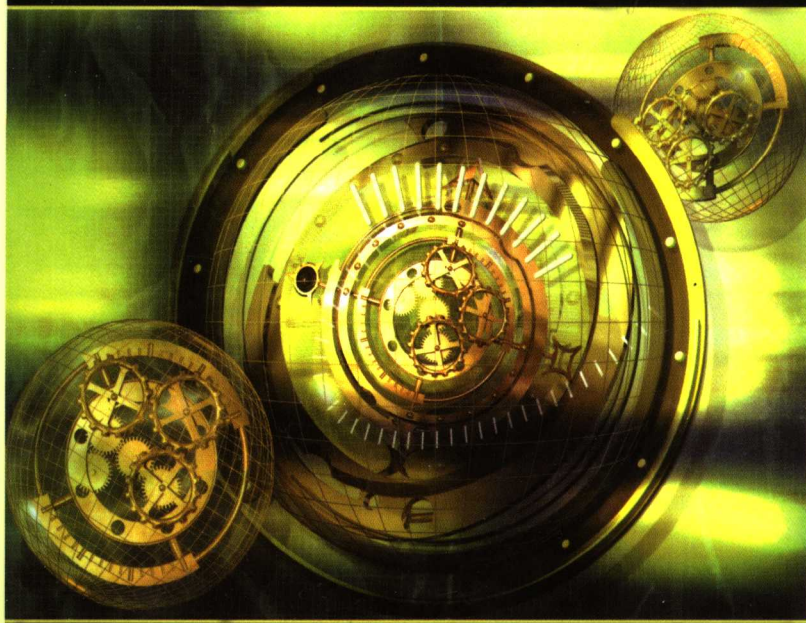


# 离散事件系统仿真

(英文版 · 第4版)

## DISCRETE-EVENT SYSTEM SIMULATION

FOURTH EDITION



JERRY BANKS · JOHN S.  
BARRY L. NELSON · DAVID M. NICOL

(美)

Jerry Banks  
John S. Carson II  
Barry L. Nelson  
David M. Nicol

著



机械工业出版社  
China Machine Press

经典原版书库

# 离散事件系统仿真

(英文版·第4版)

Discrete-Event System Simulation

(Fourth Edition)

江苏工业学院图书馆  
藏书章

(美) Jerry Banks  
John S. Carson II 著  
Barry L. Nelson  
David M. Nicol



机械工业出版社  
China Machine Press

English reprint edition copyright © 2005 by Pearson Education Asia Limited and China Machine Press.

Original English language title: *Discrete-Event System Simulation, Fourth Edition* (ISBN 0-13-144679-7) by Jerry Banks, John S. Carson II, Barry L. Nelson, and David M. Nicol, Copyright © 2005, 2001, 1999.

All rights reserved.

Published by arrangement with the original publisher, Pearson Education, Inc., publishing as Prentice Hall.

For sale and distribution in the People's Republic of China exclusively (except Taiwan, Hong Kong SAR and Macau SAR).

本书英文影印版由Pearson Education Asia Ltd.授权机械工业出版社独家出版。未经出版者书面许可,不得以任何方式复制或抄袭本书内容。

仅限于中华人民共和国境内(不包括中国香港、澳门特别行政区和中国台湾地区)销售发行。

本书封面贴有Pearson Education(培生教育出版集团)激光防伪标签,无标签者不得销售。

版权所有,侵权必究。

本书法律顾问 北京市展达律师事务所

本书版权登记号:图字:01-2005-3620

### 图书在版编目(CIP)数据

离散事件系统仿真(英文版·第4版)(美)班克斯(Banks, J.)等著.-北京:机械工业出版社,2005.9

(经典原版书库)

书名原文:Discrete-Event System Simulation, Fourth Edition

ISBN 7-111-17194-2

I. 离… II. 班… III. 离散系统(自动化)-系统仿真-英文 IV. TP271

中国版本图书馆CIP数据核字(2005)第093804号

机械工业出版社(北京市西城区百万庄大街22号 邮政编码 100037)

