

# SIMULATION WITH ARENA

S I M U L A T I O N

W. David Kelton

Randall P. Sadowski

Deborah A. Sadowski

# **Simulation with Arena**

**W. David Kelton**

*Professor*

*Department of Quantitative Analysis and Operations Management  
University of Cincinnati*

**Randall P. Sadowski**

*Chief Applications Officer and Director of Educational Services  
Systems Modeling Corporation*

**Deborah A. Sadowski**

*Senior Product Engineer  
Systems Modeling Corporation*



Boston, Massachusetts Burr Ridge, Illinois Dubuque, Iowa  
Madison, Wisconsin New York, New York San Francisco, California St. Louis, Missouri

# WCB/McGraw-Hill

*A Division of The McGraw-Hill Companies*

## SIMULATION WITH ARENA

Copyright © 1998 by The McGraw-Hill Companies, Inc. All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

This book is printed on acid-free paper.

4 5 6 7 8 9 0 DOC/DOC 9 0 9

ISBN 0-07-027509-2

Vice president and editorial director: *Kevin T. Kane*

Editorial director: *Tom Casson*

Executive editor: *Eric Munson*

Developmental editor: *Kelly Lee*

Marketing manager: *John Wannemacher*

Typeface: *10/12 Times New Roman*

Printer: *R. R. Donnelley & Sons Company*

## Library of Congress Cataloging-in-Publication Data

Kelton, W. David

Simulation with arena/W. David Kelton, Randall P. Sadowski, Deborah A. Sadowski.

p. cm.

ISBN 0-07-027509-2

Includes bibliographical references and index.

1. Computer simulation. 2. Arena (Computer file). I. Sadowski, Randall P. II. Sadowski, Deborah A.

QA76.9.C65 K45 1998

003'.35369 dc—21

97-26265

## About the Authors

**W. DAVID KELTON** is a professor in the Department of Quantitative Analysis and Operations Management, College of Business Administration, University of Cincinnati. He received a B.A. in mathematics from the University of Wisconsin-Madison, an M.S. in mathematics from Ohio University, and M.S. and Ph.D. degrees in industrial engineering from Wisconsin. He was formerly on the faculty at the University of Minnesota, The University of Michigan, and Kent State University.

His research and publications are in the probabilistic and statistical aspects of simulation, applications of simulation, and stochastic models. He is co-author, with Averill M. Law, of *Simulation Modeling and Analysis*, in its second edition with McGraw-Hill.

He serves as simulation area editor for the *INFORMS Journal on Computing* and simulation department co-editor for *IIE Transactions*, and is associate editor of *Operations Research*, the *Journal of Manufacturing Systems*, and *Simulation*; he was also guest co-editor for a special simulation issue of *IIE Transactions*. In 1994 he received the IIE Operations Research Division Award. He is a past president of the TIMS College on Simulation, and is the INFORMS College on Simulation co-representative to the Winter Simulation Conference board of directors. In 1987 he was program chair for the Winter Simulation Conference, and in 1991 was general chair. He has worked on grants and consulting contracts from a number of corporations, foundations, and agencies. He likes to think of himself as a reasonably competent bicycle mechanic and a neat barn painter.

**RANDALL P. SADOWSKI** is currently director of university relations and chief applications officer at Systems Modeling Corporation. He was previously vice president of consulting services and user education.

Before joining Systems Modeling, he was on the faculty at Purdue University in the School of Industrial Engineering, and at the University of Massachusetts. He received his bachelor's and master's degrees in industrial engineering from Ohio University, and his Ph.D. in industrial engineering from Purdue.

He has authored over 50 technical articles and papers, served as chair of the Third International Conference on Production Research, and was the general chair of the 1990 Winter Simulation Conference. He is on the visiting committee for the IE departments at Lehigh University and the University of Pittsburgh. He is co-author, with C. Dennis Pegden and Robert E. Shannon, of *Introduction to Simulation Using SIMAN*, now in its second edition with McGraw-Hill.

