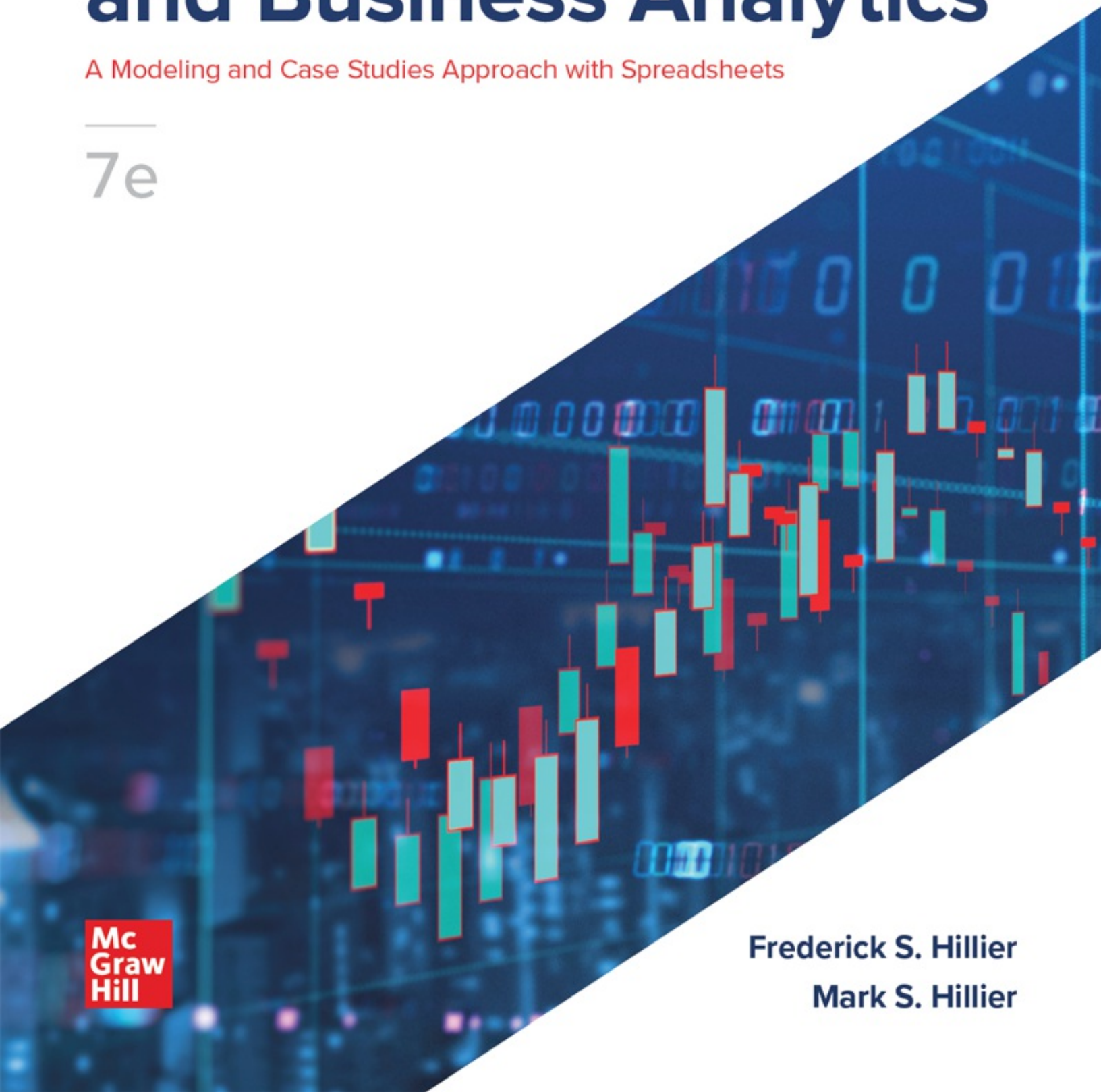
This International Student Edition is for use outside of the U.S.