责任编辑:迟振春

北京京北制版厂印刷·新华书店北京发行所发行

2005年9月第1版第1次印刷

718mm×1020mm 1/16·39.25印张

印数:0 001-3 000册

定价:65.00元

凡购本书,如有倒页、脱页、缺页,由本社发行部调换

本社购书热线:(010) 68326294

# 出版者的话

文艺复兴以降，源远流长的科学精神和逐步形成的学术规范，使西方国家在自然科学的各个领域取得了垄断性的优势；也正是这样的传统，使美国在信息技术发展的六十多年间名家辈出、独领风骚。在商业化的进程中，美国的产业界与教育界越来越紧密地结合，计算机学科中的许多泰山北斗同时身处科研和教学的最前线，由此而产生的经典科学著作，不仅肇划了研究的范畴，还揭橥了学术的源变，既遵循学术规范，又自有学者个性，其价值并不会因年月的流逝而减退。

近年，在全球信息化大潮的推动下，我国的计算机产业发展迅猛，对专业人才的需求日益迫切。这对计算机教育界和出版界都既是机遇，也是挑战；而专业教材的建设在教育战略上显得举足轻重。在我国信息技术发展时间较短、从业人员较少的现状下，美国等发达国家在其计算机科学发展的几十年间积淀的经典教材仍有许多值得借鉴之处。因此，引进一批国外优秀计算机教材将对我国计算机教育事业的发展起积极的推动作用，也是与世界接轨、建设真正的世界一流大学的必由之路。

机械工业出版社华章图文信息有限公司较早意识到“出版要为教育服务”。自1998年开始，华章公司就将工作重点放在了遴选、移译国外优秀教材上。经过几年的不懈努力，我们与Prentice Hall, Addison-Wesley, McGraw-Hill, Morgan Kaufmann等世界著名出版公司建立了良好的合作关系，从它们现有的数百种教材中甄选出Tanenbaum, Stroustrup, Kernighan, Jim Gray等大师名家的一批经典作品，以“计算机科学丛书”为总称出版，供读者学习、研究及收藏。大理石纹理的封面，也正体现了这套丛书的品位和格调。

“计算机科学丛书”的出版工作得到了国内外学者的鼎力襄助，国内的专家不仅提供了中肯的选题指导，还不辞劳苦地担任了翻译和审校的工作；而原书的作者也相当关注其作品在中国的传播，有的还专程为其书的中译本作序。迄今，“计算机科学丛书”已经出版了近百个品种，这些书籍在读者中树立了良好的口碑，并被许多高校采用为正式教材和参考书籍，为进一步推广与发展打下了坚实的基础。

随着学科建设的初步完善和教材改革的逐渐深化，教育界对国外计算机教材的需求和应用都步入一个新的阶段。为此，华章公司将加大引进教材的力度，在“华章教育”的总体规划之下出版三个系列的计算机教材：除“计算机科学丛书”之外，对影印版的教材，则单独开辟出“经典原版书库”；同时，引进全美通行的教学辅导书“Schaum's Outlines”系列组成“全美经典学习指导系列”。为了保证这三套丛书的权威性，同时也为了更好地为学校和老师服务，华章公司聘请了中国科学院、北京大学、清华大学、国防科技大学、复旦大学、上海交通大学、南京大学、浙江大学、中国科技大学、哈尔滨工业大学、西安交通大学、中国人民大学、北京航空航天大学、北京邮电大学、中山大学、解放军理工大学、郑州大学、湖北工学院、中国国家信息安全测评认证中心等国内重点大学和科研机构在计

算机的各个领域的著名学者组成“专家指导委员会”，为我们提供选题意见和出版监督。

这三套丛书是响应教育部提出的使用外版教材的号召，为国内高校的计算机及相关专业的教学度身订造的。其中许多教材均已为M. I. T., Stanford, U.C. Berkeley, C. M. U.等世界名牌大学所采用。不仅涵盖了程序设计、数据结构、操作系统、计算机体系结构、数据库、编译原理、软件工程、图形学、通信与网络、离散数学等国内大学计算机专业普遍开设的核心课程，而且各具特色——有的出自语言设计者之手、有的历经三十年而不衰、有的已被全世界的几百所高校采用。在这些圆熟通博的名师大作的指引之下，读者必将在计算机科学的宫殿中由登堂而入室。

