

OPERATIONS
RESEARCH
AND
MANAGEMENT
SCIENCE
H A N D B O O K

EDITED BY
A. RAVI RAVINDRAN



CRC Press
Taylor & Francis Group

OPERATIONS RESEARCH AND MANAGEMENT SCIENCE HANDBOOK

Operations Research (OR) began as an interdisciplinary activity to solve complex military problems during World War II. Utilizing principles from mathematics, engineering, business, computer science, economics, and statistics, OR has developed into a full-fledged academic discipline with practical applications in business, industry, government, and the military. Currently regarded as a body of established mathematical models and methods essential to solving complicated management issues, OR provides quantitative analysis of problems from which managers can make objective decisions. Operations Research and Management Science (OR/MS) methodologies continue to flourish in numerous decision making fields.

Featuring a mix of international authors, *Operations Research and Management Science Handbook* combines OR/MS models, methods, and applications into one comprehensive, yet concise volume. The first resource to reach for when confronting OR/MS difficulties, this text —

- Provides a single source guide in OR/MS
- Bridges theory and practice
- Covers all topics relevant to OR/MS
- Offers a quick reference guide for students, researchers, and practitioners
- Contains unified and up-to-date coverage designed and edited with non-experts in mind
- Discusses software availability for all OR/MS techniques
- Includes contributions from a mix of domestic and international experts

The 26 chapters in the handbook are divided into two parts. Part I contains 14 chapters that cover the fundamental OR/MS models and methods. Each chapter gives an overview of a particular OR/MS model, its solution methods and illustrates successful applications. Part II of the handbook contains 11 chapters discussing the OR/MS applications in specific areas. They include airlines, e-commerce, energy systems, finance, military, production systems, project management, quality control, reliability, supply chain management, and water resources. Part II ends with a chapter on the future of OR/MS applications.



CRC Press

Taylor & Francis Group
an **informa** business

www.taylorandfrancisgroup.com

6000 Broken Sound Parkway, NW
Suite 300, Boca Raton, FL 33487
270 Madison Avenue
New York, NY 10016
2 Park Square, Milton Park
Abingdon, Oxon OX14 4RN, UK

9721

ISBN 0-8493-9721-9



9 780849 397219

www.crcpress.com

RAVINDRAN

OPERATIONS
RESEARCH
AND
MANAGEMENT
SCIENCE
HANDBOOK



OPERATIONS RESEARCH AND MANAGEMENT SCIENCE HANDBOOK

EDITED BY
A. RAVI RAVINDRAN



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **Informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2008 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works
Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number-13: 978-0-8493-9721-9 (Hardcover)

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC) 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Operations research and management science handbook / editor, A. Ravi Ravindran.
p. cm. -- (Operations research series)

Includes bibliographical references and index.

ISBN 978-0-8493-9721-9 (alk. paper)

I. Operations research--Handbooks, manuals, etc. I. Ravindran, Ravi. II. Title. III. Series.

T57.6.A32 1982

658.4'034--dc22

2007019976

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

OPERATIONS
RESEARCH

AND

MANAGEMENT
SCIENCE

H A N D B O O K

The Operations Research Series

Series Editor: A. Ravi Ravindran

*Dept. of Industrial & Manufacturing Engineering
The Pennsylvania State University, USA*

Integer Programming: Theory and Practice

John K. Karlof

Operations Research: A Practical Approach

Michael W. Carter and Camille C. Price

Operations Research and Management Science Handbook

A. Ravi Ravindran

Operations Research Calculations Handbook

Dennis Blumenfeld

Forthcoming Titles

Applied Nonlinear Optimization in Modeling Environments

Janos D. Pinter

Operations Research Calculations Handbook, Second Edition

Dennis Blumenfeld

Probability Models in Operations Research

Richard C. Cassady and Joel A. Nachlas

Dedication

This book is dedicated to the memory of Professor G. V. Loganathan,
author of Chapter 24, who was killed in the Virginia Tech
campus tragedy on April 16, 2007.

