GLOBAL EDITION

Quantitative Analysis for Management

THIRTEENTH EDITION

Barry Render • Ralph M. Stair, Jr. • Michael E. Hanna • Trevor S. Hale

Pearson

THIRTEENTH EDITION
GLOBAL EDITION

QUANTITATIVE ANALYSIS for MANAGEMENT

BARRY RENDER
Charles Harwood Professor Emeritus of Management Science
Crummer Graduate School of Business, Rollins College

RALPH M. STAIR, JR.
Professor Emeritus of Information and Management Sciences,
Florida State University

MICHAEL E. HANNA
Professor of Decision Sciences,
University of Houston–Clear Lake

TREVOR S. HALE
Associate Professor of Management Sciences,
University of Houston–Downtown

Pearson

Harlow, England • London • New York • Boston • San Francisco • Toronto • Sydney • Dubai • Singapore • Hong Kong
Tokyo • Seoul • Taipei • New Delhi • Cape Town • Sao Paulo • Mexico City • Madrid • Amsterdam • Munich • Paris • Milan

To my wife and sons—BR

To Lila and Leslie—RMS

To Zoe and Gigi—MEH

To Valerie and Lauren—TSH

Vice President, Business Publishing: Donna Battista
Director, Courseware Portfolio Management: Ashley Dodge
Director of Portfolio Management: Stephanie Wall
Senior Sponsoring Editor: Neeraj Bhalla
Managing Producer: Vamanan Namboodiri M.S.
Editorial Assistant: Linda Albelli
Vice President, Product Marketing: Roxanne McCarley
Director of Strategic Marketing: Brad Parkins
Strategic Marketing Manager: Deborah Strickland
Product Marketer: Becky Brown
Field Marketing Manager: Natalie Wagner
Field Marketing Assistant: Kristen Compton
Product Marketing Assistant: Jessica Quazza
Vice President, Production and Digital Studio, Arts and Business: Etain O'Dea
Director of Production, Business: Jeff Holcomb
Managing Producer, Business: Ashley Santora
Project Manager, Global Edition: Nitin Shankar
Associate Acquisitions Editor, Global Edition: Ananya Srivastava
Senior Project Editor, Global Edition: Daniel Luiz
Assistant Project Editor, Global Edition: Arka Basu
Manufacturing Controller, Production, Global Edition: Angela Hawksbee
Operations Specialist: Carol Melville
Creative Director: Blair Brown
Manager, Learning Tools: Brian Surette
Content Developer, Learning Tools: Lindsey Sloan
Managing Producer, Digital Studio, Arts and Business: Diane Lombardo
Digital Studio Producer: Regina DaSilva
Digital Studio Producer: Alana Coles
Full-Service Project Management and Composition: Thistle Hill Publishing Services / Cenveo® Publisher Services
Interior Design: Cenveo® Publisher Services
Cover Design: Lumina Datamatics, Inc.
Cover Art: Shutterstock
Printer/Binder: Vivar, Malaysia
Cover Printer: Vivar, Malaysia

Pearson Education Limited
Edinburgh Gate
Harlow
Essex CM20 2JE
England

and Associated Companies throughout the world

Visit us on the World Wide Web at:
www.pearsonglobaleditions.com

Authorized adaptation from the United States edition, entitled Quantitative Analysis for Management, 13th edition, ISBN 978-0-13-454316-1, by Barry Render, Ralph M. Stair, Jr., Michaele E. Hanna, and Trevor S. Hale, published by Pearson Education © 2018.

ISBN 10: 1-292-21765-0
ISBN 13: 978-1-292-21765-9

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

10 9 8 7 6 5 4 3 2 1
14 13 12 11 10

About the Authors

Barry Render is Professor Emeritus, the Charles Harwood Distinguished Professor of Operations Management, Crummer Graduate School of Business, Rollins College, Winter Park, Florida. He received his B.S. in Mathematics and Physics at Roosevelt University and his M.S. in Operations Research and his Ph.D. in Quantitative Analysis at the University of Cincinnati. He previously taught at George Washington University, the University of New Orleans, Boston University, and George Mason University, where he held the Mason Foundation Professorship in Decision Sciences and was Chair of the Decision Science Department. Dr. Render has also worked in the aerospace industry for General Electric, McDonnell Douglas, and NASA.

Dr. Render has coauthored 10 textbooks published by Pearson, including *Managerial Decision Modeling with Spreadsheets*, *Operations Management*, *Principles of Operations Management*, *Service Management*, *Introduction to Management Science*, and *Cases and Readings in Management Science*. More than 100 articles by Dr. Render on a variety of management topics have appeared in *Decision Sciences*, *Production and Operations Management*, *Interfaces*, *Information and Management*, *Journal of Management Information Systems*, *Socio-Economic Planning Sciences*, *IIE Solutions,* and *Operations Management Review*, among others.

Dr. Render has been honored as an AACSB Fellow and was named twice as a Senior Fulbright Scholar. He was Vice President of the Decision Science Institute Southeast Region and served as software review editor for *Decision Line* for six years and as Editor of the *New York Times* Operations Management special issues for five years. From 1984 to 1993, Dr. Render was President of Management Service Associates of Virginia, Inc., whose technology clients included the FBI, the U.S. Navy, Fairfax County, Virginia, and C&P Telephone. He is currently Consulting Editor to *Financial Times Press*.

Dr. Render has taught operations management courses at Rollins College for MBA and Executive MBA programs. He has received that school's Welsh Award as leading professor and was selected by Roosevelt University as the 1996 recipient of the St. Claire Drake Award for Outstanding Scholarship. In 2005, Dr. Render received the Rollins College MBA Student Award for Best Overall Course, and in 2009 was named Professor of the Year by full-time MBA students.

Ralph Stair is Professor Emeritus at Florida State University. He earned a B.S. in chemical engineering from Purdue University and an M.B.A. from Tulane University. Under the guidance of Ken Ramsing and Alan Eliason, he received a Ph.D. in operations management from the University of Oregon. He has taught at the University of Oregon, the University of Washington, the University of New Orleans, and Florida State University.

He has taught twice in Florida State University's Study Abroad Program in London. Over the years, his teaching has been concentrated in the areas of information systems, operations research, and operations management.

Dr. Stair is a member of several academic organizations, including the Decision Sciences Institute and INFORMS, and he regularly participates in national meetings. He has published numerous articles and books, including *Managerial Decision Modeling with Spreadsheets*, *Introduction to Management Science*, *Cases and Readings in Management Science*, *Production and Operations Management: A Self-Correction Approach*, *Fundamentals of Information Systems*, *Principles of Information Systems*, *Introduction to Information Systems*, *Computers in*

Today's World, *Principles of Data Processing*, *Learning to Live with Computers*, *Programming in BASIC*, *Essentials of BASIC Programming*, *Essentials of FORTRAN Programming*, and *Essentials of COBOL Programming*. Dr. Stair divides his time between Florida and Colorado. He enjoys skiing, biking, kayaking, and other outdoor activities.

Michael E. Hanna is Professor of Decision Sciences at the University of Houston–Clear Lake (UHCL). He holds a B.A. in Economics, an M.S. in Mathematics, and a Ph.D. in Operations Research from Texas Tech University. For more than 25 years, he has been teaching courses in statistics, management science, forecasting, and other quantitative methods. His dedication to teaching has been recognized with the Beta Alpha Psi teaching award in 1995 and the Outstanding Educator Award in 2006 from the Southwest Decision Sciences Institute (SWDSI).

Dr. Hanna has authored textbooks in management science and quantitative methods, has published numerous articles and professional papers, and has served on the Editorial Advisory Board of *Computers and Operations Research*. In 1996, the UHCL Chapter of Beta Gamma Sigma presented him with the Outstanding Scholar Award.

Dr. Hanna is very active in the Decision Sciences Institute (DSI), having served on the Innovative Education Committee, the Regional Advisory Committee, and the Nominating Committee. He has served on the board of directors of DSI for two terms and also as regionally elected vice president of DSI. For SWDSI, he has held several positions, including president, and he received the SWDSI Distinguished Service Award in 1997. For overall service to the profession and to the university, he received the UHCL President's Distinguished Service Award in 2001.

Trevor S. Hale is Associate Professor of Management Science at the University of Houston–Downtown (UHD). He received a B.S. in Industrial Engineering from Penn State University, an M.S. in Engineering Management from Northeastern University, and a Ph.D. in Operations Research from Texas A&M University. He was previously on the faculty of both Ohio University–Athens and Colorado State University–Pueblo.

Dr. Hale was honored three times as an Office of Naval Research Senior Faculty Fellow. He spent the summers of 2009, 2011, and 2013 performing energy security/cyber security research for the U.S. Navy at Naval Base Ventura County in Port Hueneme, California.

Dr. Hale has published dozens of articles in the areas of operations research and quantitative analysis in journals such as the *International Journal of Production Research*, the *European Journal of Operational Research*, *Annals of Operations Research*, the *Journal of the Operational Research Society*, and the *International Journal of Physical Distribution and Logistics Management*, among several others. He teaches quantitative analysis courses at the University of Houston–Downtown. He is a senior member of both the Decision Sciences Institute and INFORMS.

Brief Contents

Contents

Preface

Overview

Welcome to the thirteenth edition of *Quantitative Analysis for Management*. Our goal is to provide undergraduate and graduate students with a genuine foundation in business analytics, quantitative methods, and management science. In doing so, we owe thanks to the hundreds of users and scores of reviewers who have provided invaluable counsel and pedagogical insight for more than 30 years.

To help students connect how the techniques presented in this book apply in the real world, computer-based applications and examples are a major focus of this edition. Mathematical models, with all the necessary assumptions, are presented in a clear and "plain-English" manner. The ensuing solution procedures are then applied to example problems alongside step-by-step "how-to" instructions. We have found this method of presentation to be very effective, and students are very appreciative of this approach. In places where the mathematical computations are intricate, the details are presented in such a manner that the instructor can omit these sections without interrupting the flow of material. The use of computer software enables the instructor to focus on the managerial problem and spend less time on the details of the algorithms. Computer output is provided for many examples throughout the book.

The only mathematical prerequisite for this textbook is algebra. One chapter on probability and another on regression analysis provide introductory coverage on these topics. We employ standard notation, terminology, and equations throughout the book. Careful explanation is provided for the mathematical notation and equations that are used.

Special Features

Many features have been popular in previous editions of this textbook, and they have been updated and expanded in this edition. They include the following:

- *Modeling in the Real World* boxes demonstrate the application of the quantitative analysis approach to every technique discussed in the book. Three new ones have been added.
- *Procedure* boxes summarize the more complex quantitative techniques, presenting them as a series of easily understandable steps.
- *Margin notes* highlight the important topics in the text.
- *History* boxes provide interesting asides related to the development of techniques and the people who originated them.
- *QA in Action* boxes illustrate how real organizations have used quantitative analysis to solve problems. Several new *QA in Action* boxes have been added.
- *Solved Problems*, included at the end of each chapter, serve as models for students in solving their own homework problems.
- *Discussion Questions* are presented at the end of each chapter to test the student's understanding of the concepts covered and definitions provided in the chapter.

