, are presented. In Chapter 2 we examine philosophies of such leading experts as Deming, Crosby, and Juran. Deming’s 14 points for management are analyzed, and the three philosophies are compared. Features of quality in the service sector are introduced. Chapter 3 covers quality management practices, tools, and standards. Topics such as total quality management, balanced scorecard, quality function deployment, benchmarking, failure mode and effects criticality analysis, and tools for quality improvement are presented. Concepts of health care analytics and its associated challenges are discussed.
Part II deals with the statistical foundations of quality control and consists of two chapters. Chapter 4 offers a detailed coverage of statistical concepts and techniques in quality control and improvement. It presents a thorough treatment of inferential statistics. Depending on the student’s background, only selected sections of this chapter will need to be covered.

Chapter 5 covers some graphical methods of analyzing empirical distributions. Identification of the population distribution using probability plotting along with the several transformations to achieve normality are presented. Analysis of count data, including contingency table analysis and measures of association, are discussed. Strategic and operational decision making, through analyses of survey data from customers, is included. Finally, some common sampling designs and determination of an appropriate sample size are features of this chapter.

The field of statistical quality control consists of two areas: statistical process control and acceptance sampling. Part III deals with statistical process control and consists of four chapters. Chapter 6 provides an overview of the principles and use of control charts. A variety of control charts for variables are discussed in detail in Chapter 7. In addition to charts for the mean and range, those for the mean and standard deviation, individual units, cumulative sum, moving average, and geometric moving average are presented. Several types of risk-adjusted control charts are included. Multivariate control charts are also introduced. Control charts for attributes are discussed in Chapter 8. Charts such as the $p$-chart, $np$-chart, $c$-chart, $u$-chart, $g$-chart, and $U$-chart are presented. Here also, risk-adjusted $p$-charts and $u$-charts are included. The topic of process capability analysis is discussed in Chapter 9. The ability of a process to meet customer specifications is examined in detail. Process capability analysis procedures and process capability indices are also treated in depth. The chapter covers proper approaches to setting tolerances on assemblies and components. Part III should form a core of material to be covered in most courses.

Part IV deals with acceptance sampling procedures and consists of one chapter. Methods of acceptance of a product based on information from a sample are described. Chapter 10 presents acceptance sampling plans for attributes and variables. Lot-by-lot attribute and variable sampling plans are described. With the emphasis on process control and improvement, sampling plans do not occupy the forefront. Nevertheless, they are included to make the discussion complete.

Part V deals with product and process design and consists of three chapters. With the understanding that quality improvement efforts are generally being moved further upstream, these chapters constitute the backbone of current methodology. Chapter 11 deals with reliability and explores the effects of time on the proper functioning of a product. The topic of survival analysis is included. Chapter 12 provides the fundamentals of experimental design and the Taguchi method. Different designs, such as the completely randomized design, randomized block design, and Latin square design are presented. Estimation of treatment effects using factorial experiments is included. This chapter also provides a treatment of the Taguchi method for design and quality improvement; the philosophy and fundamentals of this method are discussed. Chapter 13 discusses process modeling through regression analysis. Estimation of model parameters, making inferences from the model, and issues in multiple regression are covered. Logistic regression analysis is also introduced. Various sections of Part V could also be included in the core material for a quality control course.

This book may serve as a text for an undergraduate or graduate course for students in business and management. It may also serve the needs of students in engineering, technology, and related disciplines. For a one-semester or one-quarter course, Part I, selected portions of Part II, selected portions of Part III, and selected portions of Part V could be covered. For a
two-semester or two-quarter course, all of Parts II, III, and V, along with portions from Part IV, could be covered as well.

Changes in the Fourth Edition

Some major changes have been made in the fourth edition. With the growing importance of the field of health care, an effort has been made to incorporate concepts, tools, and techniques to address issues in the domain of health care quality. These are dealt with over a multitude of chapters, that is, Chapters 3, 5, 7, 8, 11, and 13.

