

Table of Contents

Chapter 1: Introduction to Simulation and Modeling	1
1.1 System Concepts.....	2
1.1.1 Definition of System.....	2
1.1.2 System Environment	2
1.1.3 System Boundary.....	2
1.1.4 Components of a System	3
1.1.5 State of the System.....	3
1.1.6 Types of Activities in a System	4
1.2 Types of Systems.....	4
1.3 Model of a System.....	6
1.4 Types of Models of a System	7
1.4.1 Physical (iconic) Models.....	7
1.4.2 Mathematical (logical) Models.....	8
1.5 Concepts of Simulation	9
1.6 Types of Simulation Models.....	9
1.7 Application Areas of Simulation	10
1.8 When Simulation is Appropriate and Not Appropriate	11
1.9 Advantages and Disadvantages of Simulation	12
1.10 Steps in a Simulation Study	13
Summary	15
References.....	16
Review Exercises	16
Multiple Choice Questions	16
Descriptive Questions.....	17
Chapter 2: Simulation Examples	27
2.1 Simulation Experiment.....	27
2.2 Simulation of a Static System.....	28
2.2.1 Monte Carlo Technique	28
2.2.2 Monte Carlo Examples	29
2.3 Simulation of Dynamic Systems.....	40
2.3.1 Queuing Systems.....	40
2.3.2 Inventory Systems	57
2.3.3 Reliability Problem.....	67
Summary	79
References.....	80
Review Exercises	80

	Numerical Problems.....	80
	Multiple Choice Questions.....	87
	Descriptive Questions.....	89
Chapter 3: Discrete-Event Simulation (General Principles).....		93
3.1	Concepts of Discrete-Event Simulation.....	93
3.1.1	Activity.....	94
3.1.2	Delay.....	94
3.1.3	Activity versus Delay.....	95
3.2	Discrete-Event Simulation.....	95
3.2.1	Future Event List.....	95
3.2.2	Model Components.....	96
3.3	Event-Scheduling/Time-Advance Algorithm.....	97
3.4	World Views on DES.....	103
3.4.1	The Process-Interaction Approach.....	103
3.4.2	The Activity-Scanning Approach.....	104
3.5	The Manual Simulation Using Event-Scheduling Approach.....	106
3.6	List Processing.....	119
3.6.1	Basic Properties of List.....	119
3.6.2	Basic Operations.....	120
3.6.3	Data Structures.....	120
	Summary.....	123
	References.....	124
	Review Exercises.....	124
	Numerical Problems.....	124
	Multiple Choice Questions.....	127
	Descriptive Questions.....	128
Chapter 4: Mathematical and Statistical Models in Simulation.....		131
4.1	Why to Use Probability and Statistics for Simulation?.....	131
4.2	Review of Terminology and Concepts in Probability and Statistics.....	132
4.3	Useful Statistical Models.....	139
4.3.1	Queuing Systems.....	139
4.3.2	Inventory and Supply-Chain Systems.....	140
4.3.3	Reliability.....	140
4.3.4	Limited Data.....	141
4.4	Popular Discrete Distributions.....	141
4.4.1	Bernoulli Trials and Bernoulli Distribution.....	141
4.4.2	Binomial Distribution.....	143

4.4.3	Geometric Distribution.....	144
4.4.4	Negative Binomial Distribution	144
4.4.5	Poisson Distribution	145
4.5	Popular Continuous Distributions.....	147
4.5.1	Uniform Distribution.....	147
4.5.2	Exponential Distribution.....	148
4.5.3	Gamma Distribution.....	151
4.5.4	Erlang Distribution.....	152
4.5.5	Weibull Distribution	153
4.5.6	Normal Distribution.....	155
4.5.7	Lognormal Distribution.....	156
4.5.8	Triangular Distribution	157
4.6	Empirical Distribution.....	159
4.7	Poisson Process.....	161
4.7.1	Properties of Poisson Process.....	163
	Summary	163
	References.....	164
	Review Exercises	164
	Numerical Problems.....	164
	Multiple Choice Questions	166
	Descriptive Questions.....	167
Chapter 5: Queuing Models		171
5.1	Characteristics of Queuing Systems	171
5.1.1	Calling Population.....	173
5.1.2	Arrival Process.....	173
5.1.3	System Capacity.....	174
5.1.4	Queue Behavior.....	175
5.1.5	Queue Discipline.....	175
5.1.6	Service Times and Service Mechanism	176
5.1.7	Queue Configuration	176
5.2	Queuing Notation	178
5.3	Long-Run Measures of Performance of Queuing Systems.....	179
5.3.1	Time-Average Number in System, L	180
5.3.2	Average Time Spent in System per Customer, w	181
5.3.3	The Conservation Equation – Little’s Law.....	182
5.3.4	Server Utilization.....	183
5.3.5	Costs in Queuing Problems.....	185

