

# CONTENTS

<b>Preface</b>	<b>xv</b>
<b>Acknowledgments</b>	<b>xvii</b>
<b>Introduction</b>	<b>xix</b>
<b>1 Simulation Modeling</b>	<b>1</b>
1.1 Simulation Modeling, 1	
1.2 Why Simulate? 2	
1.3 Types of Computer Simulation, 3	
1.4 Simulation: Descriptive or Prescriptive Modeling? 6	
1.5 Randomness in Simulation, 7	
1.6 Simulation Languages, 7	
1.7 Simulation Methodology, 8	
1.8 Organization of The Book, 15	
Exercises, 15	
<b>2 Generating Randomness in Simulation</b>	<b>17</b>
2.1 The Stochastic Nature of Simulation, 17	
2.2 Random Numbers, 18	
2.3 Random Number Generators, 19	
2.4 Testing Random Numbers, 24	
2.4.1 Distributional Tests, 25	
2.4.2 Testing Independence, 34	
2.5 Generating Random Variates from Distributions, 37	
2.5.1 Inverse Transform, 38	
2.5.2 Convolution, 46	
2.5.3 Acceptance/Rejection, 47	

2.5.4	Mixture Distributions, Truncated Distributions, and Shifted Random Variables,	50
2.6	Summary,	54
	Exercises,	54
<b>3</b>	<b>Spreadsheet Simulation</b>	<b>63</b>
3.1	Simulation in a Spreadsheet Environment,	63
3.2	Useful Spreadsheet Functions and Methods,	64
3.2.1	Using RAND() and RANDBETWEEN(),	64
3.2.2	Using VLOOKUP(),	66
3.2.3	Using Data Tables to Repeatedly Sample,	68
3.2.4	Using VBA,	69
3.3	Example Spreadsheet Simulations,	70
3.3.1	Simple Monte-Carlo Integration,	71
3.3.2	The Classic News Vendor Inventory Problem,	73
3.3.3	Simulating a Random Cash Flow,	76
3.4	Introductory Statistical Concepts,	79
3.4.1	Point Estimates and Confidence Intervals,	79
3.4.2	Determining the Sample Size,	81
3.5	Summary,	86
	Exercises,	86
<b>4</b>	<b>Introduction to Simulation in Arena®</b>	<b>97</b>
4.1	Introduction,	97
4.2	The Arena Environment,	98
4.3	Performing Simple Monte-Carlo Simulations Using Arena,	100
4.3.1	Redoing Area Estimation with Arena,	101
4.3.2	Redoing the News Vendor Problem with Arena,	104
4.4	How The Discrete-Event Clock Works,	106
4.5	Modeling a Simple Discrete-Event Dynamic System,	110
4.5.1	A Drive-through Pharmacy,	110
4.5.2	Modeling the System,	110
4.5.3	Implementing the Model in Arena,	113
4.5.4	Specify the Arrival Process,	114
4.5.5	Specify the Resources,	116
4.5.6	Specify the Process,	116
4.5.7	Specify Run Parameters,	118
4.5.8	Analyze the Results,	120
4.6	Extending the drive through pharmacy model,	123
4.7	Animating the Drive-Through Pharmacy Model,	125
4.8	Getting Help in Arena,	133
4.9	Siman and The Run Controller,	133
4.9.1	SIMAN MOD and EXP Files,	134
4.9.2	Using the Run Controller,	138
4.10	How Arena Manages Entities and Events,	145
4.11	Summary,	149
	Exercises,	150