权威的作者、经典的教材、一流的译者、严格的审校、精细的编辑，这些因素使我们的图书有了质量的保证；但我们的目标是尽善尽美，而反馈的意见正是我们达到这一终极目标的重要帮助。教材的出版只是我们的后续服务的起点。华章公司欢迎老师和读者对我们的工作提出建议或给予指正，我们的联系方式如下：

电子邮件：hzjsj@hzbook.com

联系电话：(010) 68995264

联系地址：北京市西城区百万庄南街1号

邮政编码：100037

# 专家指导委员会

(按姓氏笔画顺序)

尤晋元  
石教英  
张立昂  
邵维忠  
周克定  
郑国梁  
高传善  
裘宗燕

王 珊  
吕 建  
李伟琴  
陆丽娜  
周傲英  
施伯乐  
梅 宏  
戴 葵

冯博琴  
孙玉芳  
李师贤  
陆鑫达  
孟小峰  
钟玉琢  
程 旭

史忠植  
吴世忠  
李建中  
陈向群  
岳丽华  
唐世渭  
程时端

史美林  
吴时霖  
杨冬青  
周伯生  
范 明  
袁崇义  
谢希仁

---

# Preface

---

---

---

The objective of the text is to provide a basic treatment of all of the important aspects of discrete-event simulation, with particular emphasis on applications in manufacturing, services, and computing. The fourth edition, like earlier editions, is meant for an upper-level-undergraduate or master's-level introduction to simulation or for a second course with applications. We have updated the material extensively, revised some chapters completely, and added a new chapter on the simulation of computer networks. The associated website [www.bcnnet.net](http://www.bcnnet.net) is now closely integrated with the text, and all students and instructors should visit the site.

Chapter 1, *Introduction to Simulation*, has been generally updated, and every example in Chapter 2, *Simulation Examples*, has an Excel spreadsheet solution on the website. Exercises have been prepared that require downloading these spreadsheet solutions and using them. To reflect the continuing evolution of simulation software, Chapter 3, *General Principles*, has been modernized to include properties and operations of current simulation languages; in Chapter 4, *Simulation Software*, simulation in Java replaces C++. We also have maintained an up-to-date discussion of the features of currently available simulation software. Simulation software changes so rapidly, however, that we point to the websites of all of the software vendors mentioned in the text.

Chapter 5, *Statistical Models in Simulation*, incorporates some additional models: the beta and negative binomial distributions and the nonstationary Poisson process. These are backed up by new material on simulating (Chapter 8, *Random-Variate Generation*) and fitting (Chapter 9, *Input Modeling*) the models. For clarity, Chapter 8 has been substantially reorganized. In Chapter 7, *Random-Number Generation*, we have deemphasized statistical testing of random-number generators since the period length of modern generators has become so long that sampling-based tests are no longer feasible.

Chapter 10, *Verification and Validation*, replaces hypothesis testing by a confidence-interval approach for input-output validation.

The core chapters on the analysis of simulation output are Chapter 11, *Output Analysis for a Single Model*, and Chapter 12, *Comparison and Evaluation of Alternative System Designs*. Chapter 11 has been significantly reorganized, and there is new material on prediction intervals and on estimating probabilities and quantiles from only summary statistics. Chapter 12 contains a new procedure for screening a large number of system designs to extract a smaller group of the best.

Chapter 13, *Simulation of Manufacturing and Material-Handling Systems*, adds an extended example and analysis of a small manufacturing system.

Chapter 14, *Simulation of Computer Systems*, replaces the discussion of C++ simulation tools for computer simulation with one focused on Java in general and on the SSFNet simulator in particular. Chapter 15, *Simulation of Computer Networks*, is new. The website has examples (in Java) of simulations discussed in this Chapter and provides extensive links to supporting material.

