SIMULATION WITH ARENA

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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

This 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.

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