Simulation Modeling and Arena

Manuel D. Rossetti, Ph.D., P.E.
Associate Professor of Industrial Engineering
University of Arkansas
Department of Industrial Engineering
4207 Bell Engineering Center
Fayetteville, AR 72701
Phone: (479) 575-6756
Fax: (479) 575-8431
email: rossetti@uark.edu
www: www.uark.edu/~rossetti
Simulation Modeling and Arena  
By Manuel D. Rossetti

Preface

Intended Audience

This is an introductory textbook for a first course in discrete-event simulation modeling and analysis for upper-level undergraduate students as well as entering graduate students. While the text is focused towards engineering students (primarily industrial engineering) it could also be utilized by advanced business majors, computer science majors, and other disciplines where simulation is practiced. Practitioners interested in learning simulation and Arena could also use this book independently of a course.

Discrete-event simulation is an important tool for the modeling of complex systems. It is used to represent manufacturing, transportation, and service systems in a computer program for the purpose of performing experiments. The representation of the system via a computer program enables the testing of engineering design changes without disruption to the system being modeled. Simulation modeling involves elements of system modeling, computer programming, probability and statistics, and engineering design. Because simulation modeling involves these individually challenging topics, the teaching and learning of simulation modeling can be difficult for both instructors and students. Instructors are faced with the task of presenting computer programming concepts, probability modeling, and statistical analysis all within the context of teaching how to model complex systems such as factories and supply chains. In addition, because of the complexity associated with simulation modeling, specialized computer languages are needed and thus must be taught to students for use during the model building process. This book is intended to help instructors with this daunting task.

Traditionally, there have been two primary types of simulation textbooks 1) those that emphasize the theoretical (and mostly statistical) aspects of simulation, and 2) those that emphasize the simulation language or package. The intention of this book is to blend these two aspects of simulation textbooks together while adding and emphasizing the art of model building. Thus the book contains chapters on modeling and chapters that emphasize the statistical aspects of simulation. However, the coverage of statistical analysis is integrated with the modeling in such a way to emphasize the importance of both topics.

This book utilizes the Arena Simulation Environment as the primary modeling tool for teaching simulation. Arena is one of the leading simulation modeling packages in the world and has a strong and active user base. While the book uses Arena as the primary modeling tool, the book is not intended to be a “user’s guide to Arena”. Instead, Arena is used as the vehicle for explaining important simulation concepts.

I feel strongly that simulation is best learned by doing. The book is structured to enable and encourage students to get engaged in the material. The overall approach to presenting the material is based on a hands-on concept for student learning. The style of writing is informal, tutorial, and centered around examples that students can implement while reading the chapters. The book assumes a basic knowledge of probability and statistics, and an introductory knowledge of computer programming. Even though these
topics are assumed, the book provides integrated material that should refresh students on the basics of these topics. Thus, instructors who use this book should not have to formally cover this material, and can be assured that students who read the book will be aware of these concepts within the context of simulation.

**Organization of the Book**

Chapter 1 is an introduction to the field of simulation modeling and an introduction to the Arena modeling environment. After Chapter 1 the student should know what simulation is and be able to put the different types of simulation into context. Chapter 1 also introduces the important concept of how a discrete-event clock “ticks” and sets the stage for process modeling using activity diagramming. Finally, a simple (but comprehensive) example of Arena is presented so that students will feel comfortable with the tool.

Chapter 2 dives deeper into process-oriented modeling. The statistical aspects of simulation are downplayed within the chapter. The Basic Process template within Arena is thoroughly covered. Important concepts within process-oriented modeling (e.g. entities, attributes, activities, state variables, etc.) are discussed within the context of a number of examples. In addition, a deeper understanding of Arena is developed including flow of control, input/output, variables, arrays, and debugging. After finishing Chapter 2, student should be able to model interesting systems from a process viewpoint using Arena.

Chapter 3 emphasizes the role of randomness in simulation. Specifically, the chapter presents input modeling, random number generation, and random variate generation techniques. After Chapter 3, the student should be able to model the input distributions required for simulation using such tools as Excel, Minitab, and Arena’s input analyzer. In addition, the student will know why random number generators and their control are essential for simulation modeling. Finally, the primary techniques for generating random variates from probability distributions are covered (e.g. inversion, acceptance/rejection, convolution, and composition). An appendix is available for Chapter 3 that demonstrates how to perform Monte Carlo simulation within Excel.

Building on the use of stochastic elements in simulation, Chapter 4 discusses the major methods by which simulation output analysis must account for randomness. The different types of statistical quantities (observation based versus time-persistent) are defined and then statistical methods are introduced for their analysis. Specifically, the chapter covers the method of replication for finite horizon simulations, the analysis of the initialization transient period, the method of replication deletion, and the method of batch means. In addition, the use of simulation to make decisions between competing alternatives is presented.