Preface

Operations Research (OR), which began as an interdisciplinary activity to solve complex problems in the military during World War II, has grown in the last 50 years to a full-fledged academic discipline. Now OR is viewed as a body of established mathematical models and methods to solve complex management problems. OR provides a quantitative analysis of the problem from which management can make an objective decision. OR has drawn upon skills from mathematics, engineering, business, computer science, economics, and statistics to contribute to a wide variety of applications in business, industry, government, and military. Operations Research and Management Science (OR/MS) methodologies and their applications continue to grow and flourish in a number of decision-making fields.

The objective of this handbook is to provide a comprehensive overview of OR/MS models, methods, and applications in a single volume. The handbook is not an OR textbook or a research monograph. The intent is that the handbook becomes the first resource a practitioner would reach for when faced with an OR/MS problem or question. The key features of the handbook are the following:

- Single source guide in OR/MS
- Comprehensive resource, but concise
- Covers all topics in OR/MS
- Quick reference guide to students, researchers, and practitioners
- Bridges theory and practice
- References to computer software availability
- Designed and edited with non-experts in mind
- Unified and up-to-date coverage ideal for ready reference

The handbook is divided into two parts. Part I contains 14 chapters that cover the fundamental OR/MS models and methods. Each chapter gives an overview of a particular OR/MS model and its solution methods, illustrates successful applications, and provides references to computer software availability. Each chapter in Part I is devoted to a topic listed below:

- Linear programming
- Nonlinear programming
- Integer programming
- Network optimization
- Multiple criteria decision making
- Decision analysis
- Dynamic programming
- Stochastic processes
- Queueing theory
- Inventory control
- Complexity and large-scale networks
- Simulation
- Metaheuristics
- Robust optimization

Part II of the handbook contains 11 chapters discussing the OR/MS applications in specific areas. They include:

- Airlines
- E-commerce
- Energy systems
- Finance
- Military
- Production systems
- Project management
- Quality control
- Reliability
- Supply chain management
- Water resources

Part II ends with a chapter on the future of OR/MS applications.

The handbook is an ideal reference book for OR/MS practitioners in business, industry, government, and academia. It can also serve as a supplemental text in undergraduate and graduate OR/MS courses at the university level.

A. Ravi Ravindran
University Park, Pennsylvania

Acknowledgments

First and foremost I would like to thank the authors, who have worked diligently in writing the various handbook chapters that are comprehensive, concise, and easy to read, bridging the gap between theory and practice. The development and evolution of this handbook have also benefited substantially from the advice and counsel of my colleagues and friends in academia and industry, who are too numerous to acknowledge individually. They helped me identify the key topics to be included in the handbook, suggested chapter authors, and served as reviewers of the manuscripts.

I express my sincere appreciation to Atul Rangarajan, an industrial engineering doctoral student at Penn State University, for serving as my editorial assistant and for his careful review of the page proofs returned by the authors. Several other graduate students also helped me with the handbook work, in particular, Ufuk Bilsel, Ajay Natarajan, Richard Titus, Vijay Wadhwa, and Tao Yang. Special thanks go to Professor Prabha Sharma at the Indian Institute of Technology, Kanpur, for her careful review of several chapter manuscripts. I also acknowledge the pleasant personality and excellent typing skills of Sharon Frazier during the entire book project.

I thank Cindy Carelli, Senior Acquisitions Editor, and Jessica Vakili, project coordinator at CRC Press, for their help from inception to publication of the handbook. Finally, I wish to thank my dear wife, Bhuvana, for her patience, understanding, and support when I was focused completely on the handbook work.

A. Ravi Ravindran

A. Ravi Ravindran, Ph.D., is a professor and the past department head of Industrial and Manufacturing Engineering at the Pennsylvania State University. Formerly, he was a faculty member at the School of Industrial Engineering at Purdue University for 13 years and at the University of Oklahoma for 15 years. At Oklahoma, he served as the director of the School of Industrial Engineering for 8 years and as the associate provost of the university for 7 years, with responsibility for budget, personnel, and space for the academic area. He holds a B.S. in electrical engineering with honors from the Birla Institute of Technology and Science, Pilani, India. His graduate degrees are from the University of California, Berkeley, where he received an M.S. and a Ph.D. in industrial engineering and operations research.