Chapter 3 now includes a discussion of the uniqueness of the health care sector and the utilization of health care analytics using data, from various sources, to create a decision support system. Such a system will not only improve processes and patient outcomes as well as physician performance but also lead to an improved population health.

An important form of feedback from customers on a product or service is through surveys. In health care, patients, for example, indicate their degree of satisfaction, with the various processes/procedures encountered, through questionnaires that are usually based on a five-point ordinal Likert scale. Chapter 5 presents some methods for displaying and analyzing ordinal or count data based on questionnaires. Strategic implications on decisions for management are also discussed, based on the degree of satisfaction and the degree of importance of each question item included in the survey.

The concept of risk adjustment, as it applies to health care applications, has been incorporated in the material on variable control charts in Chapter 7. In this context, the risk-adjusted cumulative sum chart, risk-adjusted sequential probability ratio test, risk-adjusted exponentially weighted moving average chart, and variable life-adjusted display chart are presented in this chapter.

Under attribute control charts, risk-adjusted p-charts for the proportion of patients that survive a certain type of illness or surgical procedure and risk-adjusted u-charts for monitoring the number of nonconformities per unit, for example, the number of pressure ulcers per patient day, are presented in Chapter 8. Further, monitoring of low-occurrence nonconformities in health care, such as surgical wound infections or gastrointestinal infections, are also discussed. Such monitoring may be accomplished through tracking of the time between events, in this case, infections, through a g-chart.

Another important application in health care is that of survival analysis. Often, in observational studies dealing with patients, the exact time of death of a patient may not be known. Moreover, some patients may leave the observational study. In such instances, censored data are available. The Kaplan–Meier product limit estimator of the survival function is introduced in Chapter 11. Methods are presented for comparison of survival functions of two groups in order to determine the statistical significance of a particular treatment.

A new chapter on process modeling through regression analysis has been added in this edition. Regression modeling is a versatile tool that may be used in manufacturing and service applications. It promotes the development of a functional relationship between a selected dependent variable and one or more independent variables. Chapter 13 discusses the concepts in the formulation of such models and assists with the identification of independent variables that have a significant effect on the dependent variable. In this chapter, logistic regression models are also introduced where the dependent variable is binary in nature. Such models have useful applications in health care.
ACKNOWLEDGMENTS

Many people have contributed to the development of this book, and thanks are due to them. Modern trends in product/process quality through design and improvement, as well as discussions and questions from undergraduate and graduate classes over the years, have shaped this book. Applications encountered in a consulting environment have provided a scenario for examples and exercises. Input from faculty and professional colleagues, here and abroad, has facilitated composition of the material. Constructive comments from the reviewers have been quite helpful. Many of the changes in the fourth edition are based on input from those who have used the book as well as from reviewers.

I am grateful to Margie Maddox of the College of Business at Auburn University for a remarkable job in the preparation of the manuscript. I would like to thank Minitab, Inc. (Quality Plaza, 1829 Pine Hall Road, State College, PA 16801-3008) for its assistance in providing software support. My editor, Jon Gurstelle, is to be commended for his patience and understanding.

Learning is a never-ending process. It takes time and a lot of effort. So does writing and revising a book. That has been my reasoning to my wife, Sujata, and son, Arnab. I believe they understand this—my appreciation to them. Their continual support has provided an endless source of motivation. As I complete this edition, a source of joy has been my daughter-in-law, Sharen, who brings a charisma that bonds the family.
ABOUT THE COMPANION WEBSITE

This book is accompanied by a companion website:
www.wiley.com/go/mitra\QualityControl4e

