

Detailed Contents

List of Tables	XXXI
List of Abbreviations	XLI

Part A Fundamental Statistics and Its Applications

1 Basic Statistical Concepts

<i>Hoang Pham</i>	3
1.1 Basic Probability Measures	3
1.1.1 Probability Axioms	4
1.1.2 Basic Statistics	4
1.1.3 Reliability Measures	5
1.2 Common Probability Distribution Functions	7
1.2.1 Discrete Random Variable Distributions	7
1.2.2 Continuous Distributions	9
1.3 Statistical Inference and Estimation	17
1.3.1 Parameter Estimation	18
1.3.2 Maximum Likelihood Estimationwith Censored Data	20
1.3.3 Statistical Change-Point Estimation Methods	23
1.3.4 Goodness of Fit Techniques	25
1.3.5 Least Squared Estimation	26
1.3.6 Interval Estimation	27
1.3.7 Nonparametric Tolerance Limits	30
1.3.8 Sequential Sampling	30
1.3.9 Bayesian Methods	31
1.4 Stochastic Processes	32
1.4.1 Markov Processes	32
1.4.2 Counting Processes	37
1.5 Further Reading	42
References	42
1.A Appendix: Distribution Tables	43
1.B Appendix: Laplace Transform	47

2 Statistical Reliability with Applications

<i>Paul Kvam, Jye-Chyi Lu</i>	49
2.1 Introduction and Literature Review	49
2.2 Lifetime Distributions in Reliability	50
2.2.1 Alternative Properties to Describe Reliability	51
2.2.2 Conventional Reliability Lifetime Distributions	51
2.2.3 From Physics to Failure Distributions	51
2.2.4 Lifetime Distributions from Degradation Modeling	52
2.2.5 Censoring	53
2.2.6 Probability Plotting	53

2.3	Analysis of Reliability Data	54
2.3.1	Maximum Likelihood	54
2.3.2	Likelihood Ratio	54
2.3.3	Degradation Data	55
2.4	System Reliability	56
2.4.1	Estimating System and Component Reliability	57
2.4.2	Stochastic Dependence Between System Components	58
2.4.3	Logistics Systems	59
2.4.4	Robust Reliability Design in the Supply Chain	59
	References	60

3	Weibull Distributions and Their Applications	
	<i>Chin-Diew Lai, D.N. Pra Murthy, Min Xie</i>	63
3.1	Three-Parameter Weibull Distribution	64
3.1.1	Historical Development	64
3.1.2	Relations to Other Distributions	64
3.2	Properties	64
3.2.1	Basic Properties	64
3.2.2	Properties Related to Reliability	65
3.2.3	Simulation	66
3.3	Modeling Failure Data	67
3.3.1	Probability Plots	67
3.3.2	Estimation and Hypothesis Testing	68
3.3.3	Hypothesis Testing	69
3.4	Weibull-Derived Models	70
3.4.1	Taxonomy for Weibull Models	70
3.4.2	Univariate Models	70
3.4.3	Type VI Models (Stochastic Point Process Models)	73
3.5	Empirical Modeling of Data	73
3.6	Applications	74
3.6.1	Applications in Reliability	74
3.6.2	Applications in Other Areas	75
3.6.3	Weibull Analysis Software	75
	References	76

4	Characterizations of Probability Distributions	
	<i>H.N. Nagaraja</i>	79
4.1	Characterizing Functions	80
4.1.1	Cumulative Distribution Function (CDF)	80
4.1.2	Probability Density Function (PDF)	80
4.1.3	Quantile Function	80
4.1.4	Characteristic Function (CF) and Other Generating Functions	80
4.1.5	Reliability Considerations	81
4.2	Data Types and Characterizing Conditions	81
4.2.1	Data Models	81
4.2.2	Characterizing Conditions	82
4.2.3	General Techniques	82

4.3	A Classification of Characterizations	83
4.3.1	Uniqueness Conditions	83
4.3.2	Characterizations of Families of Distributions	84
4.3.3	Characterizations of Specific Parametric Families	84
4.4	Exponential Distribution	84
4.5	Normal Distribution	85
4.6	Other Continuous Distributions	87
4.6.1	Uniform	87
4.6.2	Gamma	87
4.6.3	Weibull	87
4.6.4	Gumbel and Other Extreme-Value Distributions	87
4.6.5	Pareto	88
4.6.6	Inverse Gaussian (IG)	88
4.7	Poisson Distribution and Process	88
4.8	Other Discrete Distributions	90
4.8.1	Geometric	90
4.8.2	Binomial and Negative Binomial	90
4.9	Multivariate Distributions and Conditional Specification	90
4.9.1	Bivariate and Multivariate Exponential Distributions	91
4.9.2	Multivariate Normal	91
4.9.3	Other Distributions	91
4.10	Stability of Characterizations	92
4.11	Applications	92
4.12	General Resources	93
	References	94
5	Two-Dimensional Failure Modeling	
	<i>D.N. Pra Murthy, Jaiwook Baik, Richard J. Wilson, Michael Bulmer</i>	97
5.1	Modeling Failures	98
5.1.1	Product Failures	98
5.1.2	Approaches to Modeling	98
5.1.3	First and Subsequent Failures	98
5.2	Black-Box Modeling Process	98
5.2.1	Data Types	98
5.2.2	Modeling Process	99
5.3	One-Dimensional Black-Box Failure Modeling	99
5.3.1	Modeling First Failure	99
5.3.2	Modeling Subsequent Failures	99
5.3.3	Exploratory Data Analysis	100
5.3.4	Model Selection	101
5.3.5	Parameter Estimation	102
5.3.6	Model Validation	102
5.4	Two-Dimensional Black-Box Failure Modeling	103
5.4.1	One-Dimensional Approach	103
5.4.2	Two-Dimensional Approach	103
5.4.3	Exploratory Data Analysis	106

5.4.4	Model Selection	107
5.4.5	Parameter Estimation and Validation	107
5.5	A New Approach to Two-Dimensional Modeling	107
5.5.1	Model Description	107
5.5.2	An Application	108
5.6	Conclusions	110
	References	110
6	Prediction Intervals for Reliability Growth Models with Small Sample Sizes	
	<i>John Quigley, Lesley Walls</i>	113
6.1	Modified IBM Model – A Brief History	114
6.2	Derivation of Prediction Intervals for the Time to Detection of Next Fault	115
6.3	Evaluation of Prediction Intervals for the Time to Detect Next Fault	117
6.4	Illustrative Example	119
6.4.1	Construction of Predictions	119
6.4.2	Diagnostic Analysis	121
6.4.3	Sensitivity with Respect to the Expected Number of Faults ...	121
6.4.4	Predicting In-Service Failure Times	122
6.5	Conclusions and Reflections	122
	References	122
7	Promotional Warranty Policies: Analysis and Perspectives	
	<i>Jun Bai, Hoang Pham</i>	125
7.1	Classification of Warranty Policies	126
7.1.1	Renewable and Nonrenewable Warranties	126
7.1.2	FRW, FRPW, PRW, CMW, and FSW Policies	127
7.1.3	Repair-Limit Warranty	128
7.1.4	One-Attribute Warranty and Two-Attribute Warranty	129
7.2	Evaluation of Warranty Policies	129
7.2.1	Warranty Cost Factors	129
7.2.2	Criteria for Comparison of Warranties	131
7.2.3	Warranty Cost Evaluation for Complex Systems	131
7.2.4	Assessing Warranty Benefits	132
7.2.5	On the Optimal Warranty Policy	133
7.3	Concluding Remarks	134
	References	134
8	Stationary Marked Point Processes	
	<i>Karl Sigman</i>	137
8.1	Basic Notation and Terminology	138
8.1.1	The Sample Space as a Sequence Space	138
8.1.2	Two-sided MPPs	138
8.1.3	Counting Processes	138
8.1.4	Forward and Backward Recurrence Times	138
8.1.5	MPPs as Random Measures: Campbell's Theorem	139
8.1.6	Stationary Versions	139

