Contents

PART I FUNDAMENTAL QUALITY CONTROL AND STATISTICAL CONCEPTS

1 Introduction 3

1.1 Quality Costs, 3
1.2 Quality and Productivity, 5
1.3 The Need for Statistics, 6
1.4 The Use of Statistics in Various Companies, 7
1.5 Early Use of Statistics for Quality Improvement, 8
1.6 Statistical Methods versus Inspection, 9
1.7 Acceptance Sampling, 11
References, 12

2. Japan's Approach to Quality Control 14

2.1 Deming's Views and Influence, 14
2.2 The Deming Award, 16
2.3 Quality Circles, 17
2.4 Japanese Companies in America, 18
2.5 Statistical Techniques, 19
2.6 Cause and Effect Diagram, 19
2.7 Pareto Diagrams, 21
2.8 Graphs, 24
References. 26

3. Basic Concepts in Statistics and Probability 27

3.1 Probability, 27
3.2 Sample versus Population, 29

3.3 Location, 31
3.4 Variation, 32
3.5 Discrete Distributions, 36
3.5.1 Binomial Distribution, 37
3.5.2 Poisson Distribution, 44
3.5.3 Hypergeometric Distribution, 45
3.6 Continuous Distributions, 47
3.6.1 Normal Distribution, 47
3.6.2 *t* Distribution, 52
3.6.3 Exponential Distribution, 55
3.6.4 Lognormal Distribution, 55
3.6.5 Weibull Distribution, 57
3.6.6 Gamma Distribution, 57
3.6.7 Chi-Square Distribution, 58
3.6.8 Truncated Normal Distribution, 58
3.6.9 Bivariate and Multivariate Normal Distribution, 59
3.6.10 *F* Distribution, 60
3.7 Statistical Inference, 61
3.7.1 Central Limit Theorem, 61
3.7.2 Point Estimation, 62
3.7.3 Confidence Intervals, 62
3.7.4 Tolerance Intervals, 64
3.7.5 Hypothesis Tests, 64
3.7.6 Bonferroni Intervals, 64
3.8 Enumerative Studies versus Analytic Studies, 65
References, 65
Exercises. 67

PART II CONTROL CHARTS AND PROCESS CAPABILITY

4. Introduction to Control Charts **71**

4.1 Basic Idea of a Control Chart, 71
4.2 Process Control versus Process Capability, 73
4.3 Real-Time Control Charting versus Analysis of Past Data. 74

4.4 Control Charts: When to Use, Where to Use, How Many to Use, 76
4.5 Benefits from the Use of Control Charts, 77
4.6 List of Control Charts Covered in This Book, 77
Appendix to Chapter 4, 79
Reference, 81

5. Control Charts for Measurements with Subgrouping (for One Variable) 82

5.1 Illustrative Example, 82
5.1.1 R Chart, 86
5.1.2 R Chart with Probability Limits, 88
5.1.3 s Chart, 89
5.1.4 s Chart with Probability Limits, 90
5.1.5 s^2 Chart, 94
5.1.6 $\bar{X}$ Chart, 94
5.1.7 Recomputing Control Limits, 97
5.1.8 Applying Control Limits to Future Production, 98
5.1.9 Standards for Control Charts, 98
5.1.10 Deleting Points, 99
5.1.11 Target Values, 100
5.2 Illustrative Example with Real Data, 100
5.3 CUSUM Procedures for Controlling a Process Mean, 102
5.3.1 CUSUM Procedure versus $\bar{X}$ Chart, 103
5.3.2 CUSUM Procedures: Principles and Historical Development, 105
5.3.3 FIR CUSUM, 110
5.3.4 Combined Shewhart–CUSUM Scheme, 112
5.3.5 V-Mask CUSUM Scheme, 116
5.4 CUSUM Procedures for Controlling Process Variability, 118
5.5 Geometric Moving Average Chart, 122
5.6 Acceptance Control Chart, 124
5.6.1 Acceptance Chart with $\bar{X}$ Control Limits, 126
5.6.2 Acceptance Charts versus Target Values, 129