Chapter 5 returns to model building by presenting models for important classic modeling situations in queuing and inventory theory. Both analytical and simulation approaches to modeling these systems are covered. For those instructors who work in a curriculum that has a separate course on these topics, this chapter presents an opportunity to concentrate on simulating these systems. The analytical material could easily be skipped without loss of continuity; however, often students learn the most about these systems through simulation. For those instructors where this material is not covered separately, background is presented on these topics to ensure that students can apply the
basics of queuing theory and are aware of basic inventory models. Then, the basic
models are extended so that students understand how simulation quickly becomes
necessary when modeling more realistic situations.

Chapter 6 presents a thorough treatment of the entity transfer and material
handling constructs within Arena. Students learn the fundamentals of resource-
constrained transfers, free path transporters, conveyors, and fixed path transporters. The
animation of models containing these elements is also emphasized.

Chapter 7 pulls together a number of miscellaneous topics that round out the use
of Arena. In particular, the chapter covers Arena’s activity based costing model and
presents advanced aspects of modeling with resources (e.g. schedules and failure
modeling). Chapter 7 also presents a few useful modules that were not previously
covered (e.g. picking stations, generic stations, picking up and dropping off entities, etc.).
An introduction to using Visual Basic and Arena is also presented.

Finally, Chapter 8 presents a detailed case study using Arena. An IIE/Rockwell
Software Arena Contest problem is solved in its entirety. This chapter ensures that
students will be ready to solve such a problem if assigned as a project for the course. The
chapter wraps up with some practical advice for performing simulation projects.

Special Features

- Each chapter begins with specific learning objectives
- Integrating the statistical aspects of simulation (e.g. output analysis) with the tool
  (e.g. Arena). More detailed discussions of the statistical aspects of simulation are
  presented than is found in many other simulation language oriented textbooks.
- Studies have shown that activity based learning is critical to student retention of
  material. The text is organized around the building of models with the intention that
  students should be following along at the computer while working through the
  chapters. Instructors can perform the activities or organize computer laboratory
  exercises around the development of the models in the text.
- Special emphasis on the computer programming aspects of simulation: Students who
  take a course based on this text will be expected to have had a least one entry level
  computer programming course; however, even with this background most students
  are woefully ill-prepared to use computers to solve problems. The theory-based
  textbooks do not cover this material and the simulation package textbooks attempt to
downplay the programming aspects of their environment so that the modeling
environment appears attractive to non-computer oriented users. This book is intended
to enable students to understand the inner workings of the simulation environment
and thus demystify the “black-box”. The language elements of the simulation
environment are compared to standard computer language elements so that students
can make the appropriate analogies to already studied material.
- While Arena is the modeling tool, the conceptual modeling process presented in the
  text is based on language independent methods including but not limited to rich
  picturing, elementary flow-charting, activity diagramming, and pseudo-code
development. The emphasis is placed on developing a specification for a model that
could be implemented in any simulation language environment.
• Coverage of classic stochastic models from operations research: One chapter is dedicated to queuing and inventory models. In many curriculums, if the analytical models are presented, they will be taught in a different course. In my opinion, the simulation of classic models along with their analytical treatment can provide for deeper student learning on these topics. In addition, the presentation of these classic models both analytically and through simulation provides simple systems on which to build the teaching of complex more practical extensions.

• Comprehensive examples, exercises, questions, and problem sets developed from the authors’ teaching, research, and industrial experiences.

• The CD that accompanies the text contains the student version of Arena. In addition, the chapter illustrations and files (e.g. Arena, Excel, etc) are contained on the disk. A comprehensive set of Powerpoint slides are also available for students and instructors to use within the classroom. Finally, solutions for many of the exercises are available to instructors.

Course Syllabus Suggestion

Early versions of the manuscript for this textbook were used for multiple semesters in my course at the University of Arkansas. The course that I teach is to junior/senior level undergraduate industrial engineering students. In addition, graduate students that have never had a course in simulation take the course. Graduate students are given extra homework assignments and are tested over some of the more theoretical aspects presented in the text (e.g. acceptance/rejection, etc.). I am able to cover Chapter 1-7 within a typical 16 week semester offering. A typical topic outline is as follows:

<table>
<thead>
<tr>
<th>#Lectures</th>
<th>Topic</th>
<th>Readings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
<td>Chapter 1</td>
</tr>
<tr>
<td>4</td>
<td>Basic Process Modeling</td>
<td>Chapter 2</td>
</tr>
<tr>
<td>2</td>
<td>Input modeling</td>
<td>Chapter 3</td>
</tr>
<tr>
<td>2</td>
<td>Random number generation</td>
<td>Chapter 3</td>
</tr>
<tr>
<td>2</td>
<td>Random variate generation</td>
<td>Chapter 3</td>
</tr>
<tr>
<td>2</td>
<td>Finite horizon simulation</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>3</td>
<td>Infinite horizon simulation</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>2</td>
<td>Comparing alternatives</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>4</td>
<td>Queuing and Inventory models</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>5</td>
<td>Entity transfer and material handling constructs</td>
<td>Chapter 6</td>
</tr>
<tr>
<td>3</td>
<td>Miscellaneous Topics in Arena Modeling</td>
<td>Chapter 7</td>
</tr>
</tbody>
</table>