8.1.7	The Relationship Between Ψ , Ψ^0 and Ψ^*	141
8.1.8	Examples	142
8.2	Inversion Formulas	144
8.2.1	Examples	144
8.2.2	The Canonical Framework	145
8.3	Campbell's Theorem for Stationary MPPs	145
8.3.1	Little's Law	145
8.3.2	The Palm–Khintchine Formula	145
8.4	The Palm Distribution: Conditioning in a Point at the Origin	146
8.5	The Theorems of Khintchine, Korolyuk, and Dobrushin	146
8.6	An MPP Jointly with a Stochastic Process	147
8.6.1	Rate Conservation Law	147
8.7	The Conditional Intensity Approach	148
8.7.1	Time Changing to a Poisson Process	149
8.7.2	Papangelou's Formula	149
8.8	The Non–Ergodic Case	150
8.9	MPPs in \mathbb{R}^d	150
8.9.1	Spatial Stationarity in \mathbb{R}^d	151
8.9.2	Point Stationarity in \mathbb{R}^d	151
8.9.3	Inversion and Voronoi Sets	151
	References	152

9 Modeling and Analyzing Yield, Burn-In and Reliability for Semiconductor Manufacturing: Overview

	<i>Way Kuo, Kyungmee O. Kim, Taeho Kim</i>	153
9.1	Semiconductor Yield	154
9.1.1	Components of Semiconductor Yield	155
9.1.2	Components of Wafer Probe Yield	155
9.1.3	Modeling Random Defect Yield	155
9.1.4	Issues for Yield Improvement	158
9.2	Semiconductor Reliability	159
9.2.1	Bathtub Failure Rate	159
9.2.2	Occurrence of Failure Mechanisms in the Bathtub Failure Rate	159
9.2.3	Issues for Reliability Improvement	160
9.3	Burn-In	160
9.3.1	The Need for Burn-In	160
9.3.2	Levels of Burn-In	161
9.3.3	Types of Burn-In	161
9.3.4	Review of Optimal Burn-In Literature	162
9.4	Relationships Between Yield, Burn-In and Reliability	163
9.4.1	Background	163
9.4.2	Time–Independent Reliability without Yield Information	164
9.4.3	Time–Independent Reliability with Yield Information	164
9.4.4	Time–Dependent Reliability	165
9.5	Conclusions and Future Research	166
	References	166

Part B Process Monitoring and Improvement

10 Statistical Methods for Quality and Productivity Improvement

Wei Jiang, Terrence E. Murphy, Kwok-Leung Tsui 173

10.1 Statistical Process Control for Single Characteristics 174

10.1.1 SPC for i.i.d. Processes 175

10.1.2 SPC for Autocorrelated Processes 175

10.1.3 SPC versus APC 177

10.1.4 SPC for Automatically Controlled Processes 178

10.1.5 Design of SPC Methods: Efficiency versus Robustness 179

10.1.6 SPC for Multivariate Characteristics 180

10.2 Robust Design for Single Responses 181

10.2.1 Experimental Designs for Parameter Design 181

10.2.2 Performance Measures in RD 182

10.2.3 Modeling the Performance Measure 184

10.3 Robust Design for Multiple Responses 185

10.3.1 Additive Combination of Univariate Loss, Utility and SNR ... 185

10.3.2 Multivariate Utility Functions from Multiplicative
Combination 186

10.3.3 Alternative Performance Measures for Multiple
Responses 186

10.4 Dynamic Robust Design 186

10.4.1 Taguchi's Dynamic Robust Design 186

10.4.2 References on Dynamic Robust Design 187

10.5 Applications of Robust Design 187

10.5.1 Manufacturing Case Studies 187

10.5.2 Reliability 187

10.5.3 Tolerance Design 187

References 188

11 Statistical Methods for Product and Process Improvement

Kailash C. Kapur, Qianmei Feng 193

11.1 Six Sigma Methodology and the (D)MAIC(T) Process 195

11.1.1 Define: What Problem Needs to Be Solved? 195

11.1.2 Measure: What Is the Current Capability of the Process? 195

11.1.3 Analyze: What Are the Root Causes of Process Variability? ... 195

11.1.4 Improve: Improving the Process Capability 195

11.1.5 Control: What Controls Can Be Put in Place to Sustain the
Improvement? 196

11.1.6 Technology Transfer: Where Else Can These Improvements
Be Applied? 196

11.2 Product Specification Optimization 196

11.2.1 Quality Loss Function 197

11.2.2 General Product Specification Optimization Model 199

11.2.3 Optimization Model with Symmetric Loss Function 200

11.2.4 Optimization Model with Asymmetric Loss Function 201

11.3	Process Optimization	204
11.3.1	Design of Experiments	204
11.3.2	Orthogonal Polynomials	206
11.3.3	Response Surface Methodology	207
11.3.4	Integrated Optimization Models	208
11.4	Summary	211
	References	212

12 Robust Optimization in Quality Engineering

	<i>Susan L. Albin, Di Xu</i>	213
12.1	An Introduction to Response Surface Methodology	216
12.2	Minimax Deviation Method to Derive Robust Optimal Solution	218
12.2.1	Motivation of the Minimax Deviation Method	218
12.2.2	Minimax Deviation Method when the Response Model Is Estimated from Data	219
12.2.3	Construction of the Confidence Region	220
12.2.4	Monte Carlo Simulation to Compare Robust and Canonical Optimization	221
12.3	Weighted Robust Optimization	222
12.4	The Application of Robust Optimization in Parameter Design	224
12.4.1	Response Model Approach to Parameter Design Problems ..	224
12.4.2	Identification of Control Factors in Parameter Design by Robust Optimization	224
12.4.3	Identification of Control Factors when the Response Model Contains Alias Terms	225
	References	227

13 Uniform Design and Its Industrial Applications

	<i>Kai-Tai Fang, Ling-Yau Chan</i>	229
13.1	Performing Industrial Experiments with a UD	231
13.2	Application of UD in Accelerated Stress Testing	233
13.3	Application of UD in Computer Experiments	234
13.4	Uniform Designs and Discrepancies	236
13.5	Construction of Uniform Designs in the Cube	237
13.5.1	Lower Bounds of Categorical, Centered and Wrap-Around Discrepancies	238
13.5.2	Some Methods for Construction	239
13.6	Construction of UD for Experiments with Mixtures	240
13.7	Relationships Between Uniform Design and Other Designs	243
13.7.1	Uniformity and Aberration	243
13.7.2	Uniformity and Orthogonality	244
13.7.3	Uniformity of Supersaturated Designs	244
13.7.4	Isomorphic Designs, and Equivalent Hadamard Matrices	245
13.8	Conclusion	245
	References	245