The website includes:
• Instructor’s solutions manual
PART I

PHILOSOPHY AND FUNDAMENTALS
INTRODUCTION TO QUALITY CONTROL AND THE TOTAL QUALITY SYSTEM

1-1 Introduction and chapter objectives
1-2 Evolution of quality control
1-3 Quality
1-4 Quality control
1-5 Quality assurance
1-6 Quality circles and quality improvement teams
1-7 Customer needs and market share
1-8 Benefits of quality control and the total quality system
1-9 Quality and reliability
1-10 Quality improvement
1-11 Product and service costing
1-12 Quality costs
1-13 Measuring quality costs
1-14 Management of quality
1-15 Quality and productivity
1-16 Total quality environmental management

Summary

1-1 INTRODUCTION AND CHAPTER OBJECTIVES

“Dad, are we there yet?” “How much longer will it take?” “Mom, I am hungry!” “Is there an eating place nearby where we may stop and get something to eat?” It was a hot summer day around the middle of June as the family was headed for a summer vacation. With due thanks to advances in technology, the answers to these questions were at the couple’s finger tips, reducing the uncertainty associated with traveling through a previously unknown place. Through the use of a smart phone that is able to download information via a global positioning system, directions to the nearly eating places were instantaneous. At the same time, estimates of the travel time provided a sense of relief. The developments of the twenty-first century and advances in quality make this possible. On the more philosophical question of “Are we there yet?” as far as quality is considered, the answer is clearly “No.” The process of quality improvement is a never-ending journey.
The objectives of this chapter are, first, to define quality as it relates to the manufacturing and service sector, to introduce the terminology related to quality, and to set up a framework for the design and implementation of quality. Of importance will be the ability to identify the unique needs of the customer, which will assist in maintaining and growing market share. A study of activity-based product costing will be introduced along with the impact of quality improvement on various quality-related costs. The reader should be able to interpret the relationships among quality, productivity, long-term growth, and customer satisfaction.

1-2 EVOLUTION OF QUALITY CONTROL

The quality of goods produced and services rendered has been monitored, either directly or indirectly, since time immemorial. However, using a quantitative base involving statistical principles to control quality is a modern concept.

The ancient Egyptians demonstrated a commitment to quality in the construction of their pyramids. The Greeks set high standards in arts and crafts. The quality of Greek architecture of the fifth century B.C. was so envied that it profoundly affected the subsequent architectural constructions of Rome. Roman-built cities, churches, bridges, and roads inspire us even today.

During the Middle Ages and up to the nineteenth century, the production of goods and services was confined predominantly to a single person or a small group. The groups were often family-owned businesses, so the responsibility for controlling the quality of a product or service lay with that person or small group—those also responsible for producing items conforming to those standards. This phase, comprising the time period up to 1900, has been labeled by Feigenbaum (1983) the operator quality control period. The entire product was manufactured by one person or by a very small group of persons. For this reason, the quality of the product could essentially be controlled by a person who was also the operator, and the volume of production was limited. The worker felt a sense of accomplishment, which lifted morale and motivated the worker to new heights of excellence. Controlling the quality of the product was thus embedded in the philosophy of the worker because pride in workmanship was widespread.

Starting in the early twentieth century and continuing to about 1920, a second phase evolved, called the foreman quality control period (Feigenbaum 1983). With the Industrial Revolution came the concept of mass production, which was based on the principle of specialization of labor. A person was responsible not for production of an entire product but rather for only a portion of it. One drawback of this approach was the decrease in the workers’ sense of accomplishment and pride in their work. However, most tasks were still not very complicated, and workers became skilled at the particular operations that they performed. People who performed similar operations were grouped together. A supervisor who directed that operation now had the task of ensuring that quality was achieved. Foremen or supervisors controlled the quality of the product, and they were also responsible for operations in their span of control.

The period from about 1920 to 1940 saw the next phase in the evolution of quality control. Feigenbaum (1983) calls this the inspection quality control period. Products and processes became more complicated, and production volume increased. As the number of workers reporting to a foreman grew in number, it became impossible for the foreman to keep close watch over individual operations. Inspectors were therefore designated to check the quality of a product after certain operations. Standards were set, and inspectors compared the quality