He is a senior member of the Institute of Industrial Engineers and served as editor of a two-year series on Computer Integrated Manufacturing Systems for *IE Magazine* that received the 1987 IIE Outstanding Publication award. He has served in several positions at IIE, including president at the chapter and division levels, and vice president of Systems Integration at the international level. He founded and continues to organize the

annual IIE/SM Student Simulation Contest. Some people claim they actually like the beef jerky he makes and he's envied for his three chain saws, but he is a sloppy barn painter.

**DEBORAH A. SADOWSKI** is a senior member of Systems Modeling's Arena product team. At present, she works on numerous special projects related to product creation and application, as well as customer training and support. Previously, she served as vice president of development for SM, ushering in the age of Arena, and as a product manager and developer. Since joining the company, she has delivered simulation consulting projects and has trained hundreds of budding simulationists. She also has written product manuals and online help, aided customers via the help desk (see Chapter 8), marketed and sold SM products, and performed quality assurance on product releases.

She received her bachelor's and master's degrees in industrial engineering and operations research from The Pennsylvania State University. She continues affiliation with her alma mater through service on its Engineering Industrial and Professional Advisory Council, whose industrial engineering team she recently chaired.

Professionally, Deb currently represents the IEEE Computer Society on the Winter Simulation Conference board of directors. She was the general chair of WSC 1994, as well as serving as business and exhibits chairs for previous conferences. In addition to INFORMS, IIE, SCS, ACM, and IEEE, Deb is a member of BPA (Barn Painters Anonymous), a support group for families and friends of barn painters neat and sloppy alike.

To those in the truly important arena of our lives:

Albert, Anna, Anne, Charity, Christie, Jenny, Molly, Noah,  
Sammy, Sean, Shelley, Tierney, and yet unnamed. And may we  
not forget Mr. Munchkin.

# Preface

**T**his book provides an introduction to simulation using Arena. It is intended to be used as an entry-level simulation text, most likely in a first course on simulation at the undergraduate or beginning graduate level. However, material from the later chapters could be incorporated into a second, graduate-level course. The book can also be used to learn simulation independent of a formal course (more specifically, by Arena users). The primary objective is to present the concepts and methodology of simulation using Arena as a vehicle. While we'll cover most of the capabilities of Arena, the book is not meant to be an exhaustive reference on the software, which is fully documented in its reference materials and extensive online help system.

We've chosen an organization and writing style for this book to aid the beginner in fully and easily understanding the concepts presented. Nearly all of the modeling and analysis ideas are presented in the context of examples. Ideally, readers would build simulation models as they read through each of these chapters. Rather than confining the simulation process and statistical-analysis issues to their own chapters, we've incorporated most of this material into the modeling chapters. This allows readers to absorb basic project-planning and analysis ideas along with the modeling concepts, which mirror how actual simulation projects ought to proceed. We've also devoted chapters to each of these topics individually so that we can cover the more advanced issues not treated in our modeling chapters. We believe that this approach greatly enhances the learning process by placing it in a more realistic and (frankly) less boring setting.

We assume that the reader has no prior knowledge of simulation, and no computer-programming experience is required. We assume basic familiarity with computing in general (files, folders, basic editing operations, etc.), but nothing advanced. Some basic understanding of probability and statistics is needed, though we provide a self-contained refresher on what's required from these subjects in Appendices C and D.

The book starts in Chapter 1 with a general introduction and brief history of simulation and modeling concepts. Chapter 2 addresses the simulation process using a simple hand simulation. Chapter 3 acquaints readers with Arena by examining a completed simulation model of the problem simulated by hand in Chapter 2. Chapter 4 introduces the Arena user interface and provides an overview of its modeling capabilities, which will allow readers to begin to build small simulation models effectively.

The next five chapters are devoted to modeling concepts and methodologies for simulation of complex systems. Chapter 5 starts this journey by introducing sufficient high-level modeling constructs to allow readers to begin modeling more realistic systems. Included is a discussion of input data analysis and the Arena Input Analyzer tool as part of the modeling process. Chapter 6 expands on the basic modeling constructs presented in Chapter 5, discusses model verification, and shows readers how to enhance

animations. Additionally, it illustrates how to conduct basic statistical analysis on the output from terminating systems using the Arena Output Analyzer tool. At this point, readers should have learned the techniques to allow them to model systems in considerable detail using the high-level constructs provided by Arena. They should also have an understanding of the issues and approaches for verification and statistical analysis of simulation models.