14 Cuscore Statistics: Directed Process Monitoring for Early Problem Detection
Harriet B. Nembhard 249

14.1 Background and Evolution of the Cuscore in Control Chart Monitoring 250

14.2 Theoretical Development of the Cuscore Chart 251

14.3 Cuscores to Monitor for Signals in White Noise 252

14.4 Cuscores to Monitor for Signals in Autocorrelated Data 254

14.5 Cuscores to Monitor for Signals in a Seasonal Process 255

14.6 Cuscores in Process Monitoring and Control 256

14.7 Discussion and Future Work 258

References 260

15 Chain Sampling
Raj K. Govindaraju 263

15.1 ChSP-1 Chain Sampling Plan 264

15.2 Extended Chain Sampling Plans 265

15.3 Two-Stage Chain Sampling 266

15.4 Modified ChSP-1 Plan 268

15.5 Chain Sampling and Deferred Sentencing 269

15.6 Comparison of Chain Sampling with Switching Sampling Systems ... 272

15.7 Chain Sampling for Variables Inspection 273

15.8 Chain Sampling and CUSUM 274

15.9 Other Interesting Extensions 276

15.10 Concluding Remarks 276

References 276

16 Some Statistical Models for the Monitoring of High-Quality Processes
Min Xie, Thong N. Goh 281

16.1 Use of Exact Probability Limits 282

16.2 Control Charts Based on Cumulative Count of Conforming Items 283

16.2.1 CCC Chart Based on Geometric Distribution 283

16.2.2 CCC-*r* Chart Based on Negative Binomial Distribution 283

16.3 Generalization of the *c*-Chart 284

16.3.1 Charts Based on the Zero-Inflated Poisson Distribution 284

16.3.2 Chart Based on the Generalized Poisson Distribution 286

16.4 Control Charts for the Monitoring of Time-Between-Events 286

16.4.1 CQC Chart Based on the Exponential Distribution 287

16.4.2 Chart Based on the Weibull Distribution 287

16.4.3 General *t*-Chart 288

16.5 Discussion 288

References 289

17 Monitoring Process Variability Using EWMA

<i>Philippe Castagliola, Giovanni Celano, Sergio Fichera</i>	291
17.1 Definition and Properties of EWMA Sequences	292
17.1.1 Definition	292
17.1.2 Expectation and Variance of EWMA Sequences	293
17.1.3 The ARL for an EWMA Sequence	293
17.2 EWMA Control Charts for Process Position	295
17.2.1 EWMA- \bar{X} Control Chart	295
17.2.2 EWMA- \bar{X} Control Chart	296
17.2.3 ARL Optimization for the EWMA- \bar{X} and EWMA- \bar{X} Control Charts	296
17.3 EWMA Control Charts for Process Dispersion	298
17.3.1 EWMA- S^2 Control Chart	298
17.3.2 EWMA- S Control Chart	303
17.3.3 EWMA- R Control Chart	306
17.4 Variable Sampling Interval EWMA Control Charts for Process Dispersion	310
17.4.1 Introduction	310
17.4.2 VSI Strategy	310
17.4.3 Average Time to Signal for a VSI Control Chart	310
17.4.4 Performance of the VSI EWMA- S^2 Control Chart	316
17.4.5 Performance of the VSI EWMA- R Control Chart	319
17.5 Conclusions	323
References	324

**18 Multivariate Statistical Process Control Schemes
for Controlling a Mean**

<i>Richard A. Johnson, Ruojia Li</i>	327
18.1 Univariate Quality Monitoring Schemes	328
18.1.1 Shewhart \bar{X} -Bar Chart	328
18.1.2 Page's Two-Sided CUSUM Scheme	329
18.1.3 Crosier's Two-Sided CUSUM Scheme	329
18.1.4 EWMA Scheme	330
18.1.5 Summary Comments	331
18.2 Multivariate Quality Monitoring Schemes	331
18.2.1 Multivariate T^2 Chart	331
18.2.2 CUSUM of T_n (COT) Scheme	332
18.2.3 Crosier's Multivariate CUSUM Scheme	333
18.2.4 Multivariate EWMA Scheme [MEWMA(r)]	333
18.3 An Application of the Multivariate Procedures	336
18.4 Comparison of Multivariate Quality Monitoring Methods	337
18.5 Control Charts Based on Principal Components	338
18.5.1 An Application Using Principal Components	339
18.6 Difficulties of Time Dependence in the Sequence of Observations	341
References	344

Part C Reliability Models and Survival Analysis

19 Statistical Survival Analysis with Applications 347

Chengjie Xiong, Kejun Zhu, Kai Yu 347

19.1 Sample Size Determination to Compare Mean or Percentile
of Two Lifetime Distributions 349

19.1.1 The Model and Sample Size 350

19.1.2 Examples 351

19.1.3 Effect of Guarantee Time on Sample Size Determination 351

19.1.4 Application to NIA Aging Intervention Testing Program 354

19.2 Analysis of Survival Data from Special Cases 355

19.2.1 Analysis of Grouped and Censored Data from Step–Stress
Life Tests 356

19.2.2 Analysis of a Very Simple Step–Stress Life Test with
a Random Stress–Change Time 361

References 365

20 Failure Rates in Heterogeneous Populations 369

Maxim Finkelstein, Veronica Esaulova 369

20.1 Mixture Failure Rates and Mixing Distributions 371

20.1.1 Definitions 371

20.1.2 Multiplicative Model 372

20.1.3 Comparison with Unconditional Characteristics 372

20.1.4 Likelihood Ordering of Mixing Distributions 374

20.1.5 Ordering Variances of Mixing Distributions 375

20.2 Modeling the Impact of the Environment 377

20.2.1 Bounds in the Proportional Hazards Model 377

20.2.2 Change Point in the Environment 379

20.2.3 Shocks in Heterogeneous Populations 380

20.3 Asymptotic Behaviors of Mixture Failure Rates 380

20.3.1 Survival Model 380

20.3.2 Main Result 381

20.3.3 Specific Models 383

References 385

21 Proportional Hazards Regression Models 387

Wei Wang, Chengcheng Hu 387

21.1 Estimating the Regression Coefficients β 388

21.1.1 Partial Likelihood for Data with Distinct Failure Times 388

21.1.2 Partial Likelihood for Data with Tied Failure Times 389

21.2 Estimating the Hazard and Survival Functions 389

21.3 Hypothesis Testing 390

21.3.1 Likelihood Ratio Test 390

21.3.2 Wald Test 390

21.3.3 Score Test 390

21.4 Stratified Cox Model 390

21.5	Time-Dependent Covariates	390
21.6	Goodness-of-Fit and Model Checking	391
21.6.1	Tests of Proportionality	391
21.6.2	Test of the Functional Form of a Continuous Covariate	392
21.6.3	Test for the Influence of Individual Observation	392
21.6.4	Test for the Overall Fit	392
21.6.5	Test of Time-Varying Coefficients	392
21.6.6	Test for a Common Coefficient Across Different Groups	393
21.7	Extension of the Cox Model	393
21.7.1	Cox Model with Random Effects	393
21.7.2	Nonproportional Models	393
21.7.3	Multivariate Failure Time Data	394
21.8	Example	394
	References	395