- *Problems* included in every chapter are applications-oriented and test the student's ability to solve exam-type problems. They are graded by level of difficulty: introductory (one bullet), moderate (two bullets), and challenging (three bullets). Twenty-six new problems have been added.
- *Internet Homework Problems* provide additional problems for students to work. They are available on the Companion Website.
- *Self-Tests* allow students to test their knowledge of important terms and concepts in preparation for quizzes and examinations.
- *Case Studies*, at the end of most chapters, provide additional challenging managerial applications.
- *Glossaries*, at the end of each chapter, define important terms.
- *Key Equations*, provided at the end of each chapter, list the equations presented in that chapter.
- *End-of-chapter bibliographies* provide a current selection of more advanced books and articles.
- *The software POM-QM for Windows* uses the full capabilities of Windows to solve quantitative analysis problems.
- *Excel QM* and *Excel 2016* are used to solve problems throughout the book.
- Data files with Excel spreadsheets and POM-QM for Windows files containing all the examples in the textbook are available for students to download from the Companion Website. Instructors can download these plus additional files containing computer solutions to the relevant end-of-chapter problems from the Instructor Resource Center Website.
- *Online modules* provide additional coverage of topics in quantitative analysis.
- The Companion Website, at www.pearsonglobaleditions.com/render, provides the online modules, additional problems, cases, and other material for every chapter.

Significant Changes to the Thirteenth Edition

In the thirteenth edition, we have introduced Excel 2016 in all of the chapters. Updated screenshots are integrated in the appropriate sections so that students can easily learn how to use Excel 2016 for the calculations. The Excel QM add-in is used with Excel 2016, allowing students with limited Excel experience to easily perform the necessary calculations. This also allows students to improve their Excel skills as they see the formulas automatically written in Excel QM.

From the Companion Website, students can access files for all of the examples used in the textbook in Excel 2016, QM for Windows, and Excel QM. Other files with all of the end-of-chapter problems involving these software tools are available to the instructors.

Business analytics, one of the hottest topics in the business world, makes extensive use of the models in this book. A discussion of the business analytics categories is provided, and the relevant management science techniques are placed into the appropriate category.

Examples and problems have been updated, and many new ones have been added. New screenshots are provided for almost all of the examples in the book. A brief summary of the changes in each chapter of the thirteenth edition is presented here.

Chapter 1 *Introduction to Quantitative Analysis*. The section on business analytics has been updated, and a new end-of-chapter problem has been added.

Chapter 2 *Probability Concepts and Applications.* The *Modeling in the Real World* box has been updated. New screenshots of Excel 2016 have been added throughout.

Chapter 3 *Decision Analysis.* A new *QA in Action* box has been added. New screenshots of Excel 2016 have been added throughout. A new case study has been added.

Chapter 4 *Regression Models.* New screenshots of Excel 2016 have been added throughout. A new end-of-chapter problem has been added.

Chapter 5 *Forecasting*. A new *QA in Action* box has been added. New screenshots of Excel 2016 have been added throughout. Two new end-of-chapter problems have been added.

Chapter 6 *Inventory Control Models*. A new *QA in Action* box has been added. New screenshots of Excel 2016 have been added throughout. Two new end-of-chapter problems have been added.

Chapter 7 *Linear Programming Models: Graphical and Computer Methods.* The Learning Objectives have been modified slightly. Screenshots have been updated to Excel 2016.

Chapter 8 *Linear Programming Applications.* Two new problems have been added to the Internet Homework Problems. Excel 2016 screenshots have been incorporated throughout.

Chapter 9 *Transportation, Assignment, and Network Models*. Two new problems have been added to the Internet Homework Problems. Excel 2016 screenshots have been incorporated throughout.

Chapter 10 *Integer Programming, Goal Programming, and Nonlinear Programming.* Two new problems have been added to the Internet Homework Problems. Excel 2016 screenshots have been incorporated throughout.

Chapter 11 *Project Management*. Four new end-of-chapter problems and a new *Modeling in the Real World* box have been added.

Chapter 12 *Waiting Lines and Queuing Theory Models*. Four new end-of-chapter problems have been added.

Chapter 13 *Simulation Modeling*. Two new end-of-chapter problems have been added.

Chapter 14 *Markov Analysis*. Two new end-of-chapter problems have been added.

Chapter 15 *Statistical Quality Control*. Two new end-of-chapter problems have been added. Excel 2016 screenshots have been updated throughout.

Modules 1–8 The only significant change to the modules is the update to Excel 2016 throughout.

Online Modules

To streamline the book, eight topics are contained in modules available on the Companion Website for the book.

1. Analytic Hierarchy Process
2. Dynamic Programming
3. Decision Theory and the Normal Distribution
4. Game Theory
5. Mathematical Tools: Determinants and Matrices
6. Calculus-Based Optimization
7. Linear Programming: The Simplex Method
8. Transportation, Assignment, and Network Algorithms

Software

Excel 2016 Excel 2016 instructions and screen captures are provided, throughout the book. Instructions for activating the Solver and Analysis ToolPak add-ins in Excel 2016 are provided in an appendix. The use of Excel is more prevalent in this edition of the book than in previous editions.

Excel QM Using the Excel QM add-in that is available on the Companion Website makes the use of Excel even easier. Students with limited Excel experience can use this and learn from the formulas that are automatically provided by Excel QM. This is used in many of the chapters.

POM-QM for Windows This software, developed by Professor Howard Weiss, is available to students at the Companion Website. This is very user-friendly and has proven to be a very popular software tool for users of this textbook. Modules are available for every major problem type presented in the textbook. At press time, only version 4.0 of POM-QM for Windows was available. Updates for version 5.0 will be released on the Companion Website as they become available.

Companion Website

The Companion Website, located at www.pearsonglobaleditions.com/render, contains a variety of materials to help students master the material in this course. These include the following:

Modules There are eight modules containing additional material that the instructor may choose to include in the course. Students can download these from the Companion Website.

Files for Examples in Excel, Excel QM, and POM-QM for Windows Students can download the files that were used for examples throughout the book. This helps them become familiar with the software, and it helps them understand the input and formulas necessary for working the examples.

Internet Homework Problems In addition to the end-of-chapter problems in the textbook, there are additional problems that instructors may assign. These are available for download at the Companion Website.

Internet Case Studies Additional case studies are available for most chapters.

POM-QM for Windows Developed by Howard Weiss, this very user-friendly software can be used to solve most of the homework problems in the text.

Excel QM This Excel add-in will automatically create worksheets for solving problems. This is very helpful for instructors who choose to use Excel in their classes but who may have students with limited Excel experience. Students can learn by examining the formulas that have been created and by seeing the inputs that are automatically generated for using the Solver add-in for linear programming.

Instructor Resources

- ***Instructor Resource Center:*** The Instructor Resource Center contains the electronic files for the test bank, PowerPoint slides, the Solutions Manual, and data files for both Excel and POM-QM for Windows for all relevant examples and end-of-chapter problems (www.pearsonglobaleditions.com/render).
- ***Register, Redeem, Login:*** The Instructor's Resource Center, accessible from www.pearsonglobaleditions.com/render, instructors can access a variety of print, media, and presentation resources that are available with this text in downloadable, digital format.
- ***Need help?*** Our dedicated technical support team is ready to assist instructors with questions about the media supplements that accompany this text. Visit support.pearson.com/getsupport for answers to frequently asked questions and toll-free user support phone numbers. The supplements are available to adopting instructors. Detailed descriptions are provided in the Instructor Resource Center.

Instructor's Solutions Manual The Instructor's Solutions Manual, updated by the authors, is available for download from the Instructor Resource Center. Solutions to all Internet Homework Problems and Internet Case Studies are also included in the manual.

PowerPoint Presentation An extensive set of PowerPoint slides is available for download from the Instructor Resource Center.

Test Bank The updated test bank is available for download from the Instructor Resource Center.

TestGen The computerized TestGen package allows instructors to customize, save, and generate classroom tests. The test program permits instructors to edit, add, or delete questions from the test bank; edit existing graphics and create new graphics; analyze test results; and organize a database of test and student results. This software allows instructors to benefit from the extensive flexibility and ease of use. It provides many options for organizing and displaying tests, along with search and sort features. The software and the test banks can be downloaded from the Instructor Resource Center.

Acknowledgments

We gratefully thank the users of previous editions and the reviewers who provided valuable suggestions and ideas for this edition. Your feedback is valuable in our efforts for continuous improvement. The continued success of *Quantitative Analysis for Management* is a direct result of instructor and student feedback, which is truly appreciated.

The authors are indebted to many people who have made important contributions to this project. Special thanks go to Professors Faizul Huq, F. Bruce Simmons III, Khala Chand Seal, Victor E. Sower, Michael Ballot, Curtis P. McLaughlin, and Zbigniew H. Przanyski for their contributions to the excellent cases included in this edition.

We thank Howard Weiss for providing Excel QM and POM-QM for Windows, two of the most outstanding packages in the field of quantitative methods. We would also like to thank the reviewers who have helped to make this textbook the most widely used one in the field of quantitative analysis:

Stephen Achtenhagen, *San Jose University*
M. Jill Austin, *Middle Tennessee State University*
Raju Balakrishnan, *University of Michigan–Dearborn*
Hooshang Beheshti, *Radford University*
Jason Bergner, *University of Nevada*
Bruce K. Blaylock, *Radford University*
Rodney L. Carlson, *Tennessee Technological University*
Edward Chu, *California State University, Dominguez Hills*
John Cozzolino, *Pace University–Pleasantville*
Ozgun C. Demirag, *Penn State–Erie*
Shad Dowlatshahi, *University of Missouri–Kansas City*
Ike Ehie, *Kansas State University*
Richard Ehrhardt, *University of North Carolina–Greensboro*
Sean Eom, *Southeast Missouri State University*
Ephrem Eyob, *Virginia State University*
Mira Ezvan, *Lindenwood University*
Wade Ferguson, *Western Kentucky University*
Robert Fiore, *Springfield College*
Frank G. Forst, *Loyola University of Chicago*
Stephen H. Goodman, *University of Central Florida*
Irwin Greenberg, *George Mason University*
Nicholas G. Hall, *Ohio State University*
Robert R. Hill, *University of Houston–Clear Lake*
Bharat Jain, *Towson University*
Vassilios Karavas, *Nomura International*
Arun Khanal, *Nobel College*
Kenneth D. Lawrence, *New Jersey Institute of Technology*
Jooh Lee, *Rowan College*
Richard D. Legault, *University of Massachusetts–Dartmouth*
Douglas Lonnstrom, *Siena College*
Daniel McNamara, *University of St. Thomas*
Peter Miller, *University of Windsor*
Ralph Miller, *California State Polytechnic University*
Shahriar Mostashari, *Campbell University*
David Murphy, *Boston College*
Robert C. Myers, *University of Louisville*
Barin Nag, *Towson State University*
Nizam S. Najd, *St. Gregory's University*
Harvey Nye, *Central State University*
Alan D. Olinsky, *Bryant College*
Savas Ozatalay, *Widener University*
Young Park, *California University of Pennsylvania*
Yusheng Peng, *Brooklyn College*
Dane K. Peterson, *Missouri State University*
Sanjeev Phukan, *Bemidji State University*
Ranga Ramasesh, *Texas Christian University*
Bonnie Robeson, *Johns Hopkins University*
Grover Rodich, *Portland State University*
Vijay Shah, *West Virginia University–Parkersburg*
L. Wayne Shell, *Nicholls State University*

Thomas Sloan, *University of Massachusetts–Lowell*
Richard Slovacek, *North Central College*
Alan D. Smith, *Robert Morris University*
John Swearingen, *Bryant College*
Jack Taylor, *Portland State University*
Andrew Tiger, *Union University*
Chris Vertullo, *Marist College*
James Vigen, *California State University, Bakersfield*
Larry Weinstein, *Wright State University*
Fred E. Williams, *University of Michigan–Flint*
Mela Wyeth, *Charleston Southern University*
Oliver Yu, *San Jose State University*

We are very grateful to all the people at Pearson who worked so hard to make this book a success. These include Donna Battista, Jeff Holcomb, Ashley Santora, Neeraj Bhalla, Vamanan Namboodiri, and Dan Tylman. We are also grateful to Angela Urquhart and Andrea Archer at Thistle Hill Publishing Services. Thank you all!