Chapter 7 covers the concepts associated with limiting entity travel in the simulation model. Specifically, it presents material handling modeling constructs that allow effective modeling of most material handling systems, including transportation devices and conveyors. This chapter also covers the basic statistical issues for setting up and analyzing the output from steady-state systems. Chapter 8 introduces readers to a rich selection of lower-level modeling constructs that facilitate building very detailed and complex models. Chapter 9 continues this theme by digging even deeper into the extensive modeling constructs provided by Arena. It uses a series of small, focused models to present a wide variety of special-purpose modeling capabilities, including selected constructs from the underlying SIMAN simulation language. This chapter is intended primarily for the more advanced simulation user and would probably not be covered in a beginning simulation course.

Chapter 10 combines a number of topics under the aegis of customizing Arena and integrating it with other applications like spreadsheets and word processors. Included in this chapter is a high-level exploration of the capabilities of Visual Basic® for Applications (VBA) and the Arena Professional Edition, as well as how to craft custom reports for Arena models.

Chapter 11 is devoted to some of the more advanced statistical concepts underlying and often applied to simulation analysis, including random-number generators, variate and process generation, variance-reduction techniques, sequential sampling, the more specialized capabilities of the Arena Output Analyzer, and designing simulation experiments. Chapter 12 provides a broad overview of the simulation process and discusses more specifically the issues of managing a large simulation project. It also has a brief discussion of the Arena Viewer, which allows Arena models to be disseminated to systems not having the full Arena software installed.

The Appendices provide background and reference material. Appendix A describes a complete modeling specification for an actual project carried out for *The Washington Post* newspaper. In Appendix B, we give three problem statements for the Arena modeling contest held annually by the Institute of Industrial Engineers (IIE) and Systems Modeling. Appendix C gives a complete but concise review of the basics of probability and statistics couched in the framework of their role in simulation modeling and analysis. The probability distributions supported by Arena are detailed in Appendix D. Installation instructions for the Arena Academic software can be found in Appendix E.

All references are collected in a single References section at the end of the book. The index is extensive, to aid readers in locating topics and seeing how they relate to each other. The index includes authors cited.

The writing and organization have been done in what might be called "tutorial style." This style is built around a sequence of carefully crafted examples to present the concepts and applications rather than adopting the more traditional style of describing concepts first and then citing examples as an afterthought. For this reason, it probably makes sense to read (or teach) this material essentially in the order presented. A one-semester or one-quarter first course in simulation could cover all the material in Chapters 1–8, including the statistical issues. Time permitting, selected modeling and computing topics from Chapters 9 and 10 could be included, or some of the more advanced statistical issues from Chapter 11, or the project-management material from Chapter 12, according to the instructor's tastes. A second course in simulation could assume most of the material in Chapters 1–6, then cover the more advanced modeling ideas in Chapters 7–10, followed by topics from Chapters 11 and 12 as desired. For self study, we'd suggest at a minimum going through Chapters 1–5 to understand the basics of simulation and modeling with Arena, getting at least familiar with Chapters 6 and 7, then regarding the rest of the book as a source for more advanced topics and reference as needed. Regardless of what topics are covered, and whether the book is used in a formal course or independently, it will be helpful to follow along in Arena on a computer while reading this book.

To that end, the book includes a CD containing the Academic version of Arena (see Appendix E for installation instructions), which has all the modeling and analysis capabilities of the complete commercial version (the Arena Standard Edition) but limits the model size. All the examples presented in the book, as well as all the exercises at the ends of the chapters, will run with this educational version of Arena. The CD also contains files for all the example models in the book, as well as other support materials. This software can be installed on any university computer as well as on students' computers. It is intended for use in conjunction with this book for the purpose of learning simulation and Arena. It is not authorized for use in commercial environments.