22 Accelerated Life Test Models and Data Analysis

	<i>Francis Pascual, William Q. Meeker, Jr., Luis A. Escobar</i>	397
22.1	Accelerated Tests	398
22.1.1	Types of Accelerated Tests	398
22.1.2	Methods of Acceleration	399
22.1.3	Choosing an Accelerated Life Test Model	399
22.2	Life Distributions	400
22.2.1	The Lognormal Distribution	400
22.2.2	The Weibull Distribution	400
22.3	Acceleration Models	400
22.3.1	Scale-Accelerated Lifetime Model	401
22.3.2	Accelerating Product Use Rate	401
22.3.3	Models for Temperature Acceleration	401
22.3.4	Models for Voltage and Voltage-Stress Acceleration	403
22.3.5	Models for Two-or-More-Variable Acceleration	405
22.3.6	Guidelines and Issues for Using Acceleration Models	407
22.4	Analysis of Accelerated Life Test Data	407
22.4.1	Strategy for ALT Data Analysis	407
22.4.2	Data Analysis with One Accelerating Variable	408
22.5	Further Examples	412
22.5.1	Analysis of Interval Censored ALT Data	413
22.5.2	Analysis of Data From a Laminate Panel ALT	414
22.5.3	Analysis of ALT Data with Two or More Explanatory Variables	416
22.6	Practical Considerations for Interpreting the Analysis of ALT Data ...	421
22.7	Other Kinds of ATs	421
22.7.1	Continuous Product Operation Accelerated Tests	422
22.7.2	Highly Accelerated Life Tests	422
22.7.3	Environmental Stress Tests	422
22.7.4	Burn-In	422
22.7.5	Environmental Stress Screening	422

22.8	Some Pitfalls of Accelerated Testing	423
22.8.1	Failure Behavior Changes at High Levels of Accelerating Variables	423
22.8.2	Assessing Estimation Variability	423
22.8.3	Degradation and Failure Measured in Different Time Scales	424
22.8.4	Masked Failure Modes	424
22.8.5	Differences Between Product and Environmental Conditions in Laboratory and Field Conditions	424
22.9	Computer Software for Analyzing ALT Data	424
	References	425

23 Statistical Approaches to Planning of Accelerated Reliability Testing

	<i>Loon C. Tang</i>	427
23.1	Planning Constant-Stress Accelerated Life Tests	428
23.1.1	The Common Framework	429
23.1.2	Yang's Approach	430
23.1.3	Flexible Near-Optimal Plans	430
23.1.4	Numerical Example	432
23.2	Planning Step-Stress ALT (SSALT)	432
23.2.1	Planning a Simple SSALT	433
23.2.2	Planning Multiple-Step SSALT	435
23.2.3	Numerical Example	436
23.3	Planning Accelerated Degradation Tests (ADT)	436
23.3.1	Experimental Set Up and Model Assumptions	436
23.3.2	Formulation of Optimal SSADT Plans	437
23.3.3	Numerical Example	439
23.4	Conclusions	439
	References	440

24 End-to-End (E2E) Testing and Evaluation of High-Assurance Systems

	<i>Raymond A. Paul, Wei-Tek Tsai, Yinong Chen, Chun Fan, Zhibin Cao, Hai Huang</i>	443
24.1	History and Evolution of E2E Testing and Evaluation	444
24.1.1	Thin-Thread Specification and Analysis – the First Generation	444
24.1.2	Scenario Specification and Analysis – the Second Generation	445
24.1.3	Scenario-Driven System Engineering – the Third Generation	449
24.1.4	E2E on Service-Oriented Architecture – the Fourth Generation	449
24.2	Overview of the Third and Fourth Generations of the E2E T&E	449

24.3	Static Analyses	451
24.3.1	Model Checking	451
24.3.2	Completeness and Consistency Analysis	451
24.3.3	Test-Case Generation	453
24.4	E2E Distributed Simulation Framework	453
24.4.1	Simulation Framework Architecture	454
24.4.2	Simulation Agents' Architecture	454
24.4.3	Simulation Framework and Its Runtime Infrastructure (RTI) Services	455
24.5	Policy-Based System Development	459
24.5.1	Overview of E2E Policy Specification and Enforcement	460
24.5.2	Policy Specification	460
24.5.3	Policy Enforcement	463
24.6	Dynamic Reliability Evaluation	465
24.6.1	Data Collection and Fault Model	465
24.6.2	The Architecture-Based Reliability Model	467
24.6.3	Applications of the Reliability Model	469
24.6.4	Design-of-Experiment Analysis	469
24.7	The Fourth Generation of E2E T&E on Service-Oriented Architecture	470
24.7.1	Cooperative WS Construction	471
24.7.2	Cooperative WS Publishing and Ontology	471
24.7.3	Collaborative Testing and Evaluation	472
24.8	Conclusion and Summary	473
	References	474

25 Statistical Models in Software Reliability and Operations Research

	<i>P.K. Kapur, Amit K. Bardhan</i>	477
25.1	Interdisciplinary Software Reliability Modeling	479
25.1.1	Framework for Modeling	481
25.1.2	Modeling Testing Effort	482
25.1.3	Software Reliability Growth Modeling	482
25.1.4	Modeling the Number of Users in the Operational Phase	483
25.1.5	Modeling the User Growth	484
25.1.6	Estimation Methods	484
25.1.7	Numerical Illustrations	485
25.2	Release Time of Software	486
25.2.1	Release-Time Problem Formulations	488
25.3	Control Problem	489
25.3.1	Reliability Model for the Control Problem	489
25.3.2	Solution Methods for the Control Problem	490
25.4	Allocation of Resources in Modular Software	491
25.4.1	Resource-Allocation Problem	492
25.4.2	Modeling the Marginal Function	493

25.4.3 Optimization	494
References	495

26 An Experimental Study of Human Factors in Software Reliability Based on a Quality Engineering Approach

<i>Shigeru Yamada</i>	497
26.1 Design Review and Human Factors	498
26.1.1 Design Review	498
26.1.2 Human Factors	498
26.2 Design-Review Experiment	499
26.2.1 Human Factors in the Experiment	499
26.2.2 Summary of Experiment	499
26.3 Analysis of Experimental Results	500
26.3.1 Definition of SNR	500
26.3.2 Orthogonal Array $L_{18}(2^1 \times 3^7)$	501
26.4 Investigation of the Analysis Results	501
26.4.1 Experimental Results	501
26.4.2 Analysis of Variance	501
26.4.3 Discussion	501
26.5 Confirmation of Experimental Results	502
26.5.1 Additional Experiment	502
26.5.2 Comparison of Factorial Effects Under Optimal Inducer Conditions	502
26.6 Data Analysis with Classification of Detected Faults	504
26.6.1 Classification of Detected Faults	504
26.6.2 Data Analysis	504
26.6.3 Data Analysis with Correlation Among Inside and Outside Factors	505
References	506

27 Statistical Models for Predicting Reliability of Software Systems in Random Environments

<i>Hoang Pham, Xiaolin Teng</i>	507
27.1 A Generalized NHPP Software Reliability Model	509
27.2 Generalized Random Field Environment (RFE) Model	510
27.3 RFE Software Reliability Models	511
27.3.1 γ -RFE Model	511
27.3.2 β -RFE Model	512
27.4 Parameter Estimation	513
27.4.1 Maximum Likelihood Estimation (MLE)	513
27.4.2 Mean-Value Function Fits	514
27.4.3 Software Reliability	515
27.4.4 Confidence Interval	516
27.4.5 Concluding and Remarks	518
References	519