<b>5 Basic Process Modeling</b>	<b>163</b>
5.1 Elements of Process-Oriented Simulation,	163
5.2 Entities, Attributes, and Variables,	164
5.3 Creating and Disposing of Entities,	165
5.4 Defining Variables and Attributes,	169
5.5 Processing Entities,	174
5.6 Attributes, Variables, and Some I/O,	176
5.6.1 Modifying the Pharmacy Model,	176
5.6.2 Using the ASSIGN Module,	180
5.6.3 Using the READWRITE Module,	181
5.6.4 Using the RECORD Module,	184
5.6.5 Animating a Variable,	186
5.6.6 Running the Model,	187
5.7 Flow of Control in Arena,	190
5.7.1 Logical and Probabilistic Conditions,	191
5.7.2 Iterative Looping,	195
5.7.3 Example: Iterative Looping, Expressions, and Submodels,	196
5.8 Batching and Separating Entities,	210
5.8.1 Example: Tie-Dye T-Shirts,	210
5.9 Summary,	221
Exercises,	223
<b>6 Modeling Randomness in Simulation</b>	<b>233</b>
6.1 Random Variables and Probability Distributions,	233
6.2 Modeling with Discrete Distributions,	238
6.3 Modeling with Continuous Distributions,	240
6.4 Input Distribution Modeling,	242
6.5 Fitting Discrete Distributions,	244
6.5.1 Fitting a Poisson Distribution,	244
6.5.2 Visualizing the Data,	245
6.5.3 Statistical Analysis of the Data,	247
6.5.4 Checking the Goodness of Fit of the Model,	250
6.6 Fitting Continuous Distributions,	254
6.6.1 Visualizing the Data,	255
6.6.2 Statistically Summarize the Data,	256
6.6.3 Hypothesizing and Testing a Distribution,	257
6.6.4 Visualizing the Fit,	263
6.7 Using The Input Analyzer,	267
6.8 Additional Input Modeling Concepts,	276
6.9 Modeling Randomness in Arena,	279
6.9.1 Conceptualizing the Model,	280
6.9.2 Implementing the Model,	282
6.10 Summary,	292
Exercises,	293

<b>7 Analyzing Simulation Output</b>	<b>299</b>
7.1 Types of Statistical Variables, 300	
7.2 Types of Simulation with Respect to Output Analysis, 305	
7.3 Analysis of Finite-Horizon Simulations, 307	
7.3.1 Determining the Number of Replications, 309	
7.3.2 Finite Horizon Example, 311	
7.3.3 Sequential Sampling for Finite-Horizon Simulations, 318	
7.4 Analysis of Infinite-Horizon Simulations, 321	
7.4.1 Assessing the Effect of Initial Conditions, 327	
7.4.2 Performing the Method of Replication–Deletion, 332	
7.4.3 Looking for the Warm-Up Period in the Output Analyzer, 335	
7.4.4 The Method of Batch Means, 346	
7.4.5 Performing the Method of Batch Means, 350	
7.5 Comparing System Configurations, 353	
7.5.1 Comparing Two Systems, 354	
7.5.2 Analyzing Multiple Systems, 372	
7.6 Summary, 382	
Exercises, 384	
<b>8 Modeling Queuing and Inventory Systems</b>	<b>393</b>
8.1 Introduction, 393	
8.2 Single Line Queuing Stations, 394	
8.2.1 Queuing Notation, 396	
8.2.2 Little’s Formula, 398	
8.2.3 Deriving Formulas for Markovian Single-Queue Systems, 401	
8.3 Examples and Applications of Queuing Analysis, 407	
8.3.1 Infinite Queue Examples, 407	
8.3.2 Finite Queue Examples, 412	
8.4 Non-Markovian Queues and Approximations, 417	
8.5 Simulating Single Queues in Arena, 419	
8.5.1 Machine Interference Optimization Model, 419	
8.5.2 Using OptQuest on the Machine Interference Model, 424	
8.5.3 Modeling Balking and Reneging, 427	
8.6 Holding and Signaling Entities, 435	
8.6.1 Redoing the M/M/1 Model with HOLD/SIGNAL, 437	
8.7 Networks of Queuing Stations, 442	
8.7.1 STATION, ROUTE, and SEQUENCE Modules, 444	
8.8 Inventory Systems, 453	
8.8.1 Modeling an $(r, Q)$ Inventory Control Policy, 454	
8.8.2 Modeling a Multi-Echelon Inventory System, 464	
8.9 Summary, 471	
Exercises, 472	