*Discrete-Event System Simulation* can serve as a textbook in the following types of courses:

1. An introductory simulation course in engineering, computer science, or management (Chapters 1–9 and selected parts of Chapters 10–12 when no companion language text is used; if a companion language text is used, skip Chapter 4, and use the application Chapters 13, 14, and 15, as appropriate);
2. A second course in simulation (all of Chapters 10–12, a companion language text, and an outside project; add Chapter 13, 14, or 15, as appropriate)

We gratefully acknowledge the cheerful aid of Gamze Tokol and Dave Goldsman in converting some of the chapters to L<sup>A</sup>T<sub>E</sub>X for those coauthors who do not speak the language, and the assistance of Feng Yang, who checked the references and exercises in many chapters.

JERRY BANKS  
JOHN S. CARSON II  
BARRY L. NELSON  
DAVID M. NICOL



---

# About the Authors

---

---

---

Jerry Banks retired in 1999 as a professor in the School of Industrial and Systems Engineering, Georgia Institute of Technology, after which he worked as senior simulation technology advisor for Brooks Automation; he is currently an independent consultant. He is the author, coauthor, editor, or coeditor of eleven books, one set of proceedings, several chapters in texts, and numerous technical papers. He is the editor of the *Handbook of Simulation*, published in 1998 by John Wiley, which won the award for Excellence in Engineering Handbooks from the Professional Scholarly Publishing Division of the Association of American Publishers, Inc. He is also author or coauthor of *Getting Started with AutoMod*, Second Edition, *Introduction to SIMAN V and CINEMA V*, *Getting Started with GPSS/H*, Second Edition, *Forecasting and Management of Technology* and *Principles of Quality Control*. He was a founding partner in the simulation-consulting firm Carson/Banks & Associates, Inc., which was purchased by AutoSimulations, Inc. (now part of Brooks Automation). He is a full member of many technical societies, among them the Institute of Industrial Engineers (IIE); he served eight years as that organization's representative to the Board of the Winter Simulation Conference, including two years as board chair. He is the recipient of the INFORMS College on Simulation Distinguished Service Award for 1999 and was named a fellow of IIE in 2002.

John S. Carson II is the consulting technical manager for the AutoMod Group at Brooks Automation. He has over 28 years experience in simulation in a wide range of application areas, including manufacturing, distribution, warehousing and material handling, transportation and rapid transit systems, port operations (container terminals and bulk handling), and health-care systems. Currently, he is involved in the design of next-generation simulation products and in the development of tools to speed up model development for semi-conductor manufacturing, distribution centers, container terminals and other areas of special interest. He co-founded and managed an

independent simulation services company for 8 years, has been an independent simulation consultant, and has taught at the Georgia Institute of Technology, the University of Florida, and the University of Wisconsin-Madison.

Barry L. Nelson is the James N. and Margie M. Krebs Professor in the Department of Industrial Engineering and Management Sciences at Northwestern University and is director of the Master of Engineering Management Program there. His research centers on the design and analysis of computer-simulation experiments on models of stochastic systems, concentrating on multivariate input modeling and output analysis and on optimization via simulation. He has published numerous papers and two books. He has served as the simulation area editor of *Operations Research* and as president of the INFORMS (then TIMS) College on Simulation, and he has held many positions for the annual Winter Simulation Conference, including program chair in 1997 and board member currently.

David M. Nicol is professor of electrical and computer engineering at the University of Illinois at Urbana-Champaign. He is a long-time contributor in the field of parallel and distributed discrete-event simulations, having written one of the early Ph.D. dissertations on the topic. He has also worked in parallel algorithms, algorithms for mapping workload in parallel architectures, performance analysis, and reliability modeling and analysis. His research contributions extend to 150 articles in leading computer-science journals and conferences. His research is driven largely by problems encountered in industry and government—he has worked closely with researchers at NASA, IBM, AT&T, Bellcore, Motorola, and the Los Alamos, Sandia, and Oak Ridge National Laboratories. His current interests lie in modeling and simulation of very large systems, particularly communications and other infrastructure, with applications in evaluating system security. From 1997 to 2003 he was the editor-in-chief of the *ACM Transactions on Modeling and Computer Simulation*. Professor Nicol is a Fellow of the IEEE.

