Contents

Chapter 1. Computer Simulation Defined 1

Introduction 1

A Definition of Simulation 2

Why Simulate 6

Chapter 2. Computer Simulation Experiments with Models of Economic Systems 11

Methodology 11

Formulation of the Problem 11
Formulation of a Mathematical Model 12
Formulation of a Computer Program 15
Computer Program 15
Data Input and Starting Conditions 16
Data Generation 16
Validation 21
Experimental Design 22
The Problem of Stochastic Convergence 24
The Problem of Size 26
The Problem of Motive 27
The Multiple Response Problem 28
Data Analysis 29
F-Test 34
Multiple Comparisons 34
Multiple Rankings 34
Spectral Analysis 35
Sequential Sampling 35
Nonparametric Methods 36

Bibliography 36

Chapter 3. Management Science Models 40

Introduction 40

Properties of Computer Models 40

Markov Chain Models 42

Queueing Models 44

A Single-Channel, Single-Station Model 44
A Single-Channel, Multistation Model 48
A Multichannel, Multistation Model 48

Inventory Models 52

Production Models 57

Marketing Models 59

The Pillsbury Model 59
The Anheuser-Busch Model 59
The Corning Glass Model 61
Other Marketing Models. 61

Financial Models 61

The Clarkson Model 61
The Hertz Model 62
The Mattessich Model. 64
The Sun Oil Model 64
Other Financial Models 65

Corporate Models 68

The Anheuser-Busch Model 68
The IBM Model 70
The Pillsbury Model 70
The XEROX Model 72

Management Games 73

Bibliography 83

Chapter 4. Economic Models 89

Introduction 89

Models of the Firm 89

Cobweb Models 89
Cobweb Model 1 89

Cobweb Model 2 91
Cobweb Model 3 92
A Model of a Competitive Industry 93
A Duopoly Model 96
Behavioral Models 99
Duopoly Model 100
Oligopoly Model 101
Department Store Model 101
Monopoly Model 105
Bonini Model 105
Industrial Dynamic (DYNAMO) 107
Reflections on Computer Models of the Firm 111

Industry Models 113

A Model of the Textile Industry 113
Endogenous Variables 114
Exogenous Variables 114
Status Variables 115
Identities 115
Behavioral Equations 115
Apparel Demand 115
Apparent Output 115
Demand for Textile Mill Products 115
Output of Textile Mill Products 116
Employment of Production Workers 116
Earnings 116
Prices 116
Profit 116
Investment 117
A Model of the Shoe, Leather, Hide Industry 119
A Model of the Lumber Industry 124

Macroeconometric Models 126

Introduction 126
An Example Model 128
Problem Formulation 128
Model Formulation 128
Parameter Estimation 130
Computer Program Formulation 130
Experimental Design 133
Data Analysis 133

Solving Econometric Models 136
Linear Models 136
Nonlinear Models 139
PROGRAM SIMULATE 141
Large-Scale Econometric Models 142
Brookings Model 142
OBE Model 142
Wharton Model 142
Some Unresolved Problems 143
Simulation Versus Analytical Solutions 143
Perverse Simulation Results 143
Inadequate Estimation Techniques 146
Unstable Coefficients 147

Bibliography 147

Chapter 5. Validation
by Thomas H. Naylor and J. M. Finger 153

The Problem of Validation 153

Three Positions on Validation 154
Rationalism 154
Empiricism 155
Positive Economics 155

Multistage Validation 156

Goodness of Fit 159
Analysis of Variance 160
Chi-Square Test 160
Factor Analysis 160
Kolmogorov—Smirnov Test 160
Nonparametric Tests 160
Regression Analysis 160
Spectral Analysis 160
Theil's Inequality Coefficient 161

Summary 161

Bibliography 163

Chapter 6. The Design of Computer Simulation Experiments 165

Experimental Design 165

An Example Model 165

Data Analysis 167

Exploratory Experiments 167

Full Factorial Designs 167
Fractional Factorial Designs 168
Rotatable Designs 171
Response Surface Designs 172
Other Designs 175

Optimization Experiments 175

Some Pitfalls and Contingencies 180

The Problem of Sample Size 180
The Problem of Too Many Factors 180
The Multiple Response Problem 181
The Problem of Nonlinearity 181
The Problem of Convergence 181
Constrained Optimization 182

Summary 182

Bibliography 183

Chapter 7. Analysis of Variance 185

Introduction 185

A Model of the Firm 186

The Computer Program 190

Validation 195

The Experiment 196

Data Analysis 200

F-Test 201
Multiple Comparisons 203
Multiple Rankings 205

An Econometric Model 209
The Computer Program 211
Validation 212
The Experiment 212
Data Analysis 215
F-Test 215
Multiple Comparisons 216
Multiple Rankings 218
Summary 218
Bibliography 219

Chapter 8. Sequential Sampling
by W. Earl Sasser, Daniel A. Graham, Donald S. Burdick, and Thomas H. Naylor 223

Introduction 223
An Inventory Model 224
The Experiment 227
Sequential Analysis 230
Testing a Hypothesis Regarding the Mean 230
Comparing the Means of K Experimental Categories with a Control 231
A Multiple-Decision Procedure for Selecting the Best One of Several Populations [9] 232
A Heuristic Approach to the Bechhofer Procedure 233
Analysis of Simulation Results 234
Testing a Hypothesis Regarding the Mean 234
Comparing K Experimental Categories with a Control . . . 240
A Multiple-Decision Procedure for Selecting the Best One of Several Populations 242
A Heuristic Approach to Selecting the Best One of Several Populations 243
Conclusions 243
Bibliography 243