Furthermore, a Web site is maintained at <http://www.sm.com/arena.book> with a variety of materials to support instructors, students, and readers. There is a set of Microsoft® PowerPoint® lecture files that are ideal for use in the classroom with computer-projection equipment to allow for quick changing back and forth to Arena itself so students can see exactly how to work with the software and how it behaves (including dynamic animations). These files may be downloaded by instructors and used exactly as they are, as a starting point for minor or major editing, as inspiration for an individual teaching style, or ignored. The site also has an electronic "Suggestion Box" where we welcome input and comments on the book. For instructors, we have a password-protected area in the site (contact the publisher for permission to access this area) with complete solutions to all the exercises (model files or text as appropriate), and an area where instructors can contribute additional exercises and solutions for other instructors to see and use; contributed exercises incorporated into future editions of the book will acknowledge the contributor unless otherwise requested. Downloading the material we provide is possible via a standard Web browser or by anonymous ftp (see instructions on the Web site itself). The site will be maintained and updated as warranted to support the book's users, so its structure may evolve, but it will always contain descriptions and instructions.

As with any labor like this, there are a lot of people and institutions that supported us in a lot of different ways. First and foremost, Lynn Barrett at Systems Modeling really made this all happen by reading (and re-reading and re-re-reading and fixing) our semi-literate drafts, orchestrating the composing and production, reminding us of what month it was, and tolerating our tardiness and fussiness and quirky personal-hyphenation habits. Systems Modeling Corporation provided resources in the form of time, software, hardware, technical assistance, and moral encouragement; we'd particularly like to thank Sherri Blaszkiewicz, Nancy Markovitch, Tom Gurgiolo, Steve Frank, Scott Miller, Wendy Krah, Teri King, Nicoletta Bleiel, and Dennis Pegden. The Department of Quantitative Analysis and Operations Management at the University of Cincinnati was also quite supportive.

We are also grateful to Gary Lucke and Olivier Girod of *The Washington Post* for allowing us to include a simulation specification that was developed for them by Systems Modeling as part of a larger project. Special thanks go to Pete Kauffman for his cover design and production assistance, and to Jim McClure for his cartoon and illustration design. And we appreciate the skillful motivation and gentle nudging by our editor at McGraw-Hill, Eric Munson. The reviewers, Mansooreh Mollaghasemi (University of Central Florida); Barry Nelson (Northwestern University); Edward Watson (Louisiana State University); and Preston White, Jr. (University of Virginia), provided extremely valuable input and help, ranging from overall organization and content all the way to the downright subatomic. Thanks are also due to the many individuals who have used part or all of the early material in classes (with particular thanks to the students who were subjected to these early drafts). These include Michael Branson (Oklahoma State University); Chun-Hung Chen (University of Pennsylvania); John J. Clifford (The Ohio State University); Tom Crowe (University of Missouri); Patrick Delaney (United States Military Academy); Darrell Donahue (University of Maine); David Goldsman (Georgia Tech); Byron Gottfried (University of Pittsburgh); Frank Grange (Colorado School of Mines); Arthur Hsu (Carnegie Mellon University); Keebom Kang (Naval Postgraduate School); Michael Kwinn, Jr. (United States Military Academy); Mansooresh Mollaghasemi (University of Central Florida); Barry Nelson (Northwestern University); Mike Proctor (University of Central Florida); Thomas Rohleder (University of Calgary); Marvin Seppanen (University of St. Thomas); Julie Ann Stuart (The Ohio State University); Michael Taaffe (University of Minnesota); Wayne Wakeland (Portland State University); Edward Watson (Louisiana State University); Preston White, Jr. (University of Virginia); and Irving Winters (Morgan State University).

In addition, we appreciate the help, suggestions, and encouragement of a host of other people, including Christos Alexopoulos, Ken Bauer, Diane Bischak, Eberhard Blümel, Colin Campbell, John Charnes, Chun-Hung Chen, Hong Chen, Russell Cheng, Christopher Chung, Frank Ciarallo, Mary Court, Halim Damerджи, Ken Ebeling, Gerald Evans, Steve Fisk, Michael Fu, David Goldsman, John Gum, Jorge Haddock, Joe Heim, Michael Howard, Eric Johnson, Elena Joshi, Elena Katok, Gary Kochenberger, Patrick