Barry Render
brender@rollins.edu

Ralph Stair

Michael Hanna
hanna@uhcl.edu

Trevor S. Hale
halet@uhd.edu

CHAPTER

1

Introduction to Quantitative Analysis

LEARNING OBJECTIVES

After completing this chapter, students will be able to:

1.1 Describe the quantitative analysis approach and understand how to apply it to a real situation.

1.2 Describe the three categories of business analytics.

1.3 Describe the use of modeling in quantitative analysis.

1.4 Prepare a quantitative analysis model.

1.5 Use computers and spreadsheet models to perform quantitative analysis.

1.6 Recognize possible problems in using quantitative analysis.

1.7 Recognize implementation concerns of quantitative analysis.

People have been using mathematical tools to help solve problems for thousands of years; however, the formal study and application of quantitative techniques to practical decision making is largely a product of the twentieth century. The techniques we study in this book have been applied successfully to an increasingly wide variety of complex problems in business, government, health care, education, and many other areas. Many such successful uses are discussed throughout this book.

It isn't enough, though, just to know the mathematics of how a particular quantitative technique works; you must also be familiar with the limitations, assumptions, and specific applicability of the technique. The successful use of quantitative techniques usually results in a solution that is timely, accurate, flexible, economical, reliable, and easy to understand and use.

In this and other chapters, there are *QA (Quantitative Analysis) in Action* boxes that provide success stories on the applications of management science. They show how organizations have used quantitative techniques to make better decisions, operate more efficiently, and generate more profits. For example, Taco Bell has reported saving over $150 million with better forecasting of demand and better scheduling of employees. NBC television increased advertising revenue by over $200 million by using a model to help develop sales plans for advertisers. Before it merged with United Airlines, Continental Airlines saved over $40 million a year by using mathematical models to quickly recover from disruptions caused by weather delays and other factors. These are but a few of the many companies discussed in *QA in Action* boxes throughout this book.

To see other examples of how companies use quantitative analysis or operations research methods to operate better and more efficiently, go to the website www.scienceofbetter.org. The success stories presented there are categorized by industry, functional area, and benefit. These success stories illustrate how operations research is truly the "science of better."

1.1 What Is Quantitative Analysis?

Quantitative analysis uses a scientific approach to decision making.

Quantitative analysis is the scientific approach to managerial decision making. This field of study has several different names, including quantitative analysis, **management science**, and operations research. These terms are used interchangeably in this book. Also, many of the quantitative analysis methods presented in this book are used extensively in business analytics.

Whim, emotions, and guesswork are not part of the quantitative analysis approach. The approach starts with data. Like raw material for a factory, these data are manipulated or processed into information that is valuable to people making decisions. This processing and manipulating of raw data into meaningful information is the heart of quantitative analysis. Computers have been instrumental in the increasing use of quantitative analysis.

In solving a problem, managers must consider both qualitative and quantitative factors. For example, we might consider several different investment alternatives, including certificates of deposit at a bank, investments in the stock market, and an investment in real estate. We can use quantitative analysis to determine how much our investment will be worth in the future when deposited at a bank at a given interest rate for a certain number of years. Quantitative analysis can also be used in computing financial ratios from the balance sheets for several companies whose stock we are considering. Some real estate companies have developed computer programs that use quantitative analysis to analyze cash flows and rates of return for investment property.

Both qualitative and quantitative factors must be considered.

In addition to quantitative analysis, *qualitative* factors should be considered. The weather, state and federal legislation, new technological breakthroughs, the outcome of an election, and so on may all be factors that are difficult to quantify.

Because of the importance of qualitative factors, the role of quantitative analysis in the decision-making process can vary. When there is a lack of qualitative factors and when the problem, model, and input data remain the same, the results of quantitative analysis can *automate* the decision-making process. For example, some companies use quantitative inventory models to determine automatically *when* to order additional new materials. In most cases, however, quantitative analysis will be an *aid* to the decision-making process. The results of quantitative analysis will be combined with other (qualitative) information in making decisions.

Quantitative analysis has been particularly important in many areas of management. The field of production management, which evolved into production/operations management (POM) as society became more service oriented, uses quantitative analysis extensively. While POM focuses on the internal operations of a company, the field of supply chain management takes a more complete view of the business and considers the entire process of obtaining materials from suppliers, using the materials to develop products, and distributing these products to the final consumers. Supply chain management makes extensive use of many management science models. Another area of management that could not exist without the quantitative analysis methods presented in this book, and perhaps the hottest discipline in business today, is business analytics.

1.2 Business Analytics

Business analytics is a data-driven approach to decision making that allows companies to make better decisions. The study of business analytics involves the use of large amounts of data, which means that information technology related to the management of the data is very important. Statistical and quantitative methods are used to analyze the data and provide useful information to the decision maker.

Business analytics is often broken into three categories: descriptive, predictive, and prescriptive. **Descriptive analytics** involves the study and consolidation of historical data for a business and an industry. It helps a company measure how it has performed in the past and how it is performing now. **Predictive analytics** is aimed at forecasting future outcomes based on patterns in the past data. Statistical and mathematical models are used extensively for this purpose. **Prescriptive analytics** involves the use of optimization methods to provide new and better ways to operate

TABLE 1.1
Business Analytics and Quantitative Analysis Models

BUSINESS ANALYTICS CATEGORY	QUANTITATIVE ANALYSIS TECHNIQUE
Descriptive analytics	Statistical measures such as means and standard deviations (Chapter 2)
	Statistical quality control (Chapter 15)
Predictive analytics	Decision analysis and decision trees (Chapter 3)
	Regression models (Chapter 4)
	Forecasting (Chapter 5)
	Project scheduling (Chapter 11)
	Waiting line models (Chapter 12)
	Simulation (Chapter 13)
	Markov analysis (Chapter 14)
Prescriptive analytics	Inventory models such as the economic order quantity (Chapter 6)
	Linear programming (Chapters 7, 8)
	Transportation and assignment models (Chapter 9)
	Integer programming, goal programming, and nonlinear programming (Chapter 10)
	Network models (Chapter 9)

based on specific business objectives. The optimization models presented in this book are very important to prescriptive analytics. While there are only three business analytics categories, many business decisions are made based on information obtained from two or three of these categories.

The three categories of business analytics are descriptive, predictive, and prescriptive.

Many of the quantitative analysis techniques presented in the chapters of this book are used extensively in business analytics. Table 1.1 highlights the three categories of business analytics, and it places many of the topics and chapters in this book in the most relevant category. Keep in mind that some topics (and certainly some chapters with multiple concepts and models) could possibly be placed in a different category. Some of the material in this book could overlap two or even three of these categories. Nevertheless, all of these quantitative analysis techniques are very important tools in business analytics.

1.3 The Quantitative Analysis Approach

Defining the problem can be the most important step.

Concentrate on only a few problems.

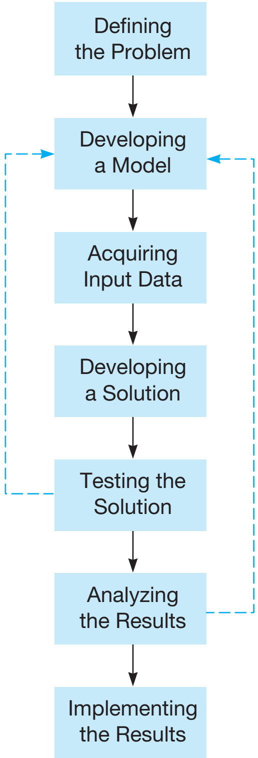
The quantitative analysis approach consists of defining a problem, developing a model, acquiring input data, developing a solution, testing the solution, analyzing the results, and implementing the results (see Figure 1.1). One step does not have to be finished completely before the next is started; in most cases, one or more of these steps will be modified to some extent before the final results are implemented. This would cause all of the subsequent steps to be changed. In some cases, testing the solution might reveal that the model or the input data are not correct. This would mean that all steps that follow defining the problem would need to be modified.

HISTORY The Origin of Quantitative Analysis

Quantitative analysis has been in existence since the beginning of recorded history, but it was Frederick Winslow Taylor who in the late 1800s and early 1900s pioneered the application of the principles of the scientific approach to management. Dubbed the "Father of Industrial Engineering," Taylor is credited with introducing many new scientific and quantitative techniques. These new developments were so successful that many companies still use his techniques in managerial decision making and planning today. Indeed, many organizations employ a staff of operations research or management science personnel or consultants to apply the principles of scientific management to the challenges and opportunities of the twenty-first century.

The origin of many of the techniques discussed in this book can be traced to individuals and organizations that have applied the principles of scientific management first developed by Taylor; they are discussed in *History* boxes throughout the book. Trivia: Taylor was also a world-class golfer and tennis player, finishing just off the medal stand in golf at the 1900 Olympics and winning the inaugural men's doubles title (with Clarence Clark) at the U.S. Open Tennis Championships.

FIGURE 1.1
The Quantitative Analysis Approach



Defining the Problem

The first step in the quantitative approach is to develop a clear, concise statement of the **problem**. This statement will give direction and meaning to the following steps.

In many cases, defining the problem is the most important and the most difficult step. It is essential to go beyond the symptoms of the problem and identify the true causes. One problem may be related to other problems; solving one problem without regard to other, related problems can make the entire situation worse. Thus, it is important to analyze how the solution to one problem affects other problems or the situation in general.

It is likely that an organization will have several problems. However, a quantitative analysis group usually cannot deal with all of an organization's problems at one time. Thus, it is usually necessary to concentrate on only a few problems. For most companies, this means selecting those problems whose solutions will result in the greatest increase in profits or reduction in costs for the company. The importance of selecting the right problems to solve cannot be overemphasized. Experience has shown that bad problem definition is a major reason for failure of management science or operations research groups to serve their organizations well.

When the problem is difficult to quantify, it may be necessary to develop *specific*, *measurable* objectives. A problem might be inadequate health care delivery in a hospital. The objectives might be to increase the number of beds, reduce the average number of days a patient spends in the hospital, increase the physician-to-patient ratio, and so on. When objectives are used, however, the real problem should be kept in mind. It is important to avoid setting specific and measurable objectives that may not solve the real problem.

Developing a Model

Once we select the problem to be analyzed, the next step is to develop a **model**. Simply stated, a model is a representation (usually mathematical) of a situation.

Even though you might not have been aware of it, you have been using models most of your life. You may have developed models about people's behavior. Your model might be that friendship is based on reciprocity, an exchange of favors. If you need a favor such as a small loan, your model would suggest that you ask a good friend.

The types of models include physical, scale, schematic, and mathematical models.

Of course, there are many other types of models. Architects sometimes make a *physical model* of a building that they will construct. Engineers develop *scale models* of chemical plants, called pilot plants. A *schematic model* is a picture, drawing, or chart of reality. Automobiles, lawn mowers, gears, fans, smartphones, and numerous other devices have schematic models (drawings and pictures) that reveal how these devices work. What sets quantitative analysis apart from other techniques is that the models that are used are mathematical. A **mathematical model** is a set of mathematical relationships. In most cases, these relationships are expressed in equations and inequalities, as they are in a spreadsheet model that computes sums, averages, or standard deviations.

Although there is considerable flexibility in the development of models, most of the models presented in this book contain one or more variables and parameters. A **variable**, as the name implies, is a measurable quantity that may vary or is subject to change. Variables can be *controllable* or *uncontrollable*. A controllable variable is also called a *decision variable*. An example would be how many inventory items to order. A **parameter** is a measurable quantity that is inherent in the problem. The cost of placing an order for more inventory items is an example of a parameter. In most cases, variables are unknown quantities, while parameters are known quantities. Hence, in our example, how much inventory to order is a variable that needs to be decided, whereas how much it will cost to place the order is a parameter that is already known. All models should be developed carefully. They should be solvable, realistic, and easy to understand and modify, and the required **input data** should be obtainable. The model developer has to be careful to include the appropriate amount of detail to be solvable yet realistic.