---

# Contents

---

---

---

<b>Preface</b>	vii
<b>About the Authors</b>	ix
 <b>I Introduction to Discrete-Event System Simulation</b>	 <b>1</b>
<b>Chapter 1 Introduction to Simulation</b>	<b>3</b>
1.1 When Simulation Is the Appropriate Tool	4
1.2 When Simulation Is Not Appropriate	4
1.3 Advantages and Disadvantages of Simulation	5
1.4 Areas of Application	7
1.5 Systems and System Environment	9
1.6 Components of a System	9
1.7 Discrete and Continuous Systems	11
1.8 Model of a System	12
1.9 Types of Models	13
1.10 Discrete-Event System Simulation	13
1.11 Steps in a Simulation Study	14
References	18
Exercises	19
 <b>Chapter 2 Simulation Examples</b>	 <b>21</b>
2.1 Simulation of Queueing Systems	22
2.2 Simulation of Inventory Systems	39

---

2.3	Other Examples of Simulation	46
2.4	Summary	57
	References	57
	Exercises	57
<b>Chapter 3</b>	<b>General Principles</b>	<b>67</b>
3.1	Concepts in Discrete-Event Simulation	68
3.1.1	The Event Scheduling/Time Advance Algorithm	71
3.1.2	World Views	74
3.1.3	Manual Simulation Using Event Scheduling	77
3.2	List Processing	86
3.2.1	Lists: Basic Properties and Operations	87
3.2.2	Using Arrays for List Processing	88
3.2.3	Using Dynamic Allocation and Linked Lists	90
3.2.4	Advanced Techniques	92
3.3	Summary	92
	References	92
	Exercises	93
<b>Chapter 4</b>	<b>Simulation Software</b>	<b>95</b>
4.1	History of Simulation Software	96
4.1.1	The Period of Search (1955–60)	97
4.1.2	The Advent (1961–65)	97
4.1.3	The Formative Period (1966–70)	97
4.1.4	The Expansion Period (1971–78)	98
4.1.5	Consolidation and Regeneration (1979–86)	98
4.1.6	Integrated Environments (1987–Present)	99
4.2	Selection of Simulation Software	99
4.3	An Example Simulation	102
4.4	Simulation in Java	104
4.5	Simulation in GPSS	112
4.6	Simulation in SSF	117
4.7	Simulation Software	120
4.7.1	Arena	122
4.7.2	AutoMod	123
4.7.3	Extend	124
4.7.4	Flexsim	124
4.7.5	Micro Saint	125
4.7.6	ProModel	125
4.7.7	QUEST	126
4.7.8	SIMUL8	127
4.7.9	WITNESS	128

4.8	Experimentation and Statistical-Analysis Tools	128
4.8.1	Common Features	128
4.8.2	Products	129
	References	131
	Exercises	132

## **II Mathematical and Statistical Models** **147**

### **Chapter 5 Statistical Models in Simulation** **149**

5.1	Review of Terminology and Concepts	150
5.2	Useful Statistical Models	156
5.3	Discrete Distributions	160
5.4	Continuous Distributions	166
5.5	Poisson Process	186
5.5.1	Properties of a Poisson Process	188
5.5.2	Nonstationary Poisson Process	189
5.6	Empirical Distributions	190
5.7	Summary	193
	References	193
	Exercises	193