5.7 Modified Limits, 129
5.8 Difference Control Charts, 130
5.9 Other Charts, 131
5.10 Unequal Sample Sizes, 132
5.11 Assumptions for the Charts in This Chapter, 132
Appendix to Chapter 5, 142
References, 144
Exercises, 147

6. Control Charts for Measurements Without Subgrouping (for One Variable) 150

6.1 Individual Observations Chart, 150
6.1.1 Control Limits for the X Chart, 151
6.1.2 Trended Data, 152
6.1.3 Illustrative Example: Random Data, 153
6.1.4 Illustrative Example: Trended Data, 155
6.1.5 Trended Real Data, 158
6.2 Moving Range Chart, 160
6.3 Moving Average Chart, 161
6.4 CUSUM for Individual Observations, 162
6.5 CUSUM for Process Variability, 167
Appendix to Chapter 6, 167
References, 168
Exercises, 169

7. Process Capability 172

7.1 Process Capability Indices, 172
7.2 Determining Process Capability with Control Charts, 174
7.2.1 Using an $\bar{X}$ Chart, 174
7.2.2 Using an X Chart, 176
References, 177
Exercises, 178

8. Control Charts for Attributes 179

8.1 Charts for Nonconforming Units, 180
8.1.1 *np* Chart, 180
8.1.2 Arcsin Transformation for Proportions Data, 182
8.1.3 *np* Chart with Runs Criteria, 186
8.1.4 *p* Chart, 188
8.1.5 Modified *p* and *np* Chart Limits, 189
8.1.6 *p* Unknown, 189
8.1.7 Unequal Sample Sizes, 192
8.1.8 CUSUM for Binomial Data, 193
8.2 Charts for Nonconformities, 196
8.2.1 *c* Chart, 196
8.2.2 Transforming Poisson Data, 197
8.2.3 Illustrative Example, 197
8.2.4 CUSUM Procedures for Nonconformity Data, 201
8.2.5 *u* Chart, 204
8.2.6 CUSUM Alternative to a *u* Chart, 206
8.2.7 *ku* Chart, 207
8.2.8 *D* Chart, 208
References, 210
Exercises, 211

9. Multivariate Control Charts for Measurement Data 215

9.1 Charts for the Process Mean Using Subgroups, 216
9.2 Variations of Hotelling's T^2, 217
9.2.1 Illustrative Example, 220
9.3 Multivariate Chart versus Individual $\bar{X}$ Charts, 223
9.4 Charts for Process Variability, 224
9.5 Charts Constructed Using Individual Observations, 224
9.6 When to Use Each Chart, 226
9.7 Actual Alpha Levels for Multiple Points, 227
9.8 Requisite Assumptions, 227
References, 227
Exercises, 228

10. Miscellaneous Control Chart Topics **230**

10.1 Economic Design of Control Charts, 230
10.2 Administrative Applications of Control Charts, 232
10.3 Software for Control Charting, 233
10.4 Applications of Control Charts in Specific Industries, 234
References, 234

PART III BEYOND CONTROL CHARTS: GRAPHICAL AND STATISTICAL METHODS

11 Graphical Methods **241**

11.1 Histogram, 242
11.2 Stem-and-Leaf Display, 245
11.3 Dot Diagrams, 247
11.4 Boxplot, 247
11.5 Normal Probability Plot, 251
11.6 Scatter Plot, 253
11.6.1 Variations of Scatter Plots, 255
11.7 Plotting Three Variables, 256
11.8 Displaying More Than Three Variables, 257
11.9 Plots to Aid in Transforming Data, 257
References, 260
Exercises, 262

12. Linear Regression

12.1 Simple Linear Regression, 264
12.2 Worth of the Prediction Equation, 269
12.3 Assumptions, 270
12.4 Checking Assumptions Through Residual Plots, 271
12.5 Confidence Intervals and Hypothesis Test, 272
12.6 Prediction Interval for Y, 273
12.7 Regression Control Chart, 274
12.8 Inverse Regression, 276
12.9 Multiple Linear Regression, 278

12.10 Issues in Multiple Regression, 278
12.10.1 Variable Selection, 279
12.10.2 Extrapolation, 279
12.10.3 Multicollinear Data, 280
12.10.4 Residual Plots, 280
12.10.5 Regression Diagnostics, 280
12.10.6 Transformations, 281
12.11 Software for Regression, 281
References, 282
Exercises, 283