Acquiring Input Data

Garbage in, garbage out means that improper data will result in misleading results.

Once we have developed a model, we must obtain the data that are used in the model (*input data*). Obtaining accurate data for the model is essential; even if the model is a perfect representation of reality, improper data will result in misleading results. This situation is called *garbage in, garbage out*. For a larger problem, collecting accurate data can be one of the most difficult steps in performing quantitative analysis.

IN ACTION | Operations Research and Oil Spills

Operations researchers and decision scientists have been investigating oil spill response and alleviation strategies since long before the BP oil spill disaster of 2010 in the Gulf of Mexico. A four-phase classification system has emerged for disaster response research: mitigation, preparedness, response, and recovery. *Mitigation* means reducing the probability that a disaster will occur and implementing robust, forward-thinking strategies to reduce the effects of a disaster that does occur. *Preparedness* is any and all organization efforts that happen in advance of a disaster. *Response* is the location, allocation, and overall coordination of resources and procedures during the disaster that are aimed at preserving life and property. *Recovery* is the set of actions taken to minimize the long-term impacts of a particular disaster after the immediate situation has stabilized.

Many quantitative tools have helped in areas of risk analysis, insurance, logistical preparation and supply management, evacuation planning, and development of communication systems. Recent research has shown that while many strides and discoveries have been made, much research is still needed. Certainly each of the four disaster response areas could benefit from additional research, but recovery seems to be of particular concern and perhaps the most promising for future research.

Source: Based on N. Altay and W. Green, "OR/MS Research in Disaster Operations Management," *European Journal of Operational Research* 175, 1 (2006): 475–493, © Trevor S. Hale.

There are a number of sources that can be used in collecting data. In some cases, company reports and documents can be used to obtain the necessary data. Another source is interviews with employees or other persons related to the firm. These individuals can sometimes provide excellent information, and their experience and judgment can be invaluable. A production supervisor, for example, might be able to tell you with a great degree of accuracy the amount of time it takes to produce a particular product. Sampling and direct measurement provide other sources of data for the model. You may need to know how many pounds of raw material are used in producing a new photochemical product. This information can be obtained by going to the plant and actually measuring with scales the amount of raw material that is being used. In other cases, statistical sampling procedures can be used to obtain data.

Developing a Solution

Developing a solution involves manipulating the model to arrive at the best (optimal) solution to the problem. In some cases, this requires that an equation be solved for the best decision. In other cases, you can use a *trial-and-error* method, trying various approaches and picking the one that results in the best decision. For some problems, you may wish to try all possible values for the variables in the model to arrive at the best decision. This is called *complete enumeration*. This book also shows you how to solve very difficult and complex problems by repeating a few simple steps until you find the best solution. A series of steps or procedures that are repeated is called an **algorithm**, named after Algorismus (derived from Muhammad ibn Musa al-Khwarizmi), a Persian mathematician of the ninth century.

The input data and model determine the accuracy of the solution.

The accuracy of a solution depends on the accuracy of the input data and the model. If the input data are accurate to only two significant digits, then the results can be accurate to only two significant digits. For example, the results of dividing 2.6 by 1.4 should be 1.9, not 1.857142857.

Testing the Solution

Testing the data and model is done before the results are analyzed.

Before a solution can be analyzed and implemented, it needs to be tested completely. Because the solution depends on the input data and the model, both require testing.

Testing the input data and the model includes determining the accuracy and completeness of the data used by the model. Inaccurate data will lead to an inaccurate solution. There are several ways to test input data. One method of testing the data is to collect additional data from a different source. If the original data were collected using interviews, perhaps some additional data can be collected by direct measurement or sampling. These additional data can then be compared with the original data, and statistical tests can be employed to determine whether there are differences between the original data and the additional data. If there are significant differences, more effort is required to obtain accurate input data. If the data are accurate but the results are inconsistent with the problem, the model may not be appropriate. The model can be checked to make sure that it is logical and represents the real situation.

Although most of the quantitative techniques discussed in this book have been computerized, you will probably be required to solve a number of problems by hand. To help detect both logical and computational mistakes, you should check the results to make sure that they are consistent with the structure of the problem. For example, (1.96)(301.7) is close to (2)(300), which is equal to 600. If your computations are significantly different from 600, you know you have made a mistake.

Analyzing the Results and Sensitivity Analysis

Analyzing the results starts with determining the implications of the solution. In most cases, a solution to a problem will result in some kind of action or change in the way an organization is operating. The implications of these actions or changes must be determined and analyzed before the results are implemented.

Sensitivity analysis determines how the solution will change with a different model or input data.

Because a model is only an approximation of reality, the sensitivity of the solution to changes in the model and input data is a very important part of analyzing the results. This type of analysis is called **sensitivity analysis** or *postoptimality analysis*. It determines how much the solution will change if there are changes in the model or the input data. When the solution is sensitive to changes in the input data and the model specification, additional testing should be performed to make sure that the model and input data are accurate and valid. If the model or data are wrong, the solution could be wrong, resulting in financial losses or reduced profits.

The importance of sensitivity analysis cannot be overemphasized. Because input data may not always be accurate or model assumptions may not be completely appropriate, sensitivity analysis can become an important part of the quantitative analysis approach. Most of the chapters in this book cover the use of sensitivity analysis as part of the decision-making and problem-solving process.

Implementing the Results

The final step is to *implement* the results. This is the process of incorporating the solution into the company's operations. This can be much more difficult than you would imagine. Even if the solution is optimal and will result in millions of dollars in additional profits, if managers resist the new solution, all of the efforts of the analysis are of no value. Experience has shown that a large number of quantitative analysis teams have failed in their efforts because they have failed to implement a good, workable solution properly.

After the solution has been implemented, it should be closely monitored. Over time, there may be numerous changes that call for modifications of the original solution. A changing economy, fluctuating demand, and model enhancements requested by managers and decision makers are only a few examples of changes that might require the analysis to be modified.

The Quantitative Analysis Approach and Modeling in the Real World

The quantitative analysis approach is used extensively in the real world. These steps, first seen in Figure 1.1 and described in this section, are the building blocks of any successful use of quantitative analysis. As seen in our first *Modeling in the Real World* box, the steps of the quantitative analysis approach can be used to help a large company such as CSX plan for critical scheduling needs now and for decades into the future. Throughout this book, you will see how the steps of the quantitative analysis approach are used to help countries and companies of all sizes save millions of dollars, plan for the future, increase revenues, and provide higher-quality products and services. The *Modeling in the Real World* boxes will demonstrate to you the power and importance of quantitative analysis in solving real problems for real organizations. Using the steps of quantitative analysis, however, does not guarantee success. These steps must be applied carefully.

1.4 How to Develop a Quantitative Analysis Model

Developing a model is an important part of the quantitative analysis approach. Let's see how we can use the following mathematical model, which represents profit:

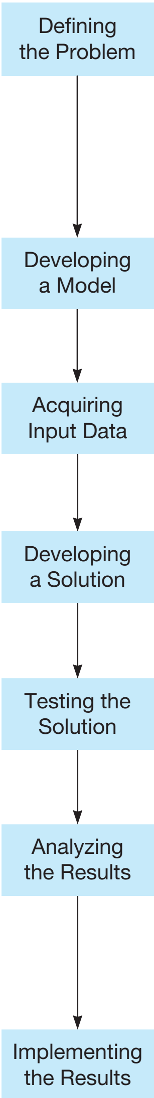
$$\text{Profit} = \text{Revenue} - \text{Expenses}$$

Expenses include fixed and variable costs.

In many cases, we can express revenue as the selling price per unit multiplied times the number of units sold. Expenses can often be determined by summing fixed cost and variable cost.

MODELING IN THE REAL WORLD

The Finn-Power Group Dealing with High Product Variety



Defining the Problem

Founded in 1969, the Finn-Power Group is Scandinavia's largest machine tool manufacturer, exporting about 88% of its products to more than 50 countries. One of Finn-Power's leading sectors is machinery automation, developed in the company's northern Italian facility. While delivering very high-quality outputs, the machines had to be configured in more than 60,000 different ways to accommodate customers' needs, and the need for successive modifications based on after sale requests created substantial optimization problems and delays in product delivery.

Developing a Model

In 1999, Finn-Power began to study the introduction of sophisticated planning bills to produce more accurate forecasts about its components' needs. The purpose of the planning bills was to simplify the master production scheduling (MPS) and the requirements of input materials.

Acquiring Input Data

The input data required consisted of specific details about the components, such as whether they were common to a set of products (modular bills) or specific to a single one. Bills were based both on historical data from previous sales and on estimates about the probability of use for each component.

Developing a Solution

In the initial solution, planning bills were implemented, and the company was able to achieve a substantial reduction of the items that required individual estimates, therefore reducing overall time. A two-level production schedule to streamline the production was also introduced.

Testing the Solution

The planning bills' solution was tested in the Italian subsidiary operations. Salespeople collected orders from customers, and requests for modifications were passed to the designers and buyers to be implemented.

Analyzing the Results

The first test was not successful as the process of updating the planning bills was not carried out with the necessary clarity of objectives. Also, the reports produced were incomplete and hard to read, and they did not convey a real picture of the modifications actually required. As a result, the company failed to deliver the scheduled models in time and in some cases had to rework some of the components. A revised model was therefore proposed to address these shortcomings.

Implementing the Results

The revised model, which enhanced product modularity, finally yielded the desired results. It dramatically improved the accuracy of forecasts, streamlined the production process as originally intended, and significantly augmented the number of on-time deliveries from 38% in 1999 to 80% in 2002. Also, it significantly reduced the value of the obsolete stock by 62.5%, resulting in huge savings and improved performance.

Source: P. Danese and P. Romano. "Finn-Power Italia Develops and Implements a Method to Cope with High Product Variety and Frequent Modifications," *Interfaces* 35, 6 (November–December 2005): 449–459.

Variable cost is often expressed as the variable cost per unit multiplied times the number of units. Thus, we can also express profit in the following mathematical model:

$$\begin{aligned}
\text{Profit} &= \text{Revenue} - (\text{Fixed cost} + \text{Variable cost}) \\
\text{Profit} &= (\text{Selling price per unit})(\text{Number of units sold}) \\
&\quad - [\text{Fixed cost} + (\text{Variable cost per unit})(\text{Number of units sold})] \\
\text{Profit} &= sX - [f + vX] \\
\text{Profit} &= sX - f - vX \qquad \textbf{(1-1)}
\end{aligned}$$

where

$$\begin{aligned}
s &= \text{selling price per unit} \\
f &= \text{fixed cost} \\
v &= \text{variable cost per unit} \\
X &= \text{number of units sold}
\end{aligned}$$

The parameters in this model are f, v, and s, as these are inputs that are inherent in the model. The number of units sold (X) is the decision variable of interest.

EXAMPLE: PRITCHETT'S PRECIOUS TIME PIECES We will use the Bill Pritchett clock repair shop example to demonstrate the use of mathematical models. Bill's company, Pritchett's Precious Time Pieces, buys, sells, and repairs old clocks and clock parts. Bill sells rebuilt springs for a price per unit of \$8. The fixed cost of the equipment to build the springs is \$1,000. The variable cost per unit is \$3 for spring material. In this example,

$$\begin{aligned}
s &= 8 \\
f &= 1{,}000 \\
v &= 3
\end{aligned}$$

The number of springs sold is X, and our profit model becomes

$$\text{Profit} = \$8X - \$1{,}000 - \$3X$$

If sales are 0, Bill will realize a \$1,000 loss. If sales are 1,000 units, he will realize a profit of \$4,000 [$\$4{,}000 = (\$8)(1{,}000) - \$1{,}000 - (\$3)(1{,}000)$]. See if you can determine the profit for other values of units sold.