5.4	Steady-State Behavior of Infinite-Population Markovian Models	187
5.4.1	Single-Server Queue with Poisson Arrivals and Unlimited Capacity (M/G/1 and M/M/1).....	188
5.4.2	Multiserver Queues with Poisson Arrivals and Unlimited Capacity (M/M/c and M/G/c).....	189
5.4.3	Multiserver Queues with Poisson Arrivals and Limited Capacity (M/M/c/N/∞).....	194
5.5	Steady-State Behavior of Finite-Population Markovian Models (M/M/c/K/K).....	196
5.6	Networks of Queues.....	198
	Summary	200
	References.....	201
	Review Exercises	201
	Numerical Problems.....	201
	Multiple Choice Questions	204
	Descriptive Questions.....	206
Chapter 6: Random Number Generation		209
6.1	Properties of Random Numbers.....	209
6.2	Pseudo Random Numbers.....	211
6.2.1	Techniques for Generating Pseudo Random Numbers	211
6.3	Tests for Random Numbers.....	223
6.3.1	Level of Significance.....	223
6.3.2	When to Use the Tests.....	224
6.3.3	Ways to Conduct the Tests.....	224
6.4	Tests for Uniformity	224
6.4.1	Kolmogorov-Smirnov Test (K-S Test).....	224
6.4.2	Chi-Square Test.....	226
6.5	Tests for Independence.....	228
6.5.1	Runs Tests.....	228
6.5.2	Autocorrelation Test.....	241
6.5.3	Gap Test	244
6.5.4	Poker Test.....	246
	Summary	248
	References.....	248
	Review Exercises	249
	Numerical Problems.....	249
	Multiple Choice Questions	256
	Descriptive Questions.....	257

Chapter 7: Random Variate Generation	261
7.1 Inverse Transform Method.....	261
7.2 Inverse Transform Method for Continuous Distribution	262
7.2.1 Exponential Distribution	262
7.2.2 Uniform Distribution.....	263
7.2.3 Weibull Distribution	263
7.2.4 Triangular Distribution	264
7.2.5 Empirical Continuous Distribution	265
7.3 Inverse Transform Method for Discrete Distribution	268
7.3.1 Empirical Discrete Distribution.....	268
7.3.2 Discrete Uniform Distribution	270
7.3.3 Geometric Distribution.....	271
7.4 Direct Transformation Method	272
7.4.1 Direct Transformation for the Normal Distribution.....	272
7.4.2 Direct Transformation for the Lognormal Distribution.....	273
7.5 Convolution Method.....	274
7.6 Acceptance-Rejection Method.....	275
7.6.1 Poisson Distribution	276
7.6.2 Non-Stationary Poisson Process (NSPP)	278
7.6.3 Gamma Distribution.....	279
Summary	280
References.....	280
Review Exercises	281
Numerical Problems.....	281
Multiple Choice Questions	285
Descriptive Questions.....	286
Chapter 8: Input Modeling	289
8.1 Input Modeling Approaches	289
8.1.1 Trace-Driven Approach.....	290
8.1.2 Empirical Distribution Approach.....	290
8.1.3 Theoretical Distribution Approach.....	291
8.2 Steps in the Development of a Useful Model of Input Data.....	292
8.3 Data Collection	292
8.3.1 Recommendations for Improving Data Collection.....	293
8.4 Identifying the Distribution with Data	294
8.4.1 Histograms.....	294
8.4.2 Selecting the Family of Distribution	299
8.4.3 Quantile-Quantile Plots	302

