Table of Contents

Preface

Part I  Introduction and Methods

1. Beyond Lean: Process and Principles
   1.1 Introduction
   1.2 An Industrial Application of Simulation
   1.3 The Process of Validating a Future State with Models
   1.4 Principles for Simulation Modeling and Experimentation
   1.5 Approach
   1.6 Summary
   Questions for Discussion
   Active Learning Exercises

2. Simulation Modeling
   2.1 Introduction
   2.2 Elementary Modeling Constructs
   2.3 Models of System Components
      2.3.1 Arrivals
      2.3.2 Operations
      2.3.3 Routing Entities
      2.3.4 Batching
      2.3.5 Inventories
   2.4 Summary
   Problems

3. Modeling Random Quantities
   3.1 Introduction
   3.2 Determining a Distribution in the Absence of Data
      3.2.1 Distribution Functions Used in the Absence of Data
      3.2.2 Selecting Probability Distributions in the Absence of Data – An Illustration
   3.3 Fitting a Distribution Function to Data
      3.3.1 Some Common Data Problems
      3.3.2 Distribution Functions Most Often Used in a Simulation Model
      3.3.3 A Software Based Approach to Fitting a Data Set to a Distribution Function
   3.4 Summary
   Problems
   Active Learning Exercises
   Laboratories
   Bibliography
4. Conducting Simulation Experiments
   4.1 Introduction
   4.2 Verification and Validation
      4.2.1 Verification Procedures
      4.2.2 Validation Procedures
   4.3 The Problem of Correlated Observations
   4.4 Common Design Elements
      4.4.1 Model Parameters and Their Values
      4.4.2 Performance Measures
      4.4.3 Streams of Random Samples
   4.5 Design Elements Specific to Terminating Simulation Experiments
      4.5.1 Initial Conditions
      4.5.2 Replicates
      4.5.3 Ending the Simulation
      4.5.4 Design Summary
   4.6 Examining the Results for a Single Scenario
      4.6.1 Graphs, Histograms, and Summary Statistics
      4.6.2 Confidence Intervals
      4.6.3 Animating Model Dynamics
   4.7 Comparing Scenarios
      4.7.1 Comparison by Examination
      4.7.2 Comparison by Statistical Analysis
         4.7.2.1 A Word of Caution about Comparing Scenarios
   4.8 Summary
   Problems

5. The Simulation Engine
   5.1 Introduction
   5.2 Events and Event Graphs
   5.3 Time Advance and Event Lists
   5.4 Simulating the Two Workstation Model
   5.5 Organizing Entities Waiting for a Resource
   5.6 Random Sampling from Distribution Functions
   5.7 Pseudo-Random Number Generation
   5.8 Summary
Part II  Basic Organizations for Systems

6.  A Single Workstation
   6.1  Introduction
   6.2  Points Made in the Case Study
   6.3  The Case Study
       6.3.1  Define the Issues and Solution Objective
       6.3.2  Build Models
       6.3.3  Identify Root Causes and Assess Initial Alternatives
           6.3.3.1  Analytic Model of a Single Workstation
           6.3.3.2  Simulation Model of a Single Workstation
       6.3.4  Review and Extend Previous Work
           6.3.4.1  Detractors to Workstation Performance
   6.4  The Case Study for Detractors
       6.4.1  Define the Issues and Solution Objective
       6.4.2  Build Models
       6.4.3  Assessment of the Impact of the Detractors on Part Lead Time
   6.5  Summary
       Problems
       Application Problems

7.  Serial Systems
   7.1  Introduction
   7.2  Points Made in the Case Study
   7.3  The Case Study
       7.3.1  Define the Issues and Solution Objective
       7.3.2  Build Models
       7.3.3  Identify Root Causes and Assess Initial Alternatives
       7.3.4  Review and Extend Previous Work
           7.3.5  Implement the Selected Solution and Evaluate
   7.4  Summary
       Problems
       Application Problems

8.  Job Shops
   8.1  Introduction
   8.2  Points Made in the Case Study
   8.3  The Case Study
       8.3.1  Define the Issues and Solution Objective
       8.3.2  Build Models
       8.3.3  Identify Root Causes and Assess Initial Alternatives
       8.3.4  Review and Extend Previous Work
   8.4  The Case Study with Additional Machines
       8.4.1  Identify Root Causes and Assess Initial Alternatives
       8.4.2  Review and Extend Previous Work
       8.4.3  Implement the Selected Solution and Evaluate
   8.5  Summary
       Problems
       Application Problems
Part III Lean and Beyond Manufacturing

