

Contents

1	Basic Probability Review	1
1.1	Basic Definitions	1
1.2	Random Variables and Distribution Functions	4
1.3	Mean and Variance	10
1.4	Important Distributions	13
1.5	Multivariate Distributions	23
1.6	Combinations of Random Variables	31
1.6.1	Fixed Sum of Random Variables	32
1.6.2	Random Sum of Random Variables	33
1.6.3	Mixtures of Random Variables	34
	Appendix	36
	Problems	37
	References	44
2	Basics of Monte Carlo Simulation	45
2.1	Simulation by Hand	46
2.2	Generation of Random Numbers	49
2.2.1	Multiplicative Linear Congruential Generators	50
2.2.2	A Multiple Recursive Generator	52
2.2.3	Composite Generators	53
2.3	Generation of Random Variates	55
2.3.1	Discrete Random Variates	55
2.3.2	Continuous Random Variates	61
2.3.3	Bivariate Continuous Random Variates	64
2.3.4	Random Variates from Empirical Distributions	66
	Appendix	67
	Problems	69
	References	71

3	Basic Statistics	73
3.1	Collection of Data	73
3.1.1	Preliminary Definitions	74
3.1.2	Graphical Representations	75
3.2	Parameter Estimation	78
3.2.1	Method of Moments	80
3.2.2	Maximum Likelihood Estimation	81
3.3	Confidence Intervals	82
3.3.1	Means	83
3.3.2	Proportions	87
3.3.3	Variances	87
3.3.4	Correlation Coefficient	89
3.4	Fitting Distributions	90
3.4.1	The Chi-Square Test	91
3.4.2	The Kolmogorov-Smirnov Test	95
	Appendix	99
	Problems	101
	References	105
4	Poisson Processes	107
4.1	Basic Definitions	107
4.2	Properties and Computations	110
4.3	Extensions of a Poisson Process	113
4.3.1	Compound Poisson Processes	113
4.3.2	Non-stationary Poisson Process	115
	Appendix	116
	Problems	118
	References	120
5	Markov Chains	121
5.1	Basic Definitions	122
5.2	Multistep Transitions	125
5.3	Classification of States	129
5.4	Steady-State Behavior	137
5.5	Computations	142
	Appendix	149
	Problems	151
	References	159
6	Markov Processes	161
6.1	Basic Definitions	161
6.2	Steady-State Properties	164
6.3	Revenues and Costs	168
6.4	Time-Dependent Probabilities	171
	Appendix	175

Problems	176
7 Queueing Processes	181
7.1 Basic Definitions and Notation	181
7.2 Single Server Systems	183
7.2.1 Infinite Capacity Single-Server Systems	183
7.2.2 Finite Capacity Single Server Systems	190
7.3 Multiple Server Queues	193
7.4 Approximations	197
Appendix	199
Problems	200
References	205
8 Queueing Networks	207
8.1 Jackson Networks	207
8.1.1 Open Jackson Networks	208
8.1.2 Closed Jackson Networks	212
8.2 Network Approximations	215
8.2.1 Deterministic Routing with Poisson Input	216
8.2.2 Deterministic Routing with non-Poisson Input	222
Appendix	225
Problems	226
References	229
9 Event-Driven Simulation and Output Analyses	231
9.1 Event-Driven Simulations	231
9.2 Statistical Analysis of Output	242
9.2.1 Terminating Simulations	243
9.2.2 Steady-State Simulations	246
9.2.3 Comparing Systems	255
Problems	259
References	264
10 Inventory Theory	265
10.1 The News-Vendor Problem	266
10.2 Single-Period Inventory	269
10.2.1 No Setup Costs	269
10.2.2 Setup Costs	272
10.3 Multi-Period Inventory	275
Problems	279
References	283

11 Replacement Theory	285
11.1 Age Replacement	285
11.1.1 Discrete Life Times	286
11.1.2 Continuous Life Times	289
11.2 Minimal Repair	292
11.2.1 Minimal Repairs without Early Replacements	293
11.2.2 Minimal Repairs with Early Replacements	294
11.3 Block Replacement	296
Problems	299
12 Markov Decision Processes	303
12.1 Basic Definitions	304
12.1.1 Expected Total Discounted Cost Criterion	306
12.1.2 Average Long-Run Cost Criterion	307
12.2 Stationary Policies	307
12.3 Discounted Cost Algorithms	309
12.3.1 Value Improvement for Discounted Costs	311
12.3.2 Policy Improvement for Discounted Costs	313
12.3.3 Linear Programming for Discounted Costs	316
12.4 Average Cost Algorithms	318
12.4.1 Policy Improvement for Average Costs	321
12.4.2 Linear Programming for Average Costs	325
12.5 The Optimal Stopping Problem	327
Problems	330
13 Advanced Queues	337
13.1 Difference Equations	338
13.2 Batch Arrivals	340
13.2.1 Quasi-Birth-Death Processes	342
13.2.2 Batch Arrivals (continued)	344
13.3 Phase-Type Distributions	346
13.4 Systems with Phase-Type Service	351
13.4.1 The M/Ph/1 Queueing System	351
13.4.2 The M/Ph/c Queueing System	356
13.5 Systems with Phase-Type Arrivals	356
Problems	358
References	362
A Matrix Review	363
A.1 Matrix Addition and Subtraction	364
A.2 Matrix Multiplication	364
A.3 Determinants	365
A.4 Determinants by Cofactor Expansion	367
A.5 Nonsingular Matrices	368
A.6 Inversion-in-Place	369

Contents	xv
A.7 Derivatives	373
References	374
Index	375