Koelling, David Kohler, Bradley Kramer, Averill Law, Larry Leemis, Marty Levy, Gerald Mackulak, Deborah Mederios, Brian Melloy, Ed Mooney, Jack Morris, Charles Mosier, Marvin Nakayama, Richard Nance, James Patell, Cecil Peterson, Dave Pratt, Madhu Rao, James Reeve, Steve Roberts, Paul Rogers, Ralph Rogers, Jerzy Rozenblit, Salim Salloum, G. Sathyanarayanan, Bruce Schmeiser, Carl Schultz, Thomas Schulze, David Sieger, Robert Signorile, Darryl Starks, Jim Swain, Michael Taaffe, Laurel Travis, Reha Tutuncu, Michael Weng, Jim Wilson, Chih-Hang (John) Wu, James Wynne, Susan Xu, and Stefanos Zenios.

And, of course, we have to thank all those around us, both big and small (and in some cases, each other) who for some reason put up with us.

W. DAVID KELTON  
University of Cincinnati  
david.kelton@uc.edu

RANDALL P. SADOWSKI  
Systems Modeling Corporation  
rps@mail.sm.com

DEBORAH A. SADOWSKI  
Systems Modeling Corporation  
deb@mail.sm.com



**SYSTEMS MODELING**

The Park Building  
504 Beaver Street  
Sewickley, PA 15143 U.S.A.  
phone: 412-741-3727  
fax: 412-741-5635  
e-mail: smcorp@mail.sm.com  
internet: www.sm.com

Arena, SIMAN, and Cinema are registered trademarks of Systems Modeling Corporation. AutoCAD is a registered trademark of Autodesk. Microsoft, PowerPoint, Windows, Windows NT, and Visual Basic are registered trademarks and ActiveX, Notepad, and Outlook are trademarks of Microsoft Corporation. Visio is a registered trademark of Visio Corporation. All other trademarks and registered trademarks are acknowledged as being the property of their respective owners.

# Contents

## Chapter 1 What is Simulation?

1.1	Modeling .....	3
1.1.1	What's Being Modeled? .....	3
1.1.2	How About Just Playing with the System? .....	5
1.1.3	Sometimes You Can't (or Shouldn't) Play with the System .....	5
1.1.4	Physical Models .....	5
1.1.5	Logical (or Mathematical) Models .....	6
1.1.6	What Do You Do with a Logical Model? .....	6
1.2	Computer Simulation .....	7
1.2.1	Popularity and Advantages .....	7
1.2.2	The Bad News .....	8
1.2.3	Different Kinds of Simulations .....	9
1.3	How Simulations Get Done .....	9
1.3.1	By Hand .....	10
1.3.2	Programming in General-Purpose Languages .....	11
1.3.3	Simulation Languages .....	11
1.3.4	High-Level Simulators .....	11
1.3.5	Where Arena Fits In .....	12
1.4	When Simulations Are Used .....	13
1.4.1	The Early Years .....	13
1.4.2	The Formative Years .....	13
1.4.3	The Recent Past .....	14
1.4.4	The Present .....	14
1.4.5	The Future .....	15

## Chapter 2 Fundamental Simulation Concepts

2.1	An Example .....	19
2.1.1	The System .....	19
2.1.2	Goals of the Study .....	20
2.2	Analysis Options .....	22
2.2.1	Educated Guessing .....	22
2.2.2	Queueing Theory .....	22
2.2.3	Mechanistic Simulation .....	23
2.3	Pieces of a Simulation Model .....	24
2.3.1	Entities .....	24
2.3.2	Attributes .....	25
2.3.3	(Global) Variables .....	25
2.3.4	Resources .....	25
2.3.5	Queues .....	26

2.3.6	Statistical Accumulators .....	26
2.3.7	Events .....	26
2.3.8	Simulation Clock .....	27
2.3.9	Starting and Stopping .....	28
2.4	Event-Driven Hand Simulation .....	28
2.4.1	Outline of the Action .....	28
2.4.2	Keeping Track .....	29
2.4.3	Carrying It Out .....	31
2.4.4	Finishing Up .....	33
2.5	Event and Process-Oriented Simulation .....	33
2.6	Randomness in Simulation .....	35
2.6.1	Random Input, Random Output .....	35
2.6.2	Replicating the Example .....	35
2.6.3	Comparing Alternatives .....	37
2.7	Overview of a Simulation Study .....	38
2.8	Exercises .....	40