13. Design of Experiments 285

13.1 A Simple Example of Experimental Design Principles, 285
13.2 Statistical Concepts in Experimental Design, 287
13.3 *t* Tests, 289
13.3.1 Exact *t* Test, 290
13.3.2 Approximate *t* Test, 292
13.3.3 Confidence Intervals for Differences, 293
13.4 Analysis of Variance for One Factor, 293
13.4.1 ANOVA for a Single Factor with More Than Two Levels, 296
13.4.2 Multiple Comparison Procedures, 301
13.4.3 Sample Size Determination, 301
13.4.4 Additional Terms and Concepts in One-Factor ANOVA, 302
13.5 Regression Analysis of Data from Designed Experiments, 304
13.6 ANOVA for Two Factors, 309
13.6.1 ANOVA with Two Factors: Factorial Designs, 310
13.6.2 Effect Estimates, 312
13.6.3 ANOVA Table for Unreplicated Two-Factor Design, 313
13.6.4 Yates' Algorithm, 316
13.7 The 2^3 Design, 318

13.8 Assessment of Effects without a Residual Term, 324
13.9 Residual Plot, 326
13.10 Two-Level Designs with More Than Three Factors, 329
13.11 Three-Level Factorial Designs, 330
13.12 Mixed Factorials, 330
13.13 Fractional Factorials, 331
13.13.1 2^{k-1} Designs, 331
13.13.2 2^{k-2} Designs, 338
13.13.3 Fractions of Three-Level Factorials, 340
13.13.4 Incomplete Mixed Factorials, 340
13.14 Other Topics in Experimental Design and Their Applications, 340
13.14.1 Mixture Designs, 340
13.14.2 Response Surface Designs, 340
13.14.3 Computer-Aided Design and Expert Systems, 341
13.14.4 Sequential Experimentation, 341
References, 342
Exercises, 345

14. Taguchi Methods and Related Procedures **348**

14.1 Quality Engineering, 348
14.2 Loss Functions, 349
14.3 Distribution Not Centered at the Target, 352
14.4 Loss Functions and Specification Limits, 352
14.5 Asymmetric Loss Functions, 352
14.6 Signal-to-Noise Ratios and Alternatives, 356
14.7 Experimental Designs for Stage One, 358
14.8 Taguchi Methods of Design, 359
14.8.1 Orthogonal Arrays as Fractional Factorials, 361
14.8.2 Other Orthogonal Arrays versus Fractional Factorials, 364
14.9 Determining Optimum Conditions, 369
14.10 Taguchi or Not?, 374
References, 375
Exercises, 376

15. Evolutionary Operation

15.1 EVOP Illustrations, 379
15.2 Three Variables, 388
15.3 Simplex EVOP, 390
15.4 Other EVOP Procedures, 393
Appendix to Chapter 15, 394
References, 395
Exercises, 396

16. Analysis of Means

16.1 ANOM for One-Way Classifications, 399
16.2 ANOM for Attribute Data, 402
16.2.1 Proportions, 402
16.2.2 Count Data, 405
16.3 ANOM When Standards Are Given, 405
16.3.1 Nonconforming Units, 405
16.3.2 Nonconformities, 406
16.3.3 Measurement Data, 407
16.4 ANOM for Factorial Designs, 407
16.4.1 Assumptions, 411
16.4.2 An Alternative Way of Displaying Interaction Effects, 411
16.5 ANOM When at Least One Factor Has More Than Two Levels, 412
16.5.1 Main Effects, 412
16.5.2 Interaction Effects, 417
Appendix to Chapter 16, 422
References, 423
Exercises, 423

Answers to Selected Exercises

APPENDIX: STATISTICAL TABLES

Table A. Random Numbers

Table B. Normal Distribution

Table C. *t* **Distribution** 431

Table D. *F* **Distribution** 432

Table E. Control Chart Constants 434

Table F. Percentage Points of the Sample Range for Producing Probability Limits for *R* Charts

Table G. Analysis of Means Constants

Index