Part D Regression Methods and Data Mining

28 Measures of Influence and Sensitivity in Linear Regression

<i>Daniel Peña</i>	523
28.1 The Leverage and Residuals in the Regression Model	524
28.2 Diagnosis for a Single Outlier	525
28.2.1 Outliers	525
28.2.2 Influential Observations	526
28.2.3 The Relationship Between Outliers and Influential Observations	527
28.3 Diagnosis for Groups of Outliers	528
28.3.1 Methods Based on an Initial Clean Set	528
28.3.2 Analysis of the Influence Matrix	529
28.3.3 The Sensitivity Matrix	532
28.4 A Statistic for Sensitivity for Large Data Sets	532
28.5 An Example: The Boston Housing Data	533
28.6 Final Remarks	535
References	535

29 Logistic Regression Tree Analysis

<i>Wei-Yin Loh</i>	537
29.1 Approaches to Model Fitting	538
29.2 Logistic Regression Trees	540
29.3 LOTUS Algorithm	542
29.3.1 Recursive Partitioning	542
29.3.2 Tree Selection	543
29.4 Example with Missing Values	543
29.5 Conclusion	549
References	549

30 Tree-Based Methods and Their Applications

<i>Nan Lin, Douglas Noe, Xuming He</i>	551
30.1 Overview	552
30.1.1 Classification Example: Spam Filtering	552
30.1.2 Regression Example: Seismic Rehabilitation Cost Estimator	553
30.1.3 Outline	553
30.2 Classification and Regression Tree (CART)	555
30.2.1 Introduction	555
30.2.2 Growing the Tree	556
30.2.3 Pruning the Tree	557
30.2.4 Regression Tree	558
30.2.5 Some Algorithmic Issues	559
30.2.6 Summary	560
30.3 Other Single-Tree-Based Methods	561
30.3.1 Loh's Methods	561
30.3.2 Quinlan's C4.5	562

30.3.3	CHAID	563
30.3.4	Comparisons of Single-Tree-Based Methods	564
30.4	Ensemble Trees	565
30.4.1	Boosting Decision Trees	565
30.4.2	Random Forest	567
30.5	Conclusion	568
	References	569

31 Image Registration and Unknown Coordinate Systems

	<i>Ted Chang</i>	571
31.1	Unknown Coordinate Systems and Their Estimation	572
31.1.1	Problems of Unknown Coordinate Systems	572
31.1.2	Image Registration	572
31.1.3	The Orthogonal and Special Orthogonal Matrices	573
31.1.4	The Procrustes and Spherical Regression Models	574
31.1.5	Least Squares, L_1 , and M Estimation	574
31.2	Least Squares Estimation	575
31.2.1	Group Properties of $\mathcal{O}(p)$ and $\mathcal{SO}(p)$	575
31.2.2	Singular Value Decomposition	575
31.2.3	Least Squares Estimation in the Procrustes Model	576
31.2.4	Example: Least Squares Estimates for the Hands Data	577
31.2.5	Least Squares Estimation in the Spherical Regression Model	577
31.3	Geometry of $\mathcal{O}(p)$ and $\mathcal{SO}(p)$	578
31.3.1	$\mathcal{SO}(p)$ for $p = 2$	578
31.3.2	$\mathcal{SO}(p)$ for $p = 3$	578
31.3.3	$\mathcal{SO}(p)$ and $\mathcal{O}(p)$, for General p , and the Matrix Exponential Map	578
31.3.4	Geometry and the Distribution of M -Estimates	579
31.3.5	Numerical Calculation of M -Estimates for the Procrustes Model	579
31.4	Statistical Properties of M -Estimates	580
31.4.1	The Σ Matrix and the Geometry of the u_i	580
31.4.2	Example: Σ for the Hands Data	581
31.4.3	Statistical Assumptions for the Procrustes Model	581
31.4.4	Theorem (Distribution of $(\hat{\mathbf{A}}, \hat{\gamma}, \hat{\mathbf{b}})$ for the Procrustes Model) ..	581
31.4.5	Example: A Test of $\gamma = 1$	582
31.4.6	Example: A Test on \mathbf{A}	582
31.4.7	Asymptotic Relative Efficiency of Least Squares and L_1 Estimates	583
31.4.8	The Geometry of the Landmarks and the Errors in $\hat{\mathbf{A}}$	583
31.4.9	Statistical Properties of M -Estimates for Spherical Regressions	585
31.5	Diagnostics	587
31.5.1	Influence Diagnostics in Simple Linear Regression	587
31.5.2	Influence Diagnostics for the Procrustes Model	587
31.5.3	Example: Influence for the Hands Data	588
	References	590

32 Statistical Genetics for Genomic Data Analysis

<i>Jae K. Lee</i>	591
32.1 False Discovery Rate	592
32.2 Statistical Tests for Genomic Data	593
32.2.1 Significance Analysis of Microarrays	594
32.2.2 The Local-Pooled-Error Test	594
32.3 Statistical Modeling for Genomic Data	596
32.3.1 ANOVA Modeling	596
32.3.2 The Heterogeneous Error Model	596
32.4 Unsupervised Learning: Clustering	598
32.5 Supervised Learning: Classification	599
32.5.1 Measures for Classification Model Performance	600
32.5.2 Classification Modeling	600
32.5.3 Stepwise Cross-Validated Discriminant Analysis	601
References	603

33 Statistical Methodologies for Analyzing Genomic Data

<i>Fenghai Duan, Heping Zhang</i>	607
33.1 Second-Level Analysis of Microarray Data	609
33.1.1 Notation	609
33.1.2 Fold Change	609
33.1.3 <i>t</i> -Statistic	609
33.1.4 The Multiple Comparison Issue	609
33.1.5 Empirical Bayesian Approach	610
33.1.6 Significance Analysis of Microarray (SAM)	610
33.2 Third-Level Analysis of Microarray Data	611
33.2.1 Clustering	611
33.2.2 Classification	614
33.2.3 Tree- and Forest-Based Classification	616
33.3 Fourth-Level Analysis of Microarray Data	618
33.4 Final Remarks	618
References	619

34 Statistical Methods in Proteomics

<i>Weichuan Yu, Baolin Wu, Tao Huang, Xiaoye Li, Kenneth Williams, Hongyu Zhao</i>	623
34.1 Overview	623
34.2 MS Data Preprocessing	625
34.2.1 Peak Detection/Finding	626
34.2.2 Peak Alignment	627
34.2.3 Remaining Problems and Proposed Solutions	627
34.3 Feature Selection	628
34.3.1 A Simple Example of the Effect of Large Numbers of Features	628
34.3.2 Interaction	629
34.3.3 Reducing the Influence of Noise	630
34.3.4 Feature Selection with Machine Learning Methods	630
34.4 Sample Classification	630