### **Chapter 6 Queueing Models** **201**

6.1	Characteristics of Queueing Systems	202
6.1.1	The Calling Population	202
6.1.2	System Capacity	204
6.1.3	The Arrival Process	204
6.1.4	Queue Behavior and Queue Discipline	205
6.1.5	Service Times and the Service Mechanism	206
6.2	Queueing Notation	208
6.3	Long-Run Measures of Performance of Queueing Systems	208
6.3.1	Time-Average Number in System $L$	209
6.3.2	Average Time Spent in System Per Customer $w$	211
6.3.3	The Conservation Equation: $L = \lambda w$	212
6.3.4	Server Utilization	213
6.3.5	Costs in Queueing Problems	218
6.4	Steady-State Behavior of Infinite-Population Markovian Models	220
6.4.1	Single-Server Queues with Poisson Arrivals and Unlimited Capacity: M/G/1	221
6.4.2	Multiserver Queue: M/M/c/∞/∞	227
6.4.3	Multiserver Queues with Poisson Arrivals and Limited Capacity: M/M/c/N/∞	233
6.5	Steady-State Behavior of Finite-Population Models (M/M/c/K/K)	235

6.6	Networks of Queues	239
6.7	Summary	241
	References	242
	Exercises	243
<b>III</b>	<b>Random Numbers</b>	<b>249</b>
<b>Chapter 7</b>	<b>Random-Number Generation</b>	<b>251</b>
7.1	Properties of Random Numbers	251
7.2	Generation of Pseudo-Random Numbers	252
7.3	Techniques for Generating Random Numbers	253
7.3.1	Linear Congruential Method	254
7.3.2	Combined Linear Congruential Generators	257
7.3.3	Random-Number Streams	259
7.4	Tests for Random Numbers	260
7.4.1	Frequency Tests	261
7.4.2	Tests for Autocorrelation	265
7.5	Summary	267
	References	268
	Exercises	269
<b>Chapter 8</b>	<b>Random-Variate Generation</b>	<b>272</b>
8.1	Inverse-Transform Technique	273
8.1.1	Exponential Distribution	273
8.1.2	Uniform Distribution	276
8.1.3	Weibull Distribution	277
8.1.4	Triangular Distribution	278
8.1.5	Empirical Continuous Distributions	279
8.1.6	Continuous Distributions without a Closed-Form Inverse	283
8.1.7	Discrete Distributions	284
8.2	Acceptance-Rejection Technique	289
8.2.1	Poisson Distribution	290
8.2.2	Nonstationary Poisson Process	293
8.2.3	Gamma Distribution	294
8.3	Special Properties	296
8.3.1	Direct Transformation for the Normal and Lognormal Distributions	296
8.3.2	Convolution Method	298
8.3.3	More Special Properties	299
8.4	Summary	299
	References	299
	Exercises	300

<b>IV Analysis of Simulation Data</b>	<b>305</b>
<b>Chapter 9 Input Modeling</b>	<b>307</b>
9.1 Data Collection	308
9.2 Identifying the Distribution with Data	310
9.2.1 Histograms	310
9.2.2 Selecting the Family of Distributions	313
9.2.3 Quantile–Quantile Plots	316
9.3 Parameter Estimation	319
9.3.1 Preliminary Statistics: Sample Mean and Sample Variance	319
9.3.2 Suggested Estimators	321
9.4 Goodness-of-Fit Tests	326
9.4.1 Chi-Square Test	327
9.4.2 Chi-Square Test with Equal Probabilities	329
9.4.3 Kolmogorov–Smirnov Goodness-of-Fit Test	331
9.4.4 $p$ -Values and “Best Fits”	333
9.5 Fitting a Nonstationary Poisson Process	334
9.6 Selecting Input Models without Data	335
9.7 Multivariate and Time-Series Input Models	337
9.7.1 Covariance and Correlation	337
9.7.2 Multivariate Input Models	338
9.7.3 Time-Series Input Models	340
9.7.4 The Normal-to-Anything Transformation	342
9.8 Summary	344
References	345
Exercises	346
<b>Chapter 10 Verification and Validation of Simulation Models</b>	<b>354</b>
10.1 Model-Building, Verification, and Validation	355
10.2 Verification of Simulation Models	356
10.3 Calibration and Validation of Models	361
10.3.1 Face Validity	362
10.3.2 Validation of Model Assumptions	362
10.3.3 Validating Input–Output Transformations	363
10.3.4 Input–Output Validation: Using Historical Input Data	374
10.3.5 Input–Output Validation: Using a Turing Test	378
10.4 Summary	379
References	379
Exercises	381
<b>Chapter 11 Output Analysis for a Single Model</b>	<b>383</b>
11.1 Types of Simulations with Respect to Output Analysis	384
11.2 Stochastic Nature of Output Data	387