### **Chapter 3 A Quick Peek at Arena**

3.1	Starting Up .....	43
3.2	Browsing an Existing Model .....	44
3.2.1	Viewing the Model Window .....	45
3.2.2	The Arrive Module .....	46
3.2.3	The Server Module .....	47
3.2.4	The Depart Module .....	49
3.2.5	The Simulate Module .....	49
3.2.6	Module Connections .....	50
3.2.7	Dynamic Plots .....	51
3.2.8	Dressing Things Up .....	52
3.2.9	Running It .....	53
3.3	Understanding What Just Happened .....	54
3.3.1	Arena's Modeling Orientation .....	55
3.3.2	Launching Entities Into the Model—The Arrive Module Revisited ....	55
3.3.3	Processing the Entity—The Server Module Revisited .....	57
3.3.4	Leaving the Modeled System—The Depart Module Revisited .....	58
3.3.5	Controlling the Run—The Simulate Module Revisited .....	59
3.4	Exercises .....	59

### **Chapter 4 Working with Arena**

4.1	Basic Interaction .....	63
4.2	Menus .....	65
4.3	Toolbars .....	68
4.4	Help .....	71
4.5	Model Windows .....	72
4.6	Drawing .....	72

4.7	Printing .....	74
4.8	Running .....	74
4.9	Building the Simple Processing Model .....	75

## **Chapter 5 Modeling Basic Operations and Inputs**

5.1	Model 5.1: An Electronic Assembly and Test System .....	85
5.1.1	Developing a Modeling Approach .....	86
5.1.2	Some New Arena Concepts: Stations, Transfers, and Pictures .....	87
5.1.3	Building the Model .....	89
5.1.4	Running the Model .....	98
5.1.5	Viewing the Results .....	99
5.2	Model 5.2: The Enhanced Electronic Assembly and Test System .....	100
5.2.1	Expanding Resource Representation: Schedules and States .....	102
5.2.2	Resource Schedules .....	103
5.2.3	Resource Failures .....	106
5.2.4	Saving Statistical Data .....	107
5.2.5	Results of Model 5.2 .....	111
5.2.6	The Output Analyzer .....	112
5.3	Enhancing the Animation .....	116
5.3.1	Changing Animation Queues .....	117
5.3.2	Changing Entity Pictures .....	119
5.3.3	Changing Resource Pictures .....	122
5.3.4	Adding Plots and Variables .....	124
5.4	Input Analysis: Specifying Model Parameters and Distributions .....	128
5.4.1	Deterministic vs. Random Inputs .....	129
5.4.2	Collecting Data .....	130
5.4.3	Using Data .....	131
5.4.4	Fitting Input Distributions via the Input Analyzer .....	132
5.4.5	No Data? .....	139
5.4.6	Nonstationary Arrival Processes .....	141
5.4.7	Multivariate and Correlated Input Data .....	142
5.5	Summary and Forecast .....	142
5.6	Exercises .....	142

## **Chapter 6 Intermediate Modeling and Terminating Statistical Analysis**

6.1	Model 6.1: A Small Manufacturing System .....	149
6.2	New Arena Concepts .....	150
6.2.1	Sequences .....	150
6.2.2	Variables and Expressions .....	152
6.2.3	Sets .....	153
6.3	The Modeling Approach .....	153
6.4	Building the Model .....	154
6.4.1	The Data Modules .....	154
6.4.2	The Logic Modules .....	159

6.4.3	Animation .....	170
6.4.4	Verification .....	173
6.5	Confidence Intervals for Terminating Simulations via the Output Analyzer .....	176
6.5.1	Time Frame of Simulations .....	176
6.5.2	Model 6.2: Modifying Model 6.1 for a Terminating Analysis .....	177
6.5.3	Strategy for Data Collection and Analysis .....	180
6.5.4	Confidence Intervals for Terminating Systems .....	182
6.5.5	Comparing Alternatives .....	188
6.6	Summary and Forecast .....	190
6.7	Exercises .....	190