34.5	Random Forest: Joint Modelling of Feature Selection and Classification	630
34.5.1	Remaining Problems in Feature Selection and Sample Classification	632
34.6	Protein/Peptide Identification	633
34.6.1	Database Searching	633
34.6.2	De Novo Sequencing	633
34.6.3	Statistical and Computational Methods	633
34.7	Conclusion and Perspective	635
	References	636
35	Radial Basis Functions for Data Mining	
	<i>Miyoung Shin, Amrit L. Goel</i>	639
35.1	Problem Statement	640
35.2	RBF Model and Parameters	641
35.3	Design Algorithms	642
35.3.1	Common Algorithms	642
35.3.2	SG Algorithm	643
35.4	Illustrative Example	643
35.5	Diabetes Disease Classification	645
35.6	Analysis of Gene Expression Data	647
35.7	Concluding Remarks	648
	References	648
36	Data Mining Methods and Applications	
	<i>Kwok-Leung Tsui, Victoria Chen, Wei Jiang, Y. Alp Aslandogan</i>	651
36.1	The KDD Process	653
36.2	Handling Data	654
36.2.1	Databases and Data Warehousing	654
36.2.2	Data Preparation	654
36.3	Data Mining (DM) Models and Algorithms	655
36.3.1	Supervised Learning	655
36.3.2	Unsupervised Learning	661
36.3.3	Software	663
36.4	DM Research and Applications	664
36.4.1	Activity Monitoring	664
36.4.2	Mahalanobis–Taguchi System	665
36.4.3	Manufacturing Process Modeling	665
36.5	Concluding Remarks	667
	References	667

Part E Modeling and Simulation Methods

37	Bootstrap, Markov Chain and Estimating Function	
	<i>Feifang Hu</i>	673
37.1	Overview	673
37.1.1	Invariance under Reparameterization	673

37.1.2 Automatic Computation	674
37.1.3 First and Higher Order Accuracy	674
37.2 Classical Bootstrap	675
37.2.1 Efron's Bootstrap	675
37.2.2 Second-Order-Accurate Confidence Intervals	676
37.2.3 Linear Regression	677
37.2.4 Some Remarks	678
37.3 Bootstrap Based on Estimating Equations	678
37.3.1 EF Bootstrap and Studentized EF Bootstrap	678
37.3.2 The Case of a Single Parameter	679
37.3.3 The Multiparameter Case	679
37.3.4 Some Examples	680
37.4 Markov Chain Marginal Bootstrap	681
37.5 Applications	682
37.6 Discussion	684
References	684
38 Random Effects	
<i>Yi Li</i>	687
38.1 Overview	687
38.2 Linear Mixed Models	688
38.2.1 Estimation	689
38.2.2 Prediction of Random Effects	690
38.3 Generalized Linear Mixed Models	690
38.4 Computing MLEs for GLMMs	692
38.4.1 The EM Approach	692
38.4.2 Simulated Maximum Likelihood Estimation	693
38.4.3 Monte Carlo Newton-Raphson (MCNR)/ Stochastic Approximation (SA)	694
38.4.4 S-U Algorithm	694
38.4.5 Some Approximate Methods	696
38.5 Special Topics: Testing Random Effects for Clustered Categorical Data	697
38.5.1 The Variance Component Score Test in Random Effects-Generalized Logistic Models	697
38.5.2 The Variance Component Score Test in Random Effects Cumulative Probability Models	698
38.5.3 Variance Component Tests in the Presence of Measurement Errors in Covariates	699
38.5.4 Data Examples	700
38.6 Discussion	701
References	701
39 Cluster Randomized Trials: Design and Analysis	
<i>Mirjam Moerbeek</i>	705
39.1 Cluster Randomized Trials	706
39.2 Multilevel Regression Model and Mixed Effects ANOVA Model	707

39.3	Optimal Allocation of Units	709
39.3.1	Minimizing Costs to Achieve a Fixed Power Level	709
39.3.2	Maximizing Power Given a Fixed Budget	711
39.4	The Effect of Adding Covariates	712
39.5	Robustness Issues	713
39.5.1	Bayesian Optimal Designs	714
39.5.2	Designs with Sample-Size Re-Estimation	714
39.6	Optimal Designs for the Intra-Class Correlation Coefficient	715
39.7	Conclusions and Discussion	717
	References	717

40 A Two-Way Semilinear Model for Normalization and Analysis of Microarray Data

	<i>Jian Huang, Cun-Hui Zhang</i>	719
40.1	The Two-Way Semilinear Model	720
40.2	Semiparametric M-Estimation in TW-SLM	721
40.2.1	Basis-Based Method	721
40.2.2	Local Regression (Lowess) Method	722
40.2.3	Back-Fitting Algorithm in TW-SLM	722
40.2.4	Semiparametric Least Squares Estimation in TW-SLM	722
40.3	Extensions of the TW-SLM	724
40.3.1	Multi-Way Semilinear Models	724
40.3.2	Spiked Genes and Incorporation of Prior Knowledge in the MW-SLM	724
40.3.3	Location and Scale Normalization	725
40.4	Variance Estimation and Inference for β	725
40.5	An Example and Simulation Studies	727
40.5.1	Apo A1 Data	727
40.5.2	Simulation Studies	729
40.6	Theoretical Results	732
40.6.1	Distribution of $\hat{\beta}$	732
40.6.2	Convergence Rates of Estimated Normalization Curves \hat{f}_i	733
40.7	Concluding Remarks	734
	References	734

41 Latent Variable Models for Longitudinal Data with Flexible Measurement Schedule

	<i>Haiqun Lin</i>	737
41.1	Hierarchical Latent Variable Models for Longitudinal Data	738
41.1.1	Linear Mixed Model with a Single-Level Latent Variable	739
41.1.2	Generalized Linear Model with Latent Variables	740
41.1.3	Model with Hierarchical Latent Variables	740
41.2	Latent Variable Models for Multidimensional Longitudinal Data	741
41.2.1	Extended Linear Mixed Model for Multivariate Longitudinal Responses	741
41.2.2	Measurement Error Model	742
41.3	Latent Class Mixed Model for Longitudinal Data	743

41.4	Structural Equation Model with Latent Variables for Longitudinal Data	744
41.5	Concluding Remark: A Unified Multilevel Latent Variable Model	746
	References	747

42 Genetic Algorithms and Their Applications

	<i>Mitsuo Gen</i>	749
42.1	Foundations of Genetic Algorithms	750
42.1.1	General Structure of Genetic Algorithms	750
42.1.2	Hybrid Genetic Algorithms	751
42.1.3	Adaptive Genetic Algorithms	751
42.1.4	Fuzzy Logic Controller	751
42.1.5	Multiobjective Optimization Problems	752
42.2	Combinatorial Optimization Problems	753
42.2.1	Knapsack Problem	753
42.2.2	Minimum Spanning Tree Problem	754
42.2.3	Set-Covering Problem	755
42.2.4	Bin-Packing Problem	755
42.2.5	Traveling-Salesman Problem	756
42.3	Network Design Problems	757
42.3.1	Shortest-Path Problem	757
42.3.2	Maximum-Flow Problem	758
42.3.3	Minimum-Cost-Flow Problem	759
42.3.4	Centralized Network Design	760
42.3.5	Multistage Process Planning	760
42.4	Scheduling Problems	761
42.4.1	Flow-Shop Sequencing Problem	761
42.4.2	Job-Shop Scheduling	761
42.4.3	Resource-Constrained Projected Scheduling Problem	762
42.4.4	Multiprocessor Scheduling	763
42.5	Reliability Design Problem	763
42.5.1	Simple Genetic Algorithm for Reliability Optimization	764
42.5.2	Reliability Design with Redundant Unit and Alternatives ...	764
42.5.3	Network Reliability Design	765
42.5.4	Tree-Based Network Topology Design	765
42.6	Logistic Network Problems	766
42.6.1	Linear Transportation Problem	766
42.6.2	Multiobjective Transportation Problem	767
42.6.3	Bicriteria Transportation Problem with Fuzzy Coefficients	767
42.6.4	Supply-Chain Management (SCM) Network Design	768
42.7	Location and Allocation Problems	769
42.7.1	Location-Allocation Problem	769
42.7.2	Capacitated Plant Location Problem	770
42.7.3	Obstacle Location-Allocation Problem	771
	References	772