11.3 Measures of Performance and Their Estimation	390
11.3.1 Point Estimation	390
11.3.2 Confidence-Interval Estimation	392
11.4 Output Analysis for Terminating Simulations	393
11.4.1 Statistical Background	394
11.4.2 Confidence Intervals with Specified Precision	397
11.4.3 Quantiles	399
11.4.4 Estimating Probabilities and Quantiles from Summary Data	400
11.5 Output Analysis for Steady-State Simulations	402
11.5.1 Initialization Bias in Steady-State Simulations	403
11.5.2 Error Estimation for Steady-State Simulation	409
11.5.3 Replication Method for Steady-State Simulations	413
11.5.4 Sample Size in Steady-State Simulations	417
11.5.5 Batch Means for Interval Estimation in Steady-State Simulations	418
11.5.6 Quantiles	422
11.6 Summary	423
References	423
Exercises	424
 <b>Chapter 12 Comparison and Evaluation of Alternative System Designs</b>	 <b>432</b>
12.1 Comparison of Two System Designs	433
12.1.1 Independent Sampling with Equal Variances	436
12.1.2 Independent Sampling with Unequal Variances	438
12.1.3 Common Random Numbers (CRN)	438
12.1.4 Confidence Intervals with Specified Precision	446
12.2 Comparison of Several System Designs	448
12.2.1 Bonferroni Approach to Multiple Comparisons	449
12.2.2 Bonferroni Approach to Selecting the Best	454
12.2.3 Bonferroni Approach to Screening	457
12.3 Metamodeling	458
12.3.1 Simple Linear Regression	459
12.3.2 Testing for Significance of Regression	463
12.3.3 Multiple Linear Regression	466
12.3.4 Random-Number Assignment for Regression	466
12.4 Optimization via Simulation	467
12.4.1 What Does 'Optimization via Simulation' Mean?	468
12.4.2 Why is Optimization via Simulation Difficult?	469
12.4.3 Using Robust Heuristics	470
12.4.4 An Illustration: Random Search	473



12.5 Summary	476
References	476
Exercises	477
<b>V Applications</b>	<b>483</b>
<b>Chapter 13 Simulation of Manufacturing and Material-Handling Systems</b>	<b>485</b>
13.1 Manufacturing and Material-Handling Simulations	486
13.1.1 Models of Manufacturing Systems	486
13.1.2 Models of Material-Handling	487
13.1.3 Some Common Material-Handling Equipment	488
13.2 Goals and Performance Measures	489
13.3 Issues in Manufacturing and Material-Handling Simulations	490
13.3.1 Modeling Downtimes and Failures	491
13.3.2 Trace-Driven Models	495
13.4 Case Studies of the Simulation of Manufacturing and Material-Handling Systems	496
13.5 Manufacturing Example: A Job-Shop Simulation	499
13.5.1 System Description and Model Assumptions	499
13.5.2 Presimulation Analysis	502
13.5.3 Simulation Model and Analysis of the Designed System	503
13.5.4 Analysis of Station Utilization	503
13.5.5 Analysis of Potential System Improvements	504
13.5.6 Concluding Words	506
13.6 Summary	506
References	506
Exercises	507
<b>Chapter 14 Simulation of Computer Systems</b>	<b>517</b>
14.1 Introduction	517
14.2 Simulation Tools	520
14.2.1 Process Orientation	522
14.2.2 Event Orientation	524
14.3 Model Input	525
14.3.1 Modulated Poisson Process	526
14.3.2 Virtual-Memory Referencing	528
14.4 High-Level Computer-System Simulation	534
14.5 CPU Simulation	538
14.6 Memory Simulation	543