9. Inventory Organization and Control
   9.1 Introduction
   9.2 Traditional Inventory Models
      9.2.1 Trading off Number of Setups (Orders) for Inventory
      9.2.2 Trading off Customer Service Level for Inventory
   9.3 Inventory Models for Lean Manufacturing
      9.3.1 Random Demand – Normally Distributed
      9.3.2 Random Demand – Discrete Distributed
      9.3.3 Unreliable Production – Discrete Distributed
      9.3.4 Unreliable Production and Random Demand – Both Discrete Distributed
      9.3.5 Production Quantities
      9.3.6 Demand in a Discrete Time Period
      9.3.7 Simulation Model of an Inventory Situation
   9.4 Introduction to Pull Inventory Management
      9.4.1 Kanban Systems: One Implementation of the Pull Philosophy
      9.4.2 CONWIP Systems: A Second Implementation of the Pull Philosophy
      9.4.3 POLCA: An Extension to CONWIP

10. Inventory Control Using Kanbans
    10.1 Introduction
    10.2 Points Made in the Case Study
    10.3 The Case Study
       10.3.1 Define the Issues and Solution Objective
       10.3.2 Build Models
       10.3.3 Identify Root Causes and Assess Initial Alternatives
       10.3.4 Review and Extend Previous Work
       10.3.5 Implement the Selected Solution and Evaluate
    10.5 Summary
    Problems
    Application Problems

11. Cellular Manufacturing Operations
    11.1 Introduction
    11.2 Points Made in the Case Study
    11.3 The Case Study
       11.3.1 Define the Issues and Solution Objective
       11.3.2 Build Models
       11.3.3 Identify Root Causes and Assess Initial Alternatives
       11.3.4 Review and Extend Previous Work
       11.3.5 Implement the Selected Solution and Evaluate
    11.5 Summary
    Problems
    Application Problem
12. Flexible Manufacturing Systems
   12.1 Introduction
   12.2 Points Made in the Case Study
   12.3 The Case Study
      12.3.1 Define the Issues and Solution Objective
      12.3.2 Build Models
      12.3.3 Identify Root Causes and Assess Initial Alternatives
      12.3.4 Review and Extend Previous Work
      12.3.5 Implement the Selected Solution and Evaluate
   12.4 Summary
      Problems
      Application Problem

Part IV  Supply Chain Logistics

13. Automated Inventory Management
   13.1 Introduction
   13.2 Points Made in the Case Study
   13.3 The Case Study
      13.3.1 Define the Issues and Solution Objective
      13.3.2 Build Models
      13.3.3 Identify Root Causes and Assess Initial Alternatives
      13.3.4 Review and Extend Previous Work
      13.3.5 Implement the Selected Solution and Evaluate
   13.4 Summary
      Problems
      Application Problem

14. Transportation and Delivery
   14.1 Introduction
   14.2 Points Made in the Case Study
   14.3 The Case Study
      14.3.1 Define the Issues and Solution Objective
      14.3.2 Build Models
      14.3.3 Identify Root Causes and Assess Initial Alternatives
      14.3.4 Review and Extend Previous Work
      14.3.5 Implement the Selected Solution and Evaluate
   14.4 Summary
      Problems
      Application Problem

15. Integrated Supply Chains
   15.1 Introduction
   15.2 Points Made in the Case Study
   15.3 The Case Study
      15.3.1 Define the Issues and Solution Objective
      15.3.2 Build Models
      15.3.3 Identify Root Causes and Assess Initial Alternatives
      15.3.4 Review and Extend Previous Work
      15.3.5 Implement the Selected Solution and Evaluate
   15.4 Summary
      Problems
      Application Problem
Part V  Material Handling

16.  Distribution Centers and Conveyors
   16.1  Introduction
   16.2  Points Made in the Case Study
   16.3  The Case Study
       16.3.1 Define the Issues and Solution Objective
       16.3.2 Build Models
       16.3.3 Identify Root Causes and Assess Initial Alternatives
       16.3.4 Review and Extend Previous Work
   16.4  Alternative Worker Assignment
       16.4.1 Build Models
       16.4.2 Identify Root Causes and Assess Initial Alternatives
       16.4.3 Implement the Selected Solution and Evaluate
   16.5  Summary
       Problems
       Application Problem

17.  Automated Guided Vehicle Systems
   17.1  Introduction
   17.2  Points Made in the Case Study
   17.3  The Case Study
       17.3.1 Define the Issues and Solution Objective
       17.3.2 Build Models
       17.3.3 Identify Root Causes and Assess Initial Alternatives
       17.3.4 Review and Extend Previous Work
   17.4  Assessment of Alternative Pickup and Dropoff Points
       17.4.1 Identify Root Causes and Assess Initial Alternatives
       17.4.2 Review and Extend Previous Work
       17.4.3 Implement the Selected Solution and Evaluate
   17.5  Summary
       Problems
       Application Problem

18.  Automated Storage and Retrieval
   18.1  Introduction
   18.2  Points Made in the Case Study
   18.3  The Case Study
       18.3.1 Define the Issues and Solution Objective
       18.3.2 Build Models
       18.3.3 Identify Root Causes and Assess Initial Alternatives
       18.3.4 Review and Extend Previous Work
       18.3.5 Implement the Selected Solution and Evaluate
   18.4  Summary
       Problems
       Application Problem

Appendices

AutoMod Summary and Tutorial for the Chapter 6 Case Study

Distribution Function Fitting in JMP: Tutorial
Preface

Perspective

Lean thinking, as well as associated processes and tools, have evolved into a ubiquitous perspective for improving systems particularly in the manufacturing arena. With application experience has come an understanding of the boundaries of lean capabilities and the benefits of getting beyond these boundaries to further improve performance. Discrete event simulation is recognized as one beyond-the-boundaries of lean technique. Thus, the fundamental goal of this text is to show how discrete event simulation can be used in addition to lean thinking to achieve greater benefits in system improvement than with lean alone.