The BEP results in \$0 profits.

In addition to the profit model shown here, decision makers are often interested in the **break-even point** (BEP). The BEP is the number of units sold that will result in \$0 profits. We set profits equal to \$0 and solve for X, the number of units at the BEP:

$$0 = sX - f - vX$$

This can be written as

$$0 = (s - v)X - f$$

Solving for X, we have

$$\begin{aligned}
f &= (s - v)X \\
X &= \frac{f}{s - v}
\end{aligned}$$

This quantity (X) that results in a profit of zero is the BEP, and we now have this model for the BEP:

$$\begin{aligned}
\text{BEP} &= \frac{\text{Fixed cost}}{(\text{Selling price per unit}) - (\text{Variable cost per unit})} \\
\text{BEP} &= \frac{f}{s - v} \qquad \textbf{(1-2)}
\end{aligned}$$

For the Pritchett's Precious Time Pieces example, the BEP can be computed as follows:

$$\text{BEP} = \$1{,}000/(\$8 - \$3) = 200 \text{ units, or springs}$$

The Advantages of Mathematical Modeling

There are a number of advantages of using mathematical models:

1. Models can accurately represent reality. If properly formulated, a model can be extremely accurate. A valid model is one that is accurate and correctly represents the problem or system under investigation. The profit model in the example is accurate and valid for many business problems.
2. Models can help a decision maker formulate problems. In the profit model, for example, a decision maker can determine the important factors or contributors to revenues and expenses, such as sales, returns, selling expenses, production costs, and transportation costs.
3. Models can give us insight and information. For example, using the profit model, we can see what impact changes in revenue and expenses will have on profits. As discussed in the previous section, studying the impact of changes in a model, such as a profit model, is called *sensitivity analysis*.
4. Models can save time and money in decision making and problem solving. It usually takes less time, effort, and expense to analyze a model. We can use a profit model to analyze the impact of a new marketing campaign on profits, revenues, and expenses. In most cases, using models is faster and less expensive than actually trying a new marketing campaign in a real business setting and observing the results.
5. A model may be the only way to solve some large or complex problems in a timely fashion. A large company, for example, may produce literally thousands of sizes of nuts, bolts, and fasteners. The company may want to make the highest profits possible given its manufacturing constraints. A mathematical model may be the only way to determine the highest profits the company can achieve under these circumstances.
6. A model can be used to communicate problems and solutions to others. A decision analyst can share his or her work with other decision analysts. Solutions to a mathematical model can be given to managers and executives to help them make final decisions.

Mathematical Models Categorized by Risk

Deterministic means with complete certainty.

Some mathematical models, like the profit and break-even models previously discussed, do not involve risk or chance. We assume that we know all values used in the model with complete certainty. These are called **deterministic models**. A company, for example, might want to minimize manufacturing costs while maintaining a certain quality level. If we know all these values with certainty, the model is deterministic.

Other models involve risk or chance. For example, the market for a new product might be "good" with a chance of 60% (a probability of 0.6) or "not good" with a chance of 40% (a probability of 0.4). Models that involve chance or risk, often measured as a probability value, are called **probabilistic models**. In this book, we will investigate both deterministic and probabilistic models.

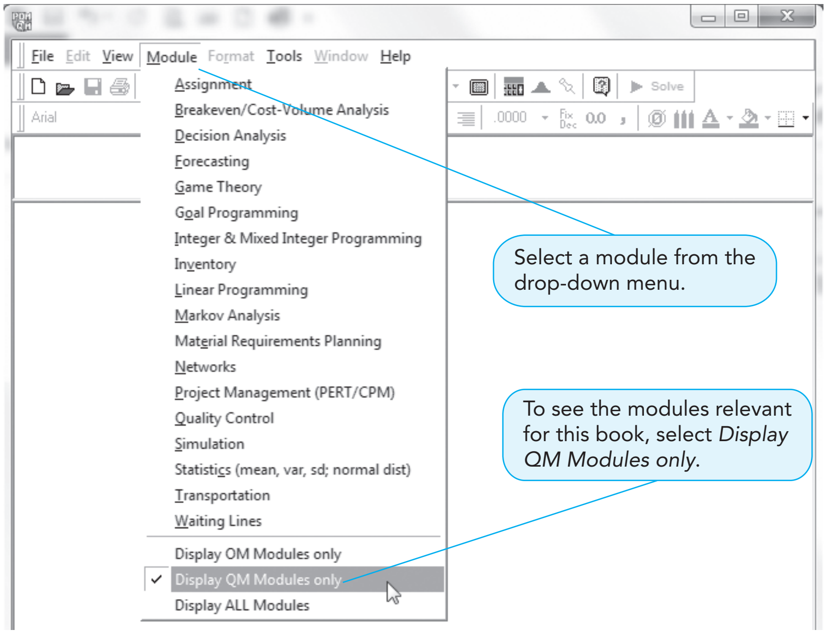
1.5 The Role of Computers and Spreadsheet Models in the Quantitative Analysis Approach

Developing a solution, testing the solution, and analyzing the results are important steps in the quantitative analysis approach. Because we will be using mathematical models, these steps require mathematical calculations. Excel 2016 can be used to help with these calculations, and some spreadsheets developed in Excel will be shown in some chapters. However, some of the techniques presented in this book require sophisticated spreadsheets and are quite tedious to develop. Fortunately, there are two software programs available from the Companion Website for this book that make this much easier:

1. POM-QM for Windows is an easy-to-use decision support program that was developed for production and operations management (POM) and quantitative methods (QM) courses.

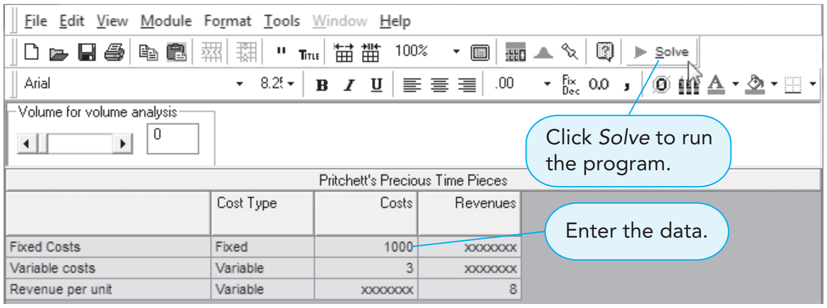
PROGRAM 1.1

The QM for Windows Main Menu



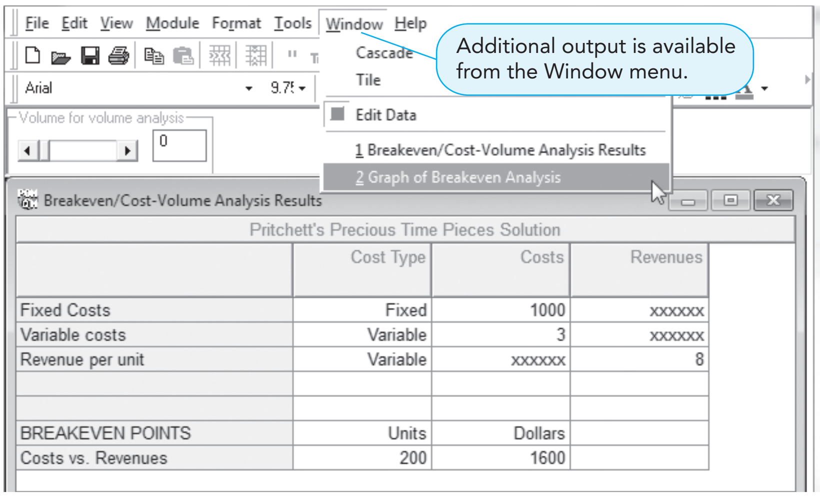
PROGRAM 1.2A

Entering the Data for Pritchett's Precious Time Pieces Example into QM for Windows



PROGRAM 1.2B

QM for Windows Solution Screen for Pritchett's Precious Time Pieces Example



POM for Windows and QM for Windows were originally separate software packages for each type of course. These are now combined into one program called POM-QM for Windows. As seen in Program 1.1, it is possible to display all the modules, only the POM modules, or only the QM modules. The images shown in this textbook will typically display only the QM modules. Hence, in this book, reference will usually be made to QM for Windows. Appendix E at the end of the book provides more information about QM for Windows.

To use QM for Windows to solve the break-even problem presented earlier, from the Module drop-down menu select *Breakeven/Cost-Volume Analysis*. Then select *New-Breakeven Analysis* to enter the problem. When the window opens, enter a name for the problem and select *OK*. Upon doing this, you will see the screen shown in Program 1.2A. The solution is shown in Program 1.2B. Notice the additional output available from the Window drop-down menu.

Files for the QM for Windows examples throughout the book can be downloaded from the Companion Website. Opening these files will demonstrate how data are input for the various modules of QM for Windows.

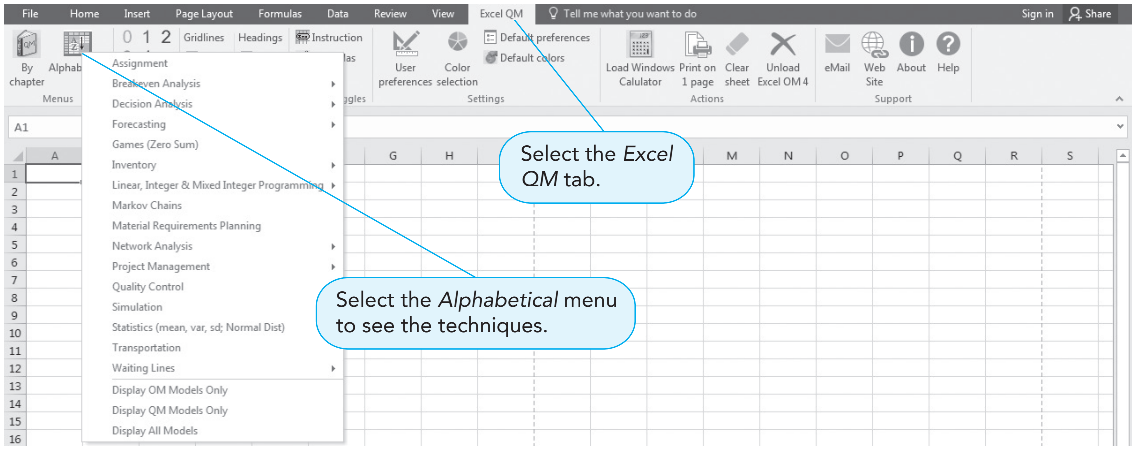
2. Excel QM, an add-in for Excel, can also be used to perform the mathematical calculations for the techniques discussed in each chapter. When installed in Excel 2016, Excel QM will appear as a tab on the ribbon. From this tab, the appropriate model can be selected from a menu, as shown in Program 1.3. Appendix F has more information about this. Excel files with the example problems shown can be downloaded from the Companion Website.

   To use Excel QM in Excel 2016 to solve the break-even problem presented earlier, from the Alphabetical menu (see Program 1.3) select *Breakeven Analysis*. When this is done, a worksheet is prepared automatically, and the user simply inputs the fixed cost, variable cost, and revenue (selling price per unit), as shown in Program 1.4. The solution is calculated when all the inputs have been entered.

   Excel 2016 contains some functions, special features, formulas, and tools that help with some of the questions that might be posed in analyzing a business problem. One such feature, Goal Seek, is shown in Program 1.5 as it is applied to the break-even example. Excel 2016 also has some add-ins that must be activated before using them the first time. These include the Data Analysis add-in and the Solver add-in, which will be discussed in later chapters.