x ► Table of Contents

8.5	Parameter Estimation.....	305
8.5.1	Sample Mean and Variance	305
8.6	Continuous Data in Class Intervals.....	307
8.7	Suggested Estimators.....	308
8.8	Goodness-of-Fit Tests	315
8.8.1	Chi-Square Goodness-of-Fit Test.....	315
8.8.2	Chi-Square with Equal Probabilities.....	318
8.8.3	Kolmogorov-Smirnov Goodness-of-Fit Test (K-S Test).....	319
8.8.4	p-Values and “Best Fits”	322
8.9	Selecting Input Models without Data.....	325
8.10	Covariance and Correlation	326
8.11	Multivariate Input Models.....	327
8.12	Time-Series Input Models.....	329
8.12.1	AR(1) Model.....	329
8.12.2	EAR(1) Model	330
	Summary	331
	References.....	332
	Review Exercises	332
	Numerical Problems.....	332
	Multiple Choice Questions	335
	Descriptive Questions.....	337
Chapter 9: Verification and Validation		339
9.1	Terminologies.....	340
9.2	Model Building	340
9.3	Verification of Simulation Models.....	342
9.3.1	Common-Sense Techniques	342
9.3.2	Thorough Documentation.....	344
9.3.3	Trace	344
9.4	Calibration and Validation of Simulation Models	346
9.4.1	Naylor and Finger Approach	347
9.4.2	t-Test.....	351
9.4.3	Power of a Test.....	354
9.4.4	Input-Output Validation Using Historical Input Data.....	355
9.4.5	Input-Output Validation Using Turing Test.....	357
	Summary	358
	References.....	358
	Review Exercises	359

	Numerical Problems.....	359
	Multiple Choice Questions.....	359
	Descriptive Questions.....	361
Chapter 10: Output Analysis for a Single System		367
10.1	Types of Simulations with Respect to Output Analysis	367
10.1.1	Terminating or Transient Simulation.....	367
10.1.2	Non-Terminating Simulation or Steady-State Simulation.....	368
10.2	Stochastic Nature of Output Data	369
10.3	Measures of Performance and Their Estimation.....	370
10.3.1	Point Estimation.....	370
10.3.2	Interval Estimation	371
10.4	Output Analysis of Terminating Simulations.....	372
10.4.1	Statistical Background-Within-Replication <i>versus</i> Across-Replication Data	372
10.4.2	Confidence Intervals with Specified Precision(ϵ)	374
10.4.3	Confidence-Interval for Quantiles.....	375
10.4.4	Estimating Probability and Quantile from Summary Data.....	377
10.5	Output Analysis of Steady-State Simulations.....	377
10.5.1	Initialization Bias in Steady-State Simulations.....	378
10.5.2	Statistical Background---Autocovariance and Autocorrelation	383
10.5.3	Replication Method for Steady-State Simulations.....	384
10.5.4	Confidence Intervals with Specified Precision(ϵ)	387
10.5.5	Batch Means for Interval Estimation.....	389
10.5.6	Confidence-Interval for Quantiles.....	392
	Summary.....	392
	References.....	392
	Review Exercises.....	393
	Numerical Problems.....	393
	Multiple Choice Questions.....	395
	Descriptive Questions.....	397
Chapter 11: Simulation of Computer Systems		401
11.1	Levels of Abstraction in Computer Systems.....	401
11.2	Simulation at Computer Network Level.....	402
11.2.1	Modeling the System Components	403
11.2.2	Modeling the Workload	404
11.3	Simulation at the Computer Subsystem Level.....	405
11.3.1	Simulation at the Processor Level.....	405
11.3.2	Simulation of Memory.....	406
11.3.3	Simulation of Disk	407

11.4	Simulation at the Combinational/Gate Level	407
	Summary	408
	References.....	408
	Review Exercises	408
	Numerical Problems.....	408
	Multiple Choice Questions	413
	Descriptive Questions.....	414
Chapter 12: Simulation of Manufacturing and Material Handling Systems.....		417
12.1	Manufacturing and Material Handling Systems.....	417
	12.1.1 Modeling Features of Simulation.....	418
12.2	Goals of Simulations.....	419
	12.2.1 Manufacturing Systems	420
	12.2.2 Material Handling Systems.....	420
12.3	Performance Measures of Manufacturing System and Material Handling Systems	421
	12.3.1 Performance Measures of Manufacturing Systems.....	421
	12.3.2 Performance Measures for Material Handling Systems.....	422
12.4	Developing Valid and Credible Simulation Models.....	422
	12.4.1 Modeling Downtimes and Failures	422
	12.4.2 Modeling System Randomness.....	423
	12.4.3 Design and Analysis of Simulation Experiments.....	424
12.5	Challenges in Simulation of Complex Systems.....	424
	Summary	424
	References.....	425
	Review Exercises	425
	Numerical Problems.....	425
	Multiple Choice Questions	426
	Descriptive Questions.....	427
Index.....		431