<b>9 Entity Movement and Material-Handling Constructs</b>	<b>489</b>
9.1 Introduction, 489	
9.2 Resource-Constrained Transfer, 490	
9.2.1 Implementing Resource-Constrained Transfer, 492	
9.2.2 Animating Resource-Constrained Transfer, 498	
9.3 Constrained Transfer with Transporters, 501	
9.3.1 Test and Repair Shop with Workers as Transporters, 504	
9.3.2 Animating Transporters, 509	
9.4 Modeling Systems with Conveyors, 511	
9.4.1 Test and Repair Shop with Conveyors, 516	
9.4.2 Animating Conveyors, 519	
9.4.3 Miscellaneous Issues in Conveyor Modeling, 522	
9.5 Modeling Guided Path Transporters, 528	
9.6 Summary, 537	
Exercises, 537	
<b>10 Miscellaneous Topics in Arena Modeling</b>	<b>543</b>
10.1 Introduction, 543	
10.2 Non-stationary Processes, 544	
10.2.1 Thinning Method, 547	
10.2.2 Rate Inversion Method, 548	
10.3 Advanced Resource Modeling, 552	
10.3.1 Scheduled Capacity Changes, 553	
10.3.2 Calculating Utilization, 559	
10.3.3 Resource Failure Modeling, 562	
10.4 Tabulating Frequencies Using the Statistic Module, 565	
10.5 Resource and Entity Costing, 568	
10.5.1 Resource Costing, 568	
10.5.2 Entity Costing, 571	
10.6 Miscellaneous Modeling Concepts, 576	
10.6.1 Picking Between Stations, 576	
10.6.2 Generic Station Modeling, 579	
10.6.3 Picking up and Dropping Off Entities, 585	
10.7 Programming Concepts Within Arena, 593	
10.7.1 Using the Generated Access File, 593	
10.7.2 Working with Files, Excel, and Access, 596	
10.7.3 Using Visual Basic for Applications, 609	
10.7.4 Generating Correlated Random Variates, 622	
10.8 Summary, 625	
Exercises, 625	

<b>11 Application of Simulation Modeling</b>	<b>633</b>
11.1 Introduction, 633	
11.2 SM Testing Contest Problem Description, 635	
11.3 Answering the Basic Modeling Questions, 640	
11.4 Detailed Modeling, 645	
11.4.1 Conveyor and Station Modeling, 646	
11.4.2 Modeling Samples and the Test Cells, 648	
11.4.3 Modeling Sample Holders and the Load/Unload Area, 655	
11.4.4 Performance Measure Modeling, 658	
11.4.5 Simulation Horizon and Run Parameters, 659	
11.4.6 Preliminary Experimental Analysis, 663	
11.5 Final Experimental Analysis and Results, 663	
11.5.1 Using the Process Analyzer on the Problem, 664	
11.5.2 Using OptQuest on the Problem, 668	
11.5.3 Investigating the New Logic Alternative, 671	
11.6 Sensitivity Analysis, 671	
11.7 Completing the Project, 672	
11.8 Some Final Thoughts, 675	
Exercises, 676	
<b>Bibliography</b>	<b>677</b>
<b>Appendix A Common Distributions</b>	<b>683</b>
<b>Appendix B Statistical Tables</b>	<b>689</b>
<b>Appendix C Distributions, Operators, Functions in Arena</b>	<b>697</b>
<b>Appendix D Queuing Theory Formulas</b>	<b>699</b>
<b>Appendix E Inventory Theory Formulas</b>	<b>703</b>
<b>Appendix F Useful Equations</b>	<b>705</b>
<b>Appendix G Arena Panel Modules</b>	<b>707</b>
<b>Index</b>	<b>711</b>