Dr. Ravindran's area of specialization is operations research with research interests in multiple criteria decision-making, financial engineering, health planning, and supply chain optimization. He has published two major textbooks (*Operations Research: Principles and Practice* and *Engineering Optimization: Methods and Applications*) and more than 100 journal articles on operations research. He is a fellow of the Institute of Industrial Engineers. In 2001, he was recognized by the Institute of Industrial Engineers with the Albert G. Holzman Distinguished Educator Award for significant contributions to the industrial engineering profession by an educator. He has won several Best Teacher awards from IE students. He has been a consultant to AT&T, General Motors, General Electric, IBM, Kimberly Clark, Cellular Telecommunication Industry Association, and the U.S. Air Force. He currently serves as the Operations Research Series editor for Taylor & Francis/CRC Press.

Contributors

Réka Albert

Pennsylvania State University
University Park, Pennsylvania

Farhad Azadivar

University of Massachusetts–Dartmouth
North Dartmouth, Massachusetts

Adedeji B. Badiru

Air Force Institute of Technology
Dayton, Ohio

P. Balasubramanian

Theme Work Analytics
Bangalore, India

Qianmei Feng

University of Houston
Houston, Texas

Bobbie L. Foote

U.S. Military Academy (Retd.)
West Point, New York

Natarajan Gautam

Texas A&M University
College Station, Texas

Robin C. Gilbert

University of Oklahoma
Norman, Oklahoma

H. J. Greenberg

University of Colorado at Denver
and
Health Sciences Center
Denver, Colorado

Catherine M. Harmonosky

Pennsylvania State University
University Park, Pennsylvania

Aliza R. Heching

IBM T. J. Watson Research Center
Yorktown Heights, New York

C. Randy Hudson

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Kailash C. Kapur

University of Washington
Seattle, Washington

Rex K. Kincaid

College of William and Mary
Williamsburg, Virginia

Alan J. King

IBM T. J. Watson Research Center
Yorktown Heights, New York

Cerry M. Klein

University of Missouri–Columbia
Columbia, Missouri

Soundar R. T. Kumara

Pennsylvania State University
University Park, Pennsylvania

Lawrence M. Leemis

College of William and Mary
Williamsburg, Virginia

G. V. Loganathan

Virginia Tech
Blacksburg, Virginia

Abu S. M. Masud

Wichita State University
Wichita, Kansas

Tod Morrison

University of Colorado at Denver
and
Health Sciences Center
Denver, Colorado

Katta G. Murty

University of Michigan
Ann Arbor, Michigan

Giuseppe Paleologo

IBM T. J. Watson Research Center
Yorktown Heights, New York

Atul Rangarajan

Pennsylvania State University
University Park, Pennsylvania

A. Ravi Ravindran

Pennsylvania State University
University Park, Pennsylvania

Sowmyanarayanan Sadagopan

Indian Institute of Information Technology
Bangalore, India

Jane L. Snowdon

IBM T. J. Watson Research Center
Yorktown Heights, New York

Hari P. Thadakamalla

Pennsylvania State University
University Park, Pennsylvania

Marlin U. Thomas

Air Force Institute of Technology
Wright-Patterson AFB, Ohio

Theodore B. Trafalis

University of Oklahoma
Norman, Oklahoma

José A. Ventura

Pennsylvania State University
University Park, Pennsylvania

Donald P. Warsing

North Carolina State University
Raleigh, North Carolina

Jeffery D. Weir

Air Force Institute of Technology
Wright-Patterson AFB, Ohio

Michael Weng

University of South Florida
Tampa, Florida

Susan H. Xu

Pennsylvania State University
University Park, Pennsylvania

Mehmet Bayram Yildirim

Wichita State University
Wichita, Kansas