43 Scan Statistics	
<i>Joseph Naus</i>	775
43.1 Overview	775
43.2 Temporal Scenarios	776
43.2.1 The Continuous Retrospective Case	777
43.2.2 Prospective Continuous Case	779
43.2.3 Discrete Binary Trials: The Prospective Case	781
43.2.4 Discrete Binary Trials: The Retrospective Case	783
43.2.5 Ratchet-Scan: The Retrospective Case	783
43.2.6 Ratchet-Scan: The Prospective Case	784
43.2.7 Events Distributed on the Circle	784
43.3 Higher Dimensional Scans	784
43.3.1 Retrospective Continuous Two-Dimensional Scan	784
43.3.2 Prospective Continuous Two-Dimensional Scan	785
43.3.3 Clustering on the Lattice	786
43.4 Other Scan Statistics	786
43.4.1 Unusually Small Scans	786
43.4.2 The Number of Scan Clusters	787
43.4.3 The Double-Scan Statistic	787
43.4.4 Scanning Trees and Upper Level Scan Statistics	788
References	788
 44 Condition-Based Failure Prediction	
<i>Shang-Kuo Yang</i>	791
44.1 Overview	792
44.2 Kalman Filtering	794
44.2.1 System Model	794
44.2.2 State Estimation	794
44.2.3 Prediction	795
44.3 Armature-Controlled DC Motor	796
44.3.1 Transfer Function	796
44.3.2 Continuous State Space Model	796
44.3.3 Discrete State Space Model	797
44.4 Simulation System	797
44.4.1 Parameters	797
44.4.2 Monte Carlo Simulation and ARMA Model	798
44.4.3 Exponential Attenuator	798
44.4.4 Simulation Results	798
44.4.5 Notes About the Simulation	800
44.5 Armature-Controlled DC Motor Experiment	801
44.5.1 Experiment Design	801
44.5.2 Experimental Results	802
44.5.3 Notes About the Experiment	803
44.6 Conclusions	804
References	804

45 Statistical Maintenance Modeling for Complex Systems

<i>Wenjian Li, Hoang Pham</i>	807
45.1 General Probabilistic Processes Description	809
45.2 Nonrepairable Degraded Systems Reliability Modeling	810
45.2.1 Degraded Systems Subject to Two Competing Processes	810
45.2.2 Systems Subject to Three Competing Processes	813
45.2.3 Reliability Evaluation	815
45.2.4 Numerical Examples	816
45.3 Repairable Degraded Systems Modeling.....	819
45.3.1 Inspection–Maintenance Model Subject to Two Competing Processes	819
45.3.2 Inspection–Maintenance Model for Degraded Systems with Three Competing Processes	825
45.4 Conclusions and Perspectives	831
45.5 Appendix A	831
45.6 Appendix B	832
References	833

46 Statistical Models on Maintenance

<i>Toshio Nakagawa</i>	835
46.1 Time-Dependent Maintenance.....	836
46.1.1 Failure Distribution	836
46.1.2 Age Replacement	837
46.1.3 Periodic Replacement.....	838
46.2 Number-Dependent Maintenance	838
46.2.1 Replacement Policies	839
46.2.2 Number-Dependent Replacement.....	840
46.2.3 Parallel System	841
46.3 Amount-Dependent Maintenance	842
46.3.1 Replacement Policies	842
46.3.2 Replacement with Minimal Repair	843
46.4 Other Maintenance Models	843
46.4.1 Repair Limit Policy	843
46.4.2 Inspection with Human Errors	844
46.4.3 Phased Array Radar	845
References	847

Part F Applications in Engineering Statistics**47 Risks and Assets Pricing**

<i>Charles S. Tapiero</i>	851
47.1 Risk and Asset Pricing	853
47.1.1 Key Terms	853
47.1.2 The Arrow–Debreu Framework	854
47.2 Rational Expectations, Risk-Neutral Pricing and Asset Pricing	857
47.2.1 Risk-Neutral Pricing and Complete Markets	858

47.2.2	Risk-Neutral Pricing in Continuous Time	859
47.2.3	Trading in a Risk-Neutral World	860
47.3	Consumption Capital Asset Price Model and Stochastic Discount Factor	862
47.3.1	A Simple Two-Period Model	863
47.3.2	Euler's Equation and the SDF	864
47.4	Bonds and Fixed-Income Pricing	865
47.4.1	Calculating the Yield of a Bond	868
47.4.2	Bonds and Risk-Neutral Pricing in Continuous Time	869
47.4.3	Term Structure and Interest Rates	870
47.4.4	Default Bonds	871
47.5	Options	872
47.5.1	Options Valuation and Martingales	872
47.5.2	The Black-Scholes Option Formula	873
47.5.3	Put-Call Parity	874
47.5.4	American Options – A Put Option	875
47.5.5	Departures from the Black-Scholes Equation	876
47.6	Incomplete Markets and Implied Risk-Neutral Distributions	880
47.6.1	Risk and the Valuation of a Rated Bond	882
47.6.2	Valuation of Default-Prone Rated Bonds	884
47.6.3	"Engineered" Risk-Neutral Distributions and Risk-Neutral Pricing	886
47.6.4	The Maximum-Entropy Approach	892
	References	898

48 Statistical Management and Modeling for Demand of Spare Parts

	<i>Emilio Ferrari, Arrigo Pareschi, Alberto Regattieri, Alessandro Persona</i>	905
48.1	The Forecast Problem for Spare Parts	905
48.1.1	Exponential Smoothing	907
48.1.2	Croston's Method	908
48.1.3	Holt-Winter Models	908
48.2	Forecasting Methods	909
48.2.1	Characterizing Forecasting Methods	910
48.3	The Applicability of Forecasting Methods to Spare-Parts Demands ..	911
48.4	Prediction of Aircraft Spare Parts: A Case Study	912
48.5	Poisson Models	915
48.5.1	Stock Level Conditioned to Minimal Availability	916
48.5.2	Stock Level Conditioned to Minimum Total Cost	916
48.6	Models Based on the Binomial Distribution	917
48.6.1	An Industrial Application	918
48.7	Extension of the Binomial Model Based on the Total Cost Function ..	920
48.7.1	Service-Level Optimization: Minimum Total Cost Method ...	920
48.7.2	Simulation and Results	921
48.7.3	An Industrial Application	922
48.8	Weibull Extension	923
48.8.1	The Extension of the Modified Model Using the Weibull Distribution	923