I use 2 exams and a project within the course. Exam 1 covers Chapters 1-3 and finite horizon simulation from Chapter 4. Exam 2 covers the remaining portion of Chapter 4 plus Chapters 5-6. I do not formally test the students on the material in Chapter 7 since they will be using all previously learned material and components of Chapter 7 when performing their final project. Students are assigned homework throughout the semester (about 8 assignments). In addition, to formal lectures my course has a computer based laboratory component that meets 1 day each week. During this time, the students are
required to work on computer-based assignments that are based on the examples in the textbook.

Author Background

Manuel D. Rossetti, PhD., P.E., is an Associate Professor in the Industrial Engineering Department at the University of Arkansas. He received his Ph.D. in Industrial and Systems Engineering from The Ohio State University. He has published over forty journal and conference articles in the areas of transportation, manufacturing, health care and simulation and he has obtained over $3.1 million dollars in extra-mural research funding. His research interests include the design, analysis, and optimization of manufacturing, health care, and transportation systems using stochastic modeling, computer simulation, and artificial intelligence techniques. He teaches courses in the area of simulation, transportation and logistics, database systems, and inventory management. He was selected as a Lilly Teaching Fellow in 1997/98 and has been nominated three times for outstanding teaching awards. He is currently serving as Departmental ABET Coordinator. He serves as an Associate Editor for the International Journal of Modeling and Simulation and is active in IIE, INFORMS, and ASEE. He served as co-editor for the 2004 Winter Simulation Conference and will be co-editor for the 2009 Winter Simulation Conference.
7.2 Tabulating Frequencies using the STATISTIC Module.............................. 7-561
7.3 Entity and Resource Costing...................................................................... 7-563
7.4 Miscellaneous Modeling Concepts.......................................................... 7-573
  7.4.1 Picking between Stations..................................................................... 7-573
  7.4.2 Generic Station Modeling................................................................... 7-577
  7.4.3 Picking up and Dropping Off Entities............................................... 7-582
7.5 Programming Concepts within Arena..................................................... 7-591
  7.5.1 Working with Files, Excel, and Access............................................. 7-592
    7.5.1.1 Example: Reading from a Text File.......................................... 7-592
    7.5.1.2 Example: Reading a Two Dimensional Array............................ 7-596
    7.5.1.3 Example: Reading from an Excel Named Range......................... 7-597
    7.5.1.4 Example: Reading Model Variables from Microsoft Access.......... 7-600
  7.5.2 Using Visual Basic for Applications............................................... 7-605
    7.5.2.1 Example: Using VBA................................................................. 7-606
    7.5.2.2 Example: The VBA Module and User Defined Functions.............. 7-611
  7.5.3 Generating Correlated Random Variates.......................................... 7-621
7.6 Summary................................................................................................. 7-625
7.7 Exercises................................................................................................. 7-625
Chapter 8: Application of Simulation Modeling ......................................... 7-631
  8 Introduction............................................................................................. 8-632
  8.1 Problem Description.............................................................................. 8-633
    8.1.1 Rockwell Software/IIE 7th Annual Contest Problem: SM Testing..... 8-633
  8.2 Detailed Solution.................................................................................... 8-640
    8.2.1 Answering the Basic Modeling Questions..................................... 8-640
    8.2.2 Detailed Modeling.......................................................................... 8-646
      8.2.2.1 Conveyor and Station Modeling.............................................. 8-647
      8.2.2.2 Modeling Samples and the Test Cells..................................... 8-649
      8.2.2.3 Modeling Sample Holders and the Load/Unload Area............... 8-656
      8.2.2.4 Performance Measure Modeling............................................. 8-660
      8.2.2.5 Simulation Horizon and Run Parameters.................................. 8-662
    8.2.3 Preliminary Experimental Analysis............................................... 8-665
    8.2.4 Final Experimental Analysis and Results....................................... 8-666
      8.2.4.1 Using the Process Analyzer on the Problem............................ 8-667
      8.2.4.2 Using OptQuest on the Problem........................................... 8-672
      8.2.4.3 Investigating the New Logic Alternative................................ 8-674
  8.3 Sensitivity Analysis.............................................................................. 8-675
  8.4 Completing the Project......................................................................... 8-676
  8.5 Some Final Thoughts............................................................................ 8-679
  8.6 Exercises.............................................................................................. 8-681
Bibliography................................................................................................. 682