## Chapter 7 Entity Transfer and Steady-State Statistical Analysis

7.1	Types of Entity Transfers .....	197
7.2	Resource-Constrained Transfers .....	199
7.3	Model 7.1: The Small Manufacturing System with Transporters .....	200
7.4	Conveyors .....	211
7.4.1	Model 7.2: The Small Manufacturing System with Nonaccumulating Conveyors .....	214
7.4.2	Model 7.3: The Small Manufacturing System with Accumulating Conveyors .....	218
7.5	Statistical Analysis of Steady-State Simulations .....	219
7.5.1	Warm Up and Run Length .....	219
7.5.2	Truncated Replications .....	223
7.5.3	Batching in a Single Run .....	224
7.5.4	Automatic Run-Time Confidence Intervals via Batch Means .....	232
7.5.5	What To Do? .....	234
7.5.6	Other Methods and Goals for Steady-State Statistical Analysis .....	234
7.6	Summary and Forecast .....	235
7.7	Exercises .....	235

## Chapter 8 Detailed Modeling

8.1	Model 8.1: A Generic Call Center System .....	242
8.2	New Modeling Issues .....	244
8.3	Terminating or Steady-State .....	247
8.4	Modeling Approach .....	247
8.5	Defining the Data .....	249
8.6	Determine Maximum Arrival Rate and Increment Time Period .....	251
8.7	Create Arrivals and Direct to Service .....	259
8.8	Technical Support Calls .....	265
8.9	Sales Calls .....	270
8.10	Order-Status Calls .....	273
8.11	Finding and Fixing Model Errors .....	274
8.12	Animating the Model .....	283
8.13	Summary and Forecast .....	291
8.14	Exercises .....	291

## Chapter 9 A Sampler of Further Modeling Issues and Techniques

9.1	Modeling Conveyors Using the Transfer Panel .....	299
9.1.1	Model 9.1: Finite Buffers at Stations .....	300
9.1.2	Model 9.2: Parts Stay on Conveyor During Processing .....	305
9.2	More on Transporters .....	306
9.3	Entity Reneging .....	308
9.3.1	Entity Balking and Reneging .....	308
9.3.2	Model 9.3: A Service Model with Balking and Reneging .....	309
9.4	Holding and Batching Entities .....	316
9.4.1	Modeling Options .....	316
9.4.2	Model 9.4: A Batching Process Example .....	317
9.5	Overlapping Resources .....	328
9.5.1	System Description .....	329
9.5.2	Model 9.5: A Tightly-Coupled Production System .....	330
9.6	A Few Miscellaneous Modeling Issues .....	350
9.6.1	Guided Transporters .....	350
9.6.2	Parallel Queues .....	350
9.6.3	Decision Logic .....	352
9.6.4	Continuous Modeling .....	352
9.7	Exercises .....	354

## Chapter 10 Arena Customization and Integration

10.1	Model 10.1: Generating Entity Arrivals from Historical Data .....	363
10.2	Model 10.2: Recording and Charting Model Results in Microsoft® Excel .....	367
10.2.1	An Overview of ActiveX™ Automation and VBA .....	367
10.2.2	VBA Events at the Beginning of a Simulation Run .....	368
10.2.3	Storing Individual Call Data Using the VBA Module .....	372
10.2.4	Charting the Results and Cleaning Up at the End of the Run .....	374
10.3	Model 10.3: Organizing and Creating Your Own Reports .....	375
10.4	Model 10.4: Linking To and Embedding Other Files .....	381
10.4.1	Placing the Word File in the Arena Model .....	381
10.4.2	Establishing a Link to the Microsoft® PowerPoint® Presentation .....	383
10.4.3	Adding the Sound File .....	384
10.4.4	Tagging the Arena Objects for Identification in VBA .....	385
10.4.5	The Welcome Form .....	386
10.5	Creating Modules Using the Arena Professional Edition: Template 10.1 .....	388
10.5.1	The Create from File Module .....	389
10.5.2	The Template Source File: Tpl_10_1.tpl .....	390
10.5.3	The Panel Icon and User View .....	390
10.5.4	The Module Logic and Operands .....	391
10.5.5	Uses of Templates .....	394
10.6	Summary .....	395
10.7	Exercises .....	395