48.8.2 Simulation and Results	924
48.8.3 Case Study: An Industrial Application	927
References	928

49 Arithmetic and Geometric Processes

<i>Kit-Nam F. Leung</i>	931
49.1 Two Special Monotone Processes	934
49.1.1 Arithmetic Processes	934
49.1.2 Geometric Processes	935
49.2 Testing for Trends	936
49.2.1 Laplace Test	936
49.2.2 Graphical Techniques	937
49.3 Estimating the Parameters	938
49.3.1 Estimate Parameters d , α_A and $\sigma_{\bar{A},\varepsilon}^2$ of K APs (or r , α_G and $\sigma_{\bar{G},\varepsilon}^2$ of K GPs)	938
49.3.2 Estimating the Parameters of a Single AP (or GP)	938
49.4 Distinguishing a Renewal Process from an AP (or a GP)	939
49.5 Estimating the Means and Variances	939
49.5.1 Estimating $\mu_{\bar{A}_1}$ and $\sigma_{\bar{A}_1}^2$ of \bar{A}_n s	939
49.5.2 Estimating $\mu_{\bar{G}_1}$ and $\sigma_{\bar{G}_1}^2$ of \bar{G}_n s	941
49.5.3 Estimating the Means and Variances of a Single AP or GP ...	944
49.6 Comparison of Estimators Using Simulation	945
49.6.1 A Single AP or GP	945
49.6.2 K Independent, Homogeneous APs or GPs	945
49.6.3 Comparison Between Averages of Estimates and Pooled Estimates	946
49.7 Real Data Analysis	946
49.8 Optimal Replacement Policies Determined Using Arithmetico-Geometric Processes	947
49.8.1 Arithmetico-Geometric Processes	947
49.8.2 Model	947
49.8.3 The Long-Run Expected Loss Rate	948
49.9 Some Conclusions on the Applicability of an AP and/or a GP	950
49.10 Concluding Remarks	951
49.A Appendix	953
References	954

50 Six Sigma

<i>Fugee Tsung</i>	957
50.0.1 What is Six Sigma?	957
50.0.2 Why Six Sigma?	958
50.0.3 Six Sigma Implementation	959
50.1 The DMAIC Methodology	960
50.1.1 Introduction	960
50.1.2 The DMAIC Process	960
50.1.3 Key Tools to Support the DMAIC Process	962

50.2	Design for Six Sigma	965
50.2.1	Why DFSS?	965
50.2.2	Design for Six Sigma: The DMADV Process	965
50.2.3	Key Tools to Support the DMADV Process	966
50.3	Six Sigma Case Study	970
50.3.1	Process Background	970
50.3.2	Define Phase	970
50.3.3	Measure Phase	970
50.3.4	Analyze Phase	970
50.3.5	Improve Phase	971
50.3.6	Control Phase	971
50.4	Conclusion	971
	References	971
 51 Multivariate Modeling with Copulas and Engineering Applications		
	<i>Jun Yan</i>	973
51.1	Copulas and Multivariate Distributions	974
51.1.1	Copulas	974
51.1.2	Copulas to Multivariate Distributions	975
51.1.3	Concordance Measures	975
51.1.4	Fréchet–Hoeffding Bounds	976
51.1.5	Simulation	977
51.2	Some Commonly Used Copulas	977
51.2.1	Elliptical Copulas	977
51.2.2	Archimedean Copulas	979
51.3	Statistical Inference	981
51.3.1	Exact Maximum Likelihood	981
51.3.2	Inference Functions for Margins (IFM)	982
51.3.3	Canonical Maximum Likelihood (CML)	982
51.4	Engineering Applications	982
51.4.1	Multivariate Process Control	982
51.4.2	Degradation Analysis	984
51.5	Conclusion	987
51.A	Appendix	987
51.A.1	The R Package Copula	987
	References	989
 52 Queuing Theory Applications to Communication Systems: Control of Traffic Flows and Load Balancing		
	<i>Panlop Zeephonsekul, Anthony Bedford, James Broberg, Peter Dimopoulos, Zahir Tari</i>	991
52.0.1	Congestion Control Using Finite-Buffer Queueing Models ...	992
52.0.2	Task Assignment Policy for Load Balancing	993
52.0.3	Modeling TCP Traffic	993
52.1	Brief Review of Queueing Theory	994
52.1.1	Queue Characteristics	994
52.1.2	Performance Metrics and Traffic Variables	996

52.1.3	The Poisson Process and the Exponential Distribution	996
52.1.4	Continuous-Time Markov Chain (CTMC)	997
52.2	Multiple-Priority Dual Queue (MPDQ)	1000
52.2.1	Simulating the MPDQ	1000
52.2.2	Solving the MPDQ Analytically	1002
52.2.3	The Waiting-Time Distribution	1004
52.3	Distributed Systems and Load Balancing	1005
52.3.1	Classical Load-Distribution Policies	1006
52.3.2	Size-Based Load Distribution Policies	1008
52.4	Active Queue Management for TCP Traffic	1012
52.4.1	TCP Algorithms	1012
52.4.2	Modeling Changes in TCP Window Sizes	1014
52.4.3	Modeling Queues of TCP Connections	1015
52.4.4	Differentiated Services	1016
52.5	Conclusion	1020
	References	1020
53	Support Vector Machines for Data Modeling with Software Engineering Applications	
	<i>Hojung Lim, Amrit L. Goel</i>	1023
53.1	Overview	1023
53.2	Classification and Prediction in Software Engineering	1024
53.2.1	Classification	1024
53.2.2	Prediction	1025
53.3	Support Vector Machines	1025
53.4	Linearly Separable Patterns	1026
53.4.1	Optimal Hyperplane	1026
53.4.2	Relationship to the SRM Principle	1027
53.4.3	Illustrative Example	1027
53.5	Linear Classifier for Nonseparable Classes	1029
53.6	Nonlinear Classifiers	1029
53.6.1	Optimal Hyperplane	1030
53.6.2	Illustrative Example	1030
53.7	SVM Nonlinear Regression	1032
53.8	SVM Hyperparameters	1033
53.9	SVM Flow Chart	1033
53.10	Module Classification	1034
53.11	Effort Prediction	1035
53.12	Concluding Remarks	1036
	References	1036
54	Optimal System Design	
	<i>Suprasad V. Amari</i>	1039
54.1	Optimal System Design	1039
54.1.1	System Design	1040
54.1.2	System Design Objectives	1041
54.1.3	Notation	1041

- 54.1.4 System Reliability 1042
 - 54.1.5 System Availability 1043
 - 54.1.6 Other Objective Functions 1044
 - 54.1.7 Existing Optimization Models 1045
- 54.2 Cost-Effective Designs 1047
 - 54.2.1 Nonrepairable Systems 1047
 - 54.2.2 Repairable Systems 1049
- 54.3 Optimal Design Algorithms 1051
 - 54.3.1 An Overview 1051
 - 54.3.2 Exact Methods 1053
- 54.4 Hybrid Optimization Algorithms 1055
 - 54.4.1 Motivation 1055
 - 54.4.2 Rationale for the Hybrid Method 1055
 - 54.4.3 Repairable Systems 1055
 - 54.4.4 Nonrepairable Systems 1061
 - 54.4.5 Conclusions 1062
- References** 1063
- Acknowledgements** 1065
- About the Authors** 1067
- Detailed Contents** 1085
- Subject Index** 1113