Chapter 9. Spectral Analysis
by Thomas H. Naylor, Kenneth Wertz, and Thomas H. Wonnacott 247

Introduction 247

An Example Model 248

Simulation Runs 250

Run 1 250
Run 2 251
Run 3 251

Theory of Spectral Analysis 251

Statistical Properties of Spectra 255

Spectral Analysis: A Larger Role? 265

Summary 266

Bibliography 266

Chapter 10. Variance Reduction
by William A. Moy 269

Introduction 269

Problem Formulation 270

Regression Sampling 271

Antithetic-Variate Sampling 274

Stratified Sampling 275

Importance Sampling 278

Experimental Results 282

Conclusions 287

Bibliography 287

Chapter 11. Stopping Rules 290

Introduction 290

Independent Observations 291

Fixed Sample Size Rules 291
Estimation of the Population Mean 291

Testing a Hypothesis about the Mean 292
F-Test 292
Multiple Ranking Procedures 292
Sequential Sampling Rules 293
Estimation of the Population Mean 293
Testing a Hypothesis about the Mean 294
Comparing the Means of K Experimental Categories . . 294
A Multiple Ranking Procedure 294

Autocorrelated Observations 295

Bibliography 296

Chapter 12. Simulation Versus Analytical Solutions by E. Philip Howrey and H. H. Kelejian 299

Introduction 299

Simulation of Linear Models 301
Nonstochastic Simulation 301
Stochastic Simulation 303

Simulation of Nonlinear Models 305
Reduced-Form Equations 306
Nonstochastic Simulation 308

Dynamic Properties of Stochastic Linear Systems 310
Final Form and Solution of a Linear Model 311
Spectral Representation of Solution 312
Application of Spectral Method 314
Spectral Representation in Validation 316

Conclusions 317

Bibliography 318

Chapter 13. A Computer Model of the Tobacco Industry by John M. Vernon, Norfleet W. Rives, and Thomas H. Naylor 320

Introduction 320

Description of the Industry 320

The Model 323

1. Leaf Production 326
2. Leaf Price 330
3. Cigarettes 332

Simulations 333

Bibliography 335

Chapter 14. Effects of Alternative Policies for Allocating Federal Aid for Education to the States by Marilyn Manser, Thomas H. Naylor and Kenneth Wertz 338

Introduction 338

The Model 338

The Policy Alternatives 343

Policy Simulations 345

Data Analysis 346
F-Test 346
Multiple Comparisons 348
Multiple Ranking 349

Bibliography 350

Chapter 15. A Model of the United States Monetary Sector by James M. Boughton and Thomas H. Naylor 353

Introduction 353

Variables 354

The Model 357

Analysis of the Model 361

Validation 363

Policy Simulations 366

Bibliography 379

Appendix A. Pseudorandom Number Generators 381

Introduction 381

Congruential Methods 382
The Multiplicative Method 383
Binary Computers 384
Decimal Computers 386
The Mixed Method 387
Binary Computers 388
Decimal Computers 388
The Combination Method 389
Autocorrelation 390
Statistical Tests 391
Bibliography 392

Appendix B. Random Variable Generators 396
Introduction 396
Continuous Probability Distributions 396
Uniform Distribution 397
Normal Distribution 397
Multivariate Normal Distribution 397
Exponential Distribution 399
Gamma Distribution 399
Other Distributions 400
Discrete Probability Distributions 400
Geometric Distribution 400
Pascal Distribution 401
Binomial Distribution 401
Hypergeometric Distribution 402
Poisson Distribution 402
Bibliography 403

Appendix C. Simulation Languages by Philip J. Kiviat 406
Introduction 406
Some Definitions 407
Principal Features of Simulation Languages 409
Reasons for Having SPL's 410
Reasons for Using Existing POL's 411

Simulation Programming Concepts 413
Describing a System: The Static Structure 413
Identification of Objects and Object Characteristics . . 414
Relationships between Objects 415
Generation of Objects 416
Describing a System: The Dynamic Structure 417
The Concept of Simulated Time 417
The Structure of Simulation Control Programs 417
Event Selections Procedures 420
The Activity Scanning Approach 420
The Event Scheduling Approach 421
The Process Iteration Approach 422

Simulation Programming Language Features 425
Specifying System Structure 425
Representating Statical Phenomena 425
Data Collection, Analysis, and Display 429
Data Collection Specification 429
Data Collection Facilities 430
Data Analysis 430
Display Media 431
Specification of Display Formats 432
Monitoring and Debugging 433
Initialization 434
Other Features 435

Some Examples of SPLS 436
SIMSCRIPT II 436
The Model 436
Initiating a Task 440
Review of Secretarial Task 443
Executive Available at the End of a Task 445
Secretary Available at the End of a Task 447
Description of the Program 447
SIMULA 456
The Model 456
The Program 458
Description of the Program 459
CSL: An Activity-Oriented Language 466
The Model 466
Description of the Program 466

GPSS/360: A Transaction-Flow Language 473
The Model 474
The Program 474
Description of the Program 475
Summary 478

Current SPL Research 478

Research on Simulation Concepts 479
Research on Operating Systems and Mechanisms 481
Interactive Languages 481
Time-Sharing 482
Graphics 482

The Future of SPLS 483

Bibliography 486

Index