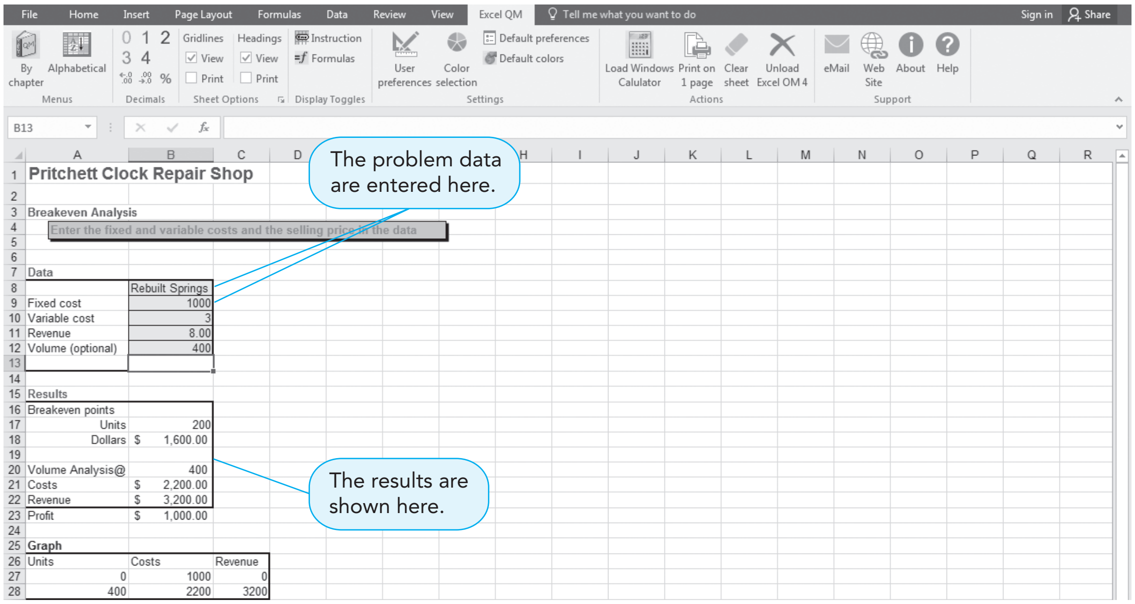
PROGRAM 1.3

Excel QM in Excel 2016 Ribbon and Menu of Techniques



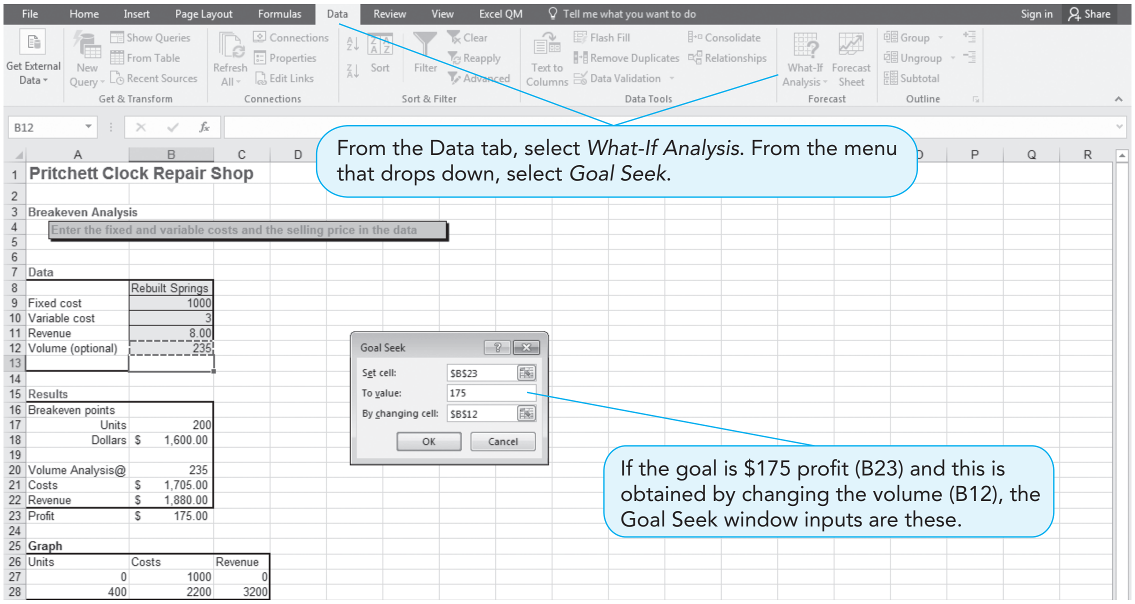
PROGRAM 1.4

Entering the Data for Pritchett's Precious Time Pieces Example into Excel QM in Excel 2016



PROGRAM 1.5

Using Goal Seek in the Break-Even Problem to Achieve a Specified Profit



IN ACTION Major League Operations Research at the Department of Agriculture

In 1997, the Pittsburgh Pirates signed Ross Ohlendorf because of his 95-mph sinking fastball. Little did they know that Ross possessed operations research skills also worthy of national merit. Ross Ohlendorf had graduated from Princeton University with a 3.8 GPA in operations research and financial engineering.

Indeed, after the 2009 baseball season, when Ross applied for an 8-week unpaid internship with the U.S. Department of Agriculture, he didn't need to mention his full-time employer because the Secretary of the Department of Agriculture at the time, Tom Vilsack, was born and raised in Pittsburgh and was an avid Pittsburgh Pirates fan. Ross spent 2 months of the ensuing off-season utilizing his educational background in operations research, helping the Department of Agriculture track disease migration in livestock, a subject Ross has a vested interest in, as his family runs a cattle ranch in Texas. Moreover, when ABC News asked Ross about his off-season unpaid internship experience, he replied, "This one's been, I'd say, the most exciting off-season I've had."

Source: From "Ross Ohlendorf: From Major League Pitcher to Unpaid Intern," by Rick Klein, © 2009, ABCnews.com.

1.6 Possible Problems in the Quantitative Analysis Approach

We have presented the quantitative analysis approach as a logical, systematic means of tackling decision-making problems. Even when these steps are followed carefully, there are many difficulties that can hurt the chances of implementing solutions to real-world problems. We now take a look at what can happen during each of the steps.

Defining the Problem

One view of decision makers is that they sit at a desk all day long, waiting until a problem arises, and then stand up and attack the problem until it is solved. Once it is solved, they sit down, relax, and wait for the next big problem. In the worlds of business, government, and education, problems are, unfortunately, not easily identified. There are four potential roadblocks that quantitative analysts face in defining a problem. We use an application, inventory analysis, throughout this section as an example.

CONFLICTING VIEWPOINTS The first difficulty is that quantitative analysts must often consider conflicting viewpoints in defining the problem. For example, there are at least two views that

All viewpoints should be considered before formally defining the problem.

managers take when dealing with inventory problems. Financial managers usually feel that inventory is too high, as inventory represents cash not available for other investments. Sales managers, on the other hand, often feel that inventory is too low, as high levels of inventory may be needed to fill an unexpected order. If analysts assume either one of these statements as the problem definition, they have essentially accepted one manager's perception and can expect resistance from the other manager when the "solution" emerges. So it's important to consider both points of view before stating the problem. Good mathematical models should include all pertinent information. As we shall see in Chapter 6, both of these factors are included in inventory models.

IMPACT ON OTHER DEPARTMENTS The next difficulty is that problems do not exist in isolation and are not owned by just one department of a firm. Inventory is closely tied with cash flows and various production problems. A change in ordering policy can seriously hurt cash flows and upset production schedules to the point that savings on inventory are more than offset by increased costs for finance and production. The problem statement should thus be as broad as possible and include input from all departments that have a stake in the solution. When a solution is found, the benefits and risks to all areas of the organization should be identified and communicated to the people involved.

BEGINNING ASSUMPTIONS The third difficulty is that people have a tendency to state problems in terms of solutions. The statement that inventory is too low implies a solution that inventory levels should be raised. The quantitative analyst who starts off with this assumption will probably indeed find that inventory should be raised. From an implementation standpoint, a "good" solution to the *right* problem is much better than an "optimal" solution to the *wrong* problem. If a problem has been defined in terms of a desired solution, the quantitative analyst should ask questions about why this solution is desired. By probing further, the true problem will surface and can be defined properly.

An optimal solution to the wrong problem leaves the real problem unsolved.

SOLUTION OUTDATED Even with the best of problem statements, however, there is a fourth danger. The problem can change as the model is being developed. In our rapidly changing business environment, it is not unusual for problems to appear or disappear virtually overnight. The analyst who presents a solution to a problem that no longer exists can't expect credit for providing timely help. However, one of the benefits of mathematical models is that once the original model has been developed, it can be used over and over again whenever similar problems arise. This allows a solution to be found very easily in a timely manner.

Developing a Model

FITTING THE TEXTBOOK MODELS One problem in developing quantitative models is that a manager's perception of a problem won't always match the textbook approach. Most inventory models involve minimizing the total of holding and ordering costs. Some managers view these costs as unimportant; instead, they see the problem in terms of cash flow, turnover, and level of customer satisfaction. Results of a model based on holding and ordering costs are probably not acceptable to such managers. This is why the analyst must completely understand the model and not simply use the computer as a "black box" where data are input and results are given with no understanding of the process. The analyst who understands the process can explain to the manager how the model does consider these other factors when estimating the different types of inventory costs. If other factors are important as well, the analyst can consider these and use sensitivity analysis and good judgment to modify the computer solution before it is implemented.

UNDERSTANDING THE MODEL A second major concern involves the trade-off between the complexity of the model and ease of understanding. Managers simply will not use the results of a model they do not understand. Complex problems, though, require complex models. One trade-off is to simplify assumptions in order to make the model easier to understand. The model loses some of its reality but gains some acceptance by management.

One simplifying assumption in inventory modeling is that demand is known and constant. This means that probability distributions are not needed and it allows us to build simple, easy-to-understand models. Demand, however, is rarely known and constant, so the model we build lacks some reality. Introducing probability distributions provides more realism but may put comprehension beyond all but the most mathematically sophisticated managers. One approach is for the quantitative analyst to start with the simple model and make sure that it is completely understood. Later, more complex models can be introduced slowly as managers gain more confidence in using the new approach. Explaining the impact of the more sophisticated models (e.g., carrying extra inventory called safety stock) without going into complete mathematical details is sometimes helpful. Managers can understand and identify with this concept, even if the specific mathematics used to find the appropriate quantity of safety stock is not totally understood.

Acquiring Input Data

Obtaining accurate input data can be very difficult.

Gathering the data to be used in the quantitative approach to problem solving is often not a simple task. One-fifth of all firms in a recent study had difficulty with data access.

USING ACCOUNTING DATA One problem is that most data generated in a firm come from basic accounting reports. The accounting department collects its inventory data, for example, in terms of cash flows and turnover. But quantitative analysts tackling an inventory problem need to collect data on holding costs and ordering costs. If they ask for such data, they may be shocked to find that the data were simply never collected for those specified costs.

Professor Gene Woolsey tells a story of a young quantitative analyst sent down to accounting to get "the inventory holding cost per item per day for part 23456/AZ." The accountant asked the young man if he wanted the first-in, first-out figure, the last-in, first-out figure, the lower of cost or market figure, or the "how-we-do-it" figure. The young man replied that the inventory model required only one number. The accountant at the next desk said, "Hell, Joe, give the kid a number." The kid was given a number and departed.

VALIDITY OF DATA A lack of "good, clean data" means that whatever data are available must often be distilled and manipulated (we call it "fudging") before being used in a model. Unfortunately, the validity of the results of a model is no better than the validity of the data that go into the model. You cannot blame a manager for resisting a model's "scientific" results when he or she knows that questionable data were used as input. This highlights the importance of the analyst understanding other business functions so that good data can be found and evaluated by the analyst. It also emphasizes the importance of sensitivity analysis, which is used to determine the impact of minor changes in input data. Some solutions are very robust and do not change at all following certain changes in the input data.