Realizing this goal requires learning the problems that simulation solves as well as the methods required to solve them. The problems that simulation solves are captured in a collection of case studies. These studies serve as metaphors for industrial problems that are commonly addressed using lean and simulation.

Learning simulation requires doing simulation. Thus, a case problem is associated with each case study. Each case problem is designed to be a challenging and less than straightforward extension of the case study. Thus, solving the case problem using simulation requires building on and extending the information and knowledge gleaned from the case study. In addition, questions are provided with each case problem so that it may be discussed in a way similar to the traditional discussion of case problems used in business schools, for example.

An understanding of simulation methods is prerequisite to the case studies. A simulation project process, basic simulation modeling methods, and basic simulation experimental methods are presented in the first part of the text. An overview of how a simulation model is executed on a computer is provided. A discussion of how to select a probability distribution function to model a random quantity is included. Exercises are included to provide practice in using the methods.

In addition to simulation methods, simple (algebra-level) analytic models are presented. These models are used in partnership with simulation models to better understand system behavior and help set the bounds on parameter values in simulation experiments.

The second part of the text presents application studies concerning prototypical systems: a single workstation, serial lines, and job shops. The goal of these studies is to illustrate and reinforce the use of the simulation project process as well as the basic modeling and experimental methods. The case problems in this part of the text are directly based on the case study and can be solved in a straightforward manner. This provides students the opportunity to practice the basic methods of simulation before attempting more challenging problems.

The remaining parts of the text present case studies in the areas of system organization for production, supply chain management, and material handling. Thus, students are exposed to typical simulation applications and are challenged to perform case problems on their own.

A typical simulation course will make use of one simulation environment and perhaps probability distribution function fitting software. Thus, software tutorials are provided to assist students in learning to use the AutoMod simulation environment and probability distribution function fitting in JMP.

The text attempts to make simulation accessible to as many students and other professionals as possible. Experience seems to indicate that students learn new methods best when they are presented in the context of realistic applications that motivate interest and retention. Only the most fundamental simulation statistical methods, as defined in Law (2007) are presented. For example, the t-confidence interval is the primary technique employed for the statistical analysis of
simulation results. References to more advanced simulation statistical analysis techniques are given as appropriate. Only the most basic simulation modeling methods are presented, plus extensions as needed for each particular application study.

The text is intended to help prepare those who read it to effectively perform simulation applications.

Using the Text

The text is designed to adapt to the needs of a wide range of introductory classes in simulation and production operations. Chapters 1 - 5 provide the foundation in simulation methods that every student needs and that is pre-requisite for studying the remaining chapters. Chapters 6, 7, and 8 cover basic ideas concerning how the simulation methods are used to analysis systems as well as how systems work. I would suggest that these 8 chapters be a part of every class.

A survey of simulation application areas can be accomplished by selecting chapters from parts III, IV, and V. A focus on manufacturing systems is achieved by covering chapters 9, 10, 11, and 12. A course on material handling and logistics could include chapters 13 through 18.

Compute-based activities that are a part of the problem sets can be used to help students better understand how systems operate and how simulation methods work. The case problems can be discussed in class only or a student can perform a complete analysis of the problem using simulation.

Acknowledgements

The greatest joy I have had in developing this text is to recall all of the colleagues and students with whom I have worked on simulation projects and other simulation related activities since A. Alan B. Pritsker introduced me to simulation in January 1975.

One genesis for this text came from Professor Ronald Askin. As we completed work on the text: Modeling and Analysis of Manufacturing Systems, we surmised that an entire text on the applications of simulation was needed to fully discuss the material that had been condensed into a single chapter.

Professor Jon Marvel provided invaluable advice and direction on the development of the chapter on cellular manufacturing systems.

Special thanks are due to Dr. David Heltne, retired from Shell Global Solutions. Our joint work on using simulation to address logistics and inventory management issues over much of two decades greatly influenced those areas of the text.

The masters work of several students in the School of Engineering at Grand Valley State University is reflected within the text. These include Mike Warber, Carrie Grimard, Sara Maas, and Eduardo Perez. Joel Oostdyk and Todd Frazee helped gather information that was used in this text.

The specific contribution of each individual has been noted at the appropriate place in the text as well.