Developing a Solution

Hard-to-understand mathematics and single solutions can become problematic in developing a solution.

HARD-TO-UNDERSTAND MATHEMATICS The first concern in developing solutions is that although the mathematical models we use may be complex and powerful, they may not be completely understood. Fancy solutions to problems may have faulty logic or data. The aura of mathematics often causes managers to remain silent when they should be critical. The well-known operations researcher C. W. Churchman cautions that "because mathematics has been so revered a discipline in recent years, it tends to lull the unsuspecting into believing that he who thinks elaborately thinks well."[1]

ONLY ONE ANSWER IS LIMITING The second problem is that quantitative models usually give just one answer to a problem. Most managers would like to have a *range* of options and not be put in a take-it-or-leave-it position. A more appropriate strategy is for an analyst to present a range of options, indicating the effect that each solution has on the objective function. This gives managers a choice, as well as information on how much it will cost to deviate from the optimal solution. It also allows problems to be viewed from a broader perspective, since nonquantitative factors can be considered.

Testing the Solution

The results of quantitative analysis often take the form of predictions of how things will work in the future if certain changes are made now. To get a preview of how well solutions will really

[1]C. W. Churchman, "Reliability of Models in the Social Sciences," *Interfaces* 4, 1 (November 1973): 1–12.

IN ACTION PLATO Helps 2004 Olympic Games in Athens

The 2004 Olympic Games were held in Athens, Greece, over a period of 16 days. More than 2,000 athletes competed in 300 events in 28 sports. The events were held in 36 different venues (stadia, competition centers, etc.), and 3.6 million tickets were sold to people who would view these events. In addition, 2,500 members of international committees and 22,000 journalists and broadcasters attended these games. Home viewers spent more than 34 billion hours watching these sporting events. The 2004 Olympic Games was the biggest sporting event in the history of the world up to that point.

In addition to the sporting venues, other noncompetitive venues, such as the airport and Olympic village, had to be considered. A successful Olympics requires tremendous planning for the transportation system that will handle the millions of spectators. Three years of work and planning were needed for the 16 days of the Olympics.

The Athens Olympic Games Organizing Committee (ATHOC) had to plan, design, and coordinate systems that would be delivered by outside contractors. ATHOC personnel would later be responsible for managing the efforts of volunteers and paid staff during the operations of the games. To make the Athens Olympics run efficiently and effectively, the Process Logistics Advanced Technical Optimization (PLATO) project was begun. Innovative techniques from management science, systems engineering, and information technology were used to change the planning, design, and operations of venues.

The objectives of PLATO were to (1) facilitate effective organizational transformation, (2) help plan and manage resources in a cost-effective manner, and (3) document lessons learned so future Olympic committees could benefit. The PLATO project developed business-process models for the various venues, developed simulation models that enable the generation of what-if scenarios, developed software to aid in the creation and management of these models, and developed process steps for training ATHOC personnel in using these models. Generic solutions were developed so that this knowledge and approach could be made available to other users.

PLATO was credited with reducing the cost of the 2004 Olympics by over $69 million. Perhaps even more important is the fact that the Athens games were universally deemed an unqualified success. The resulting increase in tourism is expected to result in economic benefit to Greece for many years in the future.

Source: Based on D. A. Beis et al., "PLATO Helps Athens Win Gold: Olympic Games Knowledge Modeling for Organizational Change and Resource Management," *Interfaces* 36, 1 (January–February 2006): 26–42, © Trevor S. Hale.

work, managers are often asked how good the solution looks to them. The problem is that complex models tend to give solutions that are not intuitively obvious. Such solutions tend to be rejected by managers. The quantitative analyst now has the chance to work through the model and the assumptions with the manager in an effort to convince the manager of the validity of the results. In the process of convincing the manager, the analyst will have to review every assumption that went into the model. If there are errors, they may be revealed during this review. In addition, the manager will be casting a critical eye on everything that went into the model, and if he or she can be convinced that the model is valid, there is a good chance that the solution results are also valid.

Assumptions should be reviewed.

Analyzing the Results

Once a solution has been tested, the results must be analyzed in terms of how they will affect the total organization. You should be aware that even small changes in organizations are often difficult to bring about. If the results indicate large changes in organization policy, the quantitative analyst can expect resistance. In analyzing the results, the analyst should ascertain who must change and by how much, if the people who must change will be better or worse off, and who has the power to direct the change.

1.7 Implementation—Not Just the Final Step

We have just presented some of the many problems that can affect the ultimate acceptance of the quantitative analysis approach and use of its models. It should be clear now that implementation isn't just another step that takes place after the modeling process is over. Each one of these steps greatly affects the chances of implementing the results of a quantitative study.

Lack of Commitment and Resistance to Change

Even though many business decisions can be made intuitively, based on hunches and experience, there are more and more situations in which quantitative models can assist. Some managers, however, fear that the use of a formal analysis process will reduce their decision-making power. Others fear that it may expose some previous intuitive decisions as inadequate. Still others just feel uncomfortable about having to reverse their thinking patterns with formal decision making. These managers often argue against the use of quantitative methods.

Many action-oriented managers do not like the lengthy formal decision-making process and prefer to get things done quickly. They prefer "quick and dirty" techniques that can yield immediate results. Once managers see some QA results that have a substantial payoff, the stage is set for convincing them that quantitative analysis is a beneficial tool.

Management support and user involvement are important.

We have known for some time that management support and user involvement are critical to the successful implementation of quantitative analysis projects. A Swedish study found that only 40% of projects suggested by quantitative analysts were ever implemented. But 70% of the quantitative projects initiated by users, and fully 98% of the projects suggested by top managers, *were* implemented.

Lack of Commitment by Quantitative Analysts

Just as managers' attitudes are to blame for some implementation problems, analysts' attitudes are to blame for others. When the quantitative analyst is not an integral part of the department facing the problem, he or she sometimes tends to treat the modeling activity as an end in itself. That is, the analyst accepts the problem as stated by the manager and builds a model to solve only that problem. When the results are computed, he or she hands them back to the manager and considers the job done. The analyst who does not care whether these results help make the final decision is not concerned with implementation.

Successful implementation requires that the analyst not *tell* the users what to do but rather work with them and take their feelings into account. An article in *Operations Research* describes an inventory control system that calculated reorder points and order quantities. But instead of insisting that computer-calculated quantities be ordered, a manual override feature was installed. This allowed users to disregard the calculated figures and substitute their own. The override was used quite often when the system was first installed. Gradually, however, as users came to realize that the calculated figures were right more often than not, they allowed the system's figures to stand. Eventually, the override feature was used only in special circumstances. This is a good example of how good relationships can aid in model implementation.

Summary

Quantitative analysis is a scientific approach to decision making. The quantitative analysis approach includes defining the problem, developing a model, acquiring input data, developing a solution, testing the solution, analyzing the results, and implementing the results. In using the quantitative approach, however, there can be potential problems, including conflicting viewpoints, the impact of quantitative analysis models on other departments, beginning assumptions, outdated solutions, fitting textbook models, understanding the model, acquiring good input data, hard-to-understand mathematics, obtaining only one answer, testing the solution, and analyzing the results. In using the quantitative analysis approach, implementation is not the final step. There can be a lack of commitment to the approach and resistance to change.

Glossary

Algorithm A set of logical and mathematical operations performed in a specific sequence.

Break-Even Point The quantity of sales that results in zero profit.

Business Analytics A data-driven approach to decision making that allows companies to make better decisions.

Descriptive Analytics The study and consolidation of historical data to describe how a company has performed in the past and how it is performing now.

Deterministic Model A model in which all values used in the model are known with complete certainty.

Input Data Data that are used in a model in arriving at the final solution.

Mathematical Model A model that uses mathematical equations and statements to represent the relationships within the model.

Model A representation of reality or of a real-life situation.

Parameter A measurable input quantity that is inherent in a problem.

Predictive Analytics The use of techniques to forecast how things will be in the future based on patterns of past data.

Prescriptive Analytics The use of optimization methods to provide new and better ways to operate based on specific business objectives.

Probabilistic Model A model in which all values used in the model are not known with certainty but rather involve some chance or risk, often measured as a probability value.

Problem A statement, which should come from a manager, that indicates a problem to be solved or an objective or a goal to be reached.

Quantitative Analysis or Management Science A scientific approach that uses quantitative techniques as a tool in decision making.

Sensitivity Analysis A process that involves determining how sensitive a solution is to changes in the formulation of a problem.

Variable A measurable quantity that is subject to change.

Key Equations

(1-1) $\text{Profit} = sX - f - vX$

where

s = selling price per unit

f = fixed cost

v = variable cost per unit

X = number of units sold

An equation to determine profit as a function of the selling price per unit, fixed cost, variable cost, and number of units sold.

(1-2) $\text{BEP} = \dfrac{f}{s - v}$

An equation to determine the break-even point (BEP) in units as a function of the selling price per unit (s), fixed cost (f), and variable cost (v).

Self-Test

- Before taking the self-test, refer to the learning objectives at the beginning of the chapter, the notes in the margins, and the glossary at the end of the chapter.
- Use the key at the back of the book (see Appendix H) to correct your answers.
- Restudy pages that correspond to any questions that you answered incorrectly or material you feel uncertain about.

1. In analyzing a problem, you should normally study
   a. the qualitative aspects.
   b. the quantitative aspects.
   c. both a and b.
   d. neither a nor b.
2. Which of the following terms is interchangeable with quantitative analysis?
   a. management science
   b. economics
   c. financial analysis
   d. statistics
3. Who is credited with pioneering the principles of the scientific approach to management?
   a. Adam Smith
   b. Henri Fayol
   c. John R. Locke
   d. Frederick W. Taylor
4. Which of the following is not one of the steps in the quantitative analysis approach?
   a. defining the problem
   b. developing a solution
   c. observing a hypothesis
   d. testing a solution
5. The condition of improper data yielding misleading results is referred to as
   a. garbage in, garbage out.
   b. break-even point.
   c. uncontrollable variable.
   d. postoptimality
6. Quantitative analysis is typically associated with the use of
   a. schematic models.
   b. physical models.
   c. mathematical models.
   d. scale models.
7. Sensitivity analysis is most often associated with which step of the quantitative analysis approach?
   a. defining a problem
   b. acquiring input data
   c. implementing the results
   d. analyzing the results
8. The break-even point is an example of a
   a. postoptimality model.
   b. quantitative analysis model.
   c. schematic model.
   d. sensitivity analysis model.

9. A set of logical and mathematical operations performed in a specific sequence is called a(n)
   a. complete enumeration.
   b. diagnostic analysis.
   c. algorithm.
   d. objective.
10. Expressing profits through the relationship between unit price, fixed costs, and variable costs is an example of a
    a. sensitivity analysis model.
    b. quantitative analysis model.
    c. postoptimality relationship.
    d. parameter specification model.
11. A controllable variable is also called a
    a. parameter.
    b. decision variable.
    c. mathematical model.
    d. measurable quantity.
12. Which of the following techniques involves the study and consolidation of historical data for a business and an industry?
    a. descriptive analytics
    b. prescriptive analytics
    c. predictive analytics
    d. management science

Discussion Questions and Problems

Discussion Questions

1-1 How can quantitative analysis techniques inform and support decision making within organizations?

1-2 Define *quantitative analysis*. Identify the steps involved in the quantitative analysis approach.

1-3 What are the three categories of business analytics?

1-4 Outline the key features of each of the seven steps in the quantitative analysis approach.

1-5 Briefly trace the history of quantitative analysis. What happened to the development of quantitative analysis during World War II?

1-6 What is the difference between models that are deterministic and those that are probabilistic? Provide examples of both.

1-7 List some sources of input data.

1-8 Identify three potential problems with people that may hinder successful implementation of a quantitative model.

1-9 Briefly describe and discuss your understanding of the phrase garbage in, garbage out.

1-10 Managers are quick to claim that quantitative analysts talk to them in a jargon that does not sound like English. List four terms that might not be understood by a manager. Then explain in nontechnical language what each term means.

1-11 Suggest some potential actions that a quantitative analyst could undertake to ensure that the implementation stage of a project is successful.

1-12 Should people who will be using the results of a new quantitative model become involved in the technical aspects of the problem-solving procedure?

1-13 C. W. Churchman once said that "mathematics … tends to lull the unsuspecting into believing that he who thinks elaborately thinks well." Do you think that the best QA models are the ones that are most elaborate and complex mathematically? Why?

1-14 What is the break-even point? What parameters are necessary to find it?

Problems

• 1-15 Gina Fox has started her own company, Foxy Shirts, which manufactures imprinted shirts for special occasions. Since she has just begun this operation, she rents the equipment from a local printing shop when necessary. The cost of using the equipment is \$350. The materials used in one shirt cost \$8, and Gina can sell these for \$15 each.

(a) If Gina sells 20 shirts, what will her total revenue be? What will her total variable cost be?
(b) How many shirts must Gina sell to break even? What is the total revenue for this?

• 1-16 Ray Bond sells handcrafted yard decorations at county fairs. The variable cost to make these is \$20 each, and he sells them for \$50. The cost to rent a booth at the fair is \$150. How many of these must Ray sell to break even?

• 1-17 Ray Bond, from Problem 1-16, is trying to find a new supplier that will reduce his variable cost of production to \$15 per unit. If he was able to succeed in reducing this cost, what would the break-even point be?

: 1-18 Katherine D'Ann is planning to finance her college education by selling programs at the football games for State University. There is a fixed cost of \$400 for printing these programs, and the variable cost is \$3. There is also a \$1,000 fee that is paid to the university for the right to sell these programs. If Katherine was able to sell programs for \$5 each, how many would she have to sell in order to break even?

: 1-19 Katherine D'Ann, from Problem 1-18, has become concerned that sales may fall, as the team is on a terrible losing streak and attendance has fallen off. In fact, Katherine believes that she will sell only 500 programs for the next game. If it was possible to raise the selling price of the program and still sell 500, what would the price have to be for Katherine to break even by selling 500?

Note: means the problem may be solved with QM for Windows; means the problem may be solved with Excel QM; and means the problem may be solved with QM for Windows and/or Excel QM.

1-20 Farris Billiard Supply sells all types of billiard equipment and is considering manufacturing its own brand of pool cues. Mysti Farris, the production manager, is currently investigating the production of a standard house pool cue that should be very popular. Upon analyzing the costs, Mysti determines that the materials and labor cost for each cue is $25 and the fixed cost that must be covered is $2,400 per week. With a selling price of $40 each, how many pool cues must be sold to break even? What would the total revenue be at this break-even point?

1-21 Mysti Farris (see Problem 1-20) is considering raising the selling price of each cue to $50 instead of $40. If this is done while the costs remain the same, what would the new break-even point be? What would the total revenue be at this break-even point?

1-22 Mysti Farris (see Problem 1-20) believes that there is a high probability that 120 pool cues can be sold if the selling price is appropriately set. What selling price would cause the break-even point to be 120?

1-23 Golden Age Retirement Planners specializes in providing financial advice for people planning for a comfortable retirement. The company offers seminars on the important topic of retirement planning. For a typical seminar, the room rental at a hotel is $1,000, and the cost of advertising and other incidentals is about $10,000 per seminar. The cost of the materials and special gifts for each attendee is $60 per person attending the seminar. The company charges $250 per person to attend the seminar, as this seems to be competitive with other companies in the same business. How many people must attend each seminar for Golden Age to break even?

1-24 A couple of entrepreneurial business students at State University decided to put their education into practice by developing a tutoring company for business students. While private tutoring was offered, it was determined that group tutoring before tests in the large statistics classes would be most beneficial. The students rented a room close to campus for $300 for 3 hours. They developed handouts based on past tests, and these handouts (including color graphs) cost $5 each. The tutor was paid $25 per hour, for a total of $75 for each tutoring session.

(a) If students are charged $20 to attend the session, how many students must enroll for the company to break even?
(b) A somewhat smaller room is available for $200 for 3 hours. The company is considering this possibility. How would this affect the break-even point?

1-25 Zoe Garcia is the manager of a small office-support business that supplies copying, binding, and other services for local companies. Zoe must replace a worn-out copy machine that is used for black-and-white copying. Two machines are being considered, and each of these has a monthly lease cost plus a cost for each page that is copied. Machine 1 has a monthly lease cost of $600, and there is a cost of $0.010 per page copied. Machine 2 has a monthly lease cost of $400, and there is a cost of $0.015 per page copied. Customers are charged $0.05 per page for copies.

(a) What is the break-even point for each machine?
(b) If Zoe expects to make 10,000 copies per month, what would be the cost for each machine?
(c) If Zoe expects to make 30,000 copies per month, what would be the cost for each machine?
(d) At what volume (the number of copies) would the two machines have the same monthly cost? What would the total revenue be for this number of copies?

1-26 Bismarck Manufacturing intends to increase capacity through the addition of new equipment. Two vendors have presented proposals. The fixed cost for proposal A is $65,000 and for proposal B, $34,000. The variable cost for A is $10 and for B, $14. The revenue generated by each unit is $18.

(a) What is the break-even point for each proposal?
(b) If the expected volume is 8,300 units, which alternative should be chosen?

Case Study

Food and Beverages at Southwestern University Football Games

Southwestern University (SWU), a large state college in Stephenville, Texas, 30 miles southwest of the Dallas/Fort Worth metroplex, enrolls close to 20,000 students. The school is the dominant force in the small city, with more students during fall and spring than permanent residents.

A longtime football powerhouse, SWU is a member of the Big Eleven conference and is usually in the top 20 in college football rankings. To bolster its chances of reaching the elusive and long-desired number-one ranking, in 2013 SWU hired the legendary Billy Bob Dillon as its head coach. Although the number-one ranking remained out of reach, attendance at the six Saturday home games each year increased. Prior to Dillon's arrival, attendance generally averaged 25,000–29,000. Season ticket sales bumped up by 10,000 just with the announcement of the new coach's arrival. Stephenville and SWU were ready to move to the big time!

With the growth in attendance came more fame, the need for a bigger stadium, and more complaints about seating, parking, long lines, and concession stand prices. Southwestern University's president, Dr. Marty Starr, was concerned not only about the cost of expanding the existing stadium versus building a new stadium but also about the ancillary activities. He wanted to be sure that these various support activities generated revenue adequate to pay for themselves. Consequently, he wanted the parking lots, game programs, and food service to all be handled as profit centers. At a recent meeting discussing the new stadium, Starr told the stadium manager, Hank Maddux, to develop a break-even chart and related data for each of the centers. He instructed Maddux to have the food service area break-even report ready for the next meeting. After discussion with other facility managers and his subordinates, Maddux developed the following table showing the suggested selling prices, his estimate of variable costs, and his estimate of the percentage of the total revenues that would be expected for each of the items based on historical sales data.

Maddux's fixed costs are interesting. He estimated that the prorated portion of the stadium cost would be as follows: salaries for food services at $300,000 ($60,000 for each of the six home games); 2,400 square feet of stadium space at $5 per square foot per game; and six people per booth in each of the six booths for 5 hours at $12 an hour. These fixed costs will be proportionately allocated to each of the products based on the percentages provided in the table. For example, the revenue from soft drinks would be expected to cover 25% of the total fixed costs.

ITEM	SELLING PRICE/UNIT	VARIABLE COST/UNIT	PERCENT REVENUE
Soft drink	$5.00	$1.50	25%
Coffee	4.00	1.00	25
Hot dogs	6.00	2.00	20
Hamburgers	7.50	3.00	20
Misc. snacks	2.00	1.00	10

Maddux wants to be sure that he has a number of things for President Starr: (1) the total fixed cost that must be covered at each of the games; (2) the portion of the fixed cost allocated to each of the items; (3) what his unit sales would be at breakeven for each item—that is, what sales of soft drinks, coffee, hot dogs, hamburgers, and snacks are necessary to cover the portion of the fixed cost allocated to each of these items; (4) what the dollar sales for each of these would be at these break-even points; and (5) realistic sales estimates per attendee for attendance of 60,000 and 35,000. (In other words, he wants to know how many dollars each attendee is spending on food at his projected break-even sales at present and if attendance grows to 60,000.) He felt this last piece of information would be helpful to understand how realistic the assumptions of his model are, and this information could be compared with similar figures from previous seasons.

Discussion Question

1. Prepare a brief report for Dr. Starr that covers the items noted.

Bibliography

Ackoff, R. L. *Scientific Method: Optimizing Applied Research Decisions*. New York: John Wiley & Sons, Inc., 1962.

Beam, Carrie. "ASP, the Art and Science of Practice: How I Started an OR/MS Consulting Practice with a Laptop, a Phone, and a PhD," *Interfaces* 34 (July–August 2004): 265–271.

Board, John, Charles Sutcliffe, and William T. Ziemba. "Applying Operations Research Techniques to Financial Markets," *Interfaces* 33 (March–April 2003): 12–24.

Churchman, C. W. "Reliability of Models in the Social Sciences," *Interfaces* 4, 1 (November 1973): 1–12.

Churchman, C. W. *The Systems Approach*. New York: Delacort Press, 1968.

Dekker, Rommert, Jacqueline Bloemhof, and Ioannis Mallidis . "Operations Research for Green Logistics—An Overview of Aspects, Issues, Contributions and Challenges," *European Journal of Operational Research* 219, 3 (June 2012): 671–679.

Dutta, Goutam. "Lessons for Success in OR/MS Practice Gained from Experiences in Indian and U.S. Steel Plants," *Interfaces* 30, 5 (September–October 2000): 23–30.

Eom, Sean B., and Eyong B. Kim. "A Survey of Decision Support System Applications (1995–2001)," *Journal of the Operational Research Society* 57, 11 (2006): 1264–1278.

Evans, James. R. "Business Analytics: The Next Frontier for Decision Sciences," *Decision Line* 43, 2 (March 2012): 4–6.

Horowitz, Ira. "Aggregating Expert Ratings Using Preference-Neutral Weights: The Case of the College Football Polls," *Interfaces* 34 (July–August 2004): 314–320.

Keskinocak, Pinar, and Sridhar Tayur. "Quantitative Analysis for Internet-Enabled Supply Chains," *Interfaces* 31, 2 (March–April 2001): 70–89.

Laval, Claude, Marc Feyhl, and Steve Kakouros. "Hewlett-Packard Combined OR and Expert Knowledge to Design Its Supply Chains," *Interfaces* 35 (May–June 2005): 238–247.

Pidd, Michael. "Just Modeling Through: A Rough Guide to Modeling," *Interfaces* 29, 2 (March–April 1999): 118–132.

Saaty, T. L. "Reflections and Projections on Creativity in Operations Research and Management Science: A Pressing Need for a Shifting Paradigm," *Operations Research* 46, 1 (1998): 9–16.

Salveson, Melvin. "The Institute of Management Science: A Prehistory and Commentary," *Interfaces* 27, 3 (May–June 1997): 74–85.

Wright, P. Daniel, Matthew J. Liberatore, and Robert L. Nydick. "A Survey of Operations Research Models and Applications in Homeland Security," *Interfaces* 36 (November–December 2006): 514–529.