Introduction to

# Management Science and Business Analytics

A Modeling and Case Studies Approach with Spreadsheets

7e



Frederick S. Hillier
Mark S. Hillier

Mc Graw Hill

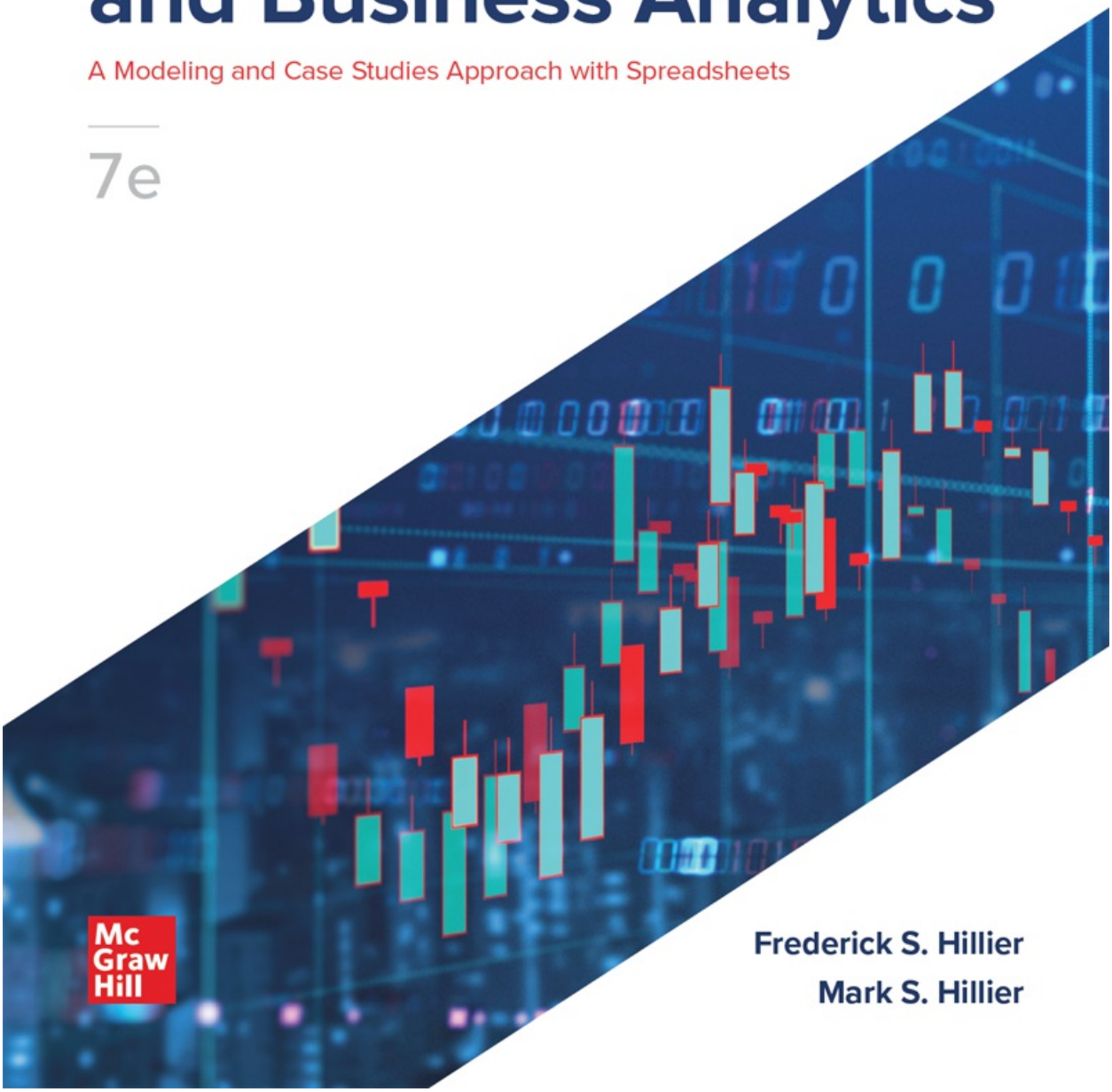
This International Student Edition is for use outside of the U.S.

Introduction to

# Management Science and Business Analytics

A Modeling and Case Studies Approach with Spreadsheets

7e



Frederick S. Hillier
Mark S. Hillier

Mc Graw Hill

# Introduction to Management Science and Business Analytics

## A Modeling and Case Studies Approach with Spreadsheets

# The McGraw Hill Series in Operations and Decision Sciences

## SUPPLY CHAIN MANAGEMENT

Bowersox, Closs, Cooper, and Bowersox
**Supply Chain Logistics Management**
*Fifth Edition*

Johnson
**Purchasing and Supply Management**
*Sixteenth Edition*

Simchi-Levi, Kaminsky, and Simchi-Levi
**Designing and Managing the Supply Chain: Concepts, Strategies, Case Studies**
*Fourth Edition*

Stock and Manrodt
**Fundamentals of Supply Chain Management**

## PROJECT MANAGEMENT

Larson and Gray
**Project Management: The Managerial Process**
*Eighth Edition*

## SERVICE OPERATIONS MANAGEMENT

Bordoloi, Fitzsimmons, and Fitzsimmons

**Service Management: Operations, Strategy, Information Technology**
*Tenth Edition*

## MANAGEMENT SCIENCE

Hillier and Hillier
**Introduction to Management Science: A Modeling and Case Studies Approach with Spreadsheets**
*Sixth Edition*

## BUSINESS RESEARCH METHODS

Schindler
**Business Research Methods**
*Fourteenth Edition*

## BUSINESS FORECASTING

Keating and Wilson
**Forecasting and Predictive Analytics**
*Seventh Edition*

## BUSINESS SYSTEMS DYNAMICS

Sterman
**Business Dynamics: Systems Thinking and Modeling for a Complex World**

## OPERATIONS MANAGEMENT

Cachon and Terwiesch
**Operations Management**
*Third Edition*

Cachon and Terwiesch

**Matching Supply with Demand: An Introduction to Operations Management**

*Fourth Edition*

Jacobs and Chase

**Operations and Supply Chain Management**

*Sixteenth Edition*

Jacobs and Chase

**Operations and Supply Chain Management: The Core**

*Sixth Edition*

Schroeder and Goldstein

**Operations Management in the Supply Chain: Decisions and Cases**

*Eighth Edition*

Stevenson

**Operations Management**

*Fourteenth Edition*

Swink, Melnyk, and Hartley

**Managing Operations Across the Supply Chain**

*Fourth Edition*

## BUSINESS STATISTICS

Bowerman, Drougas, Duckworth, Froelich, Hummel, Moninger, and Schur

**Business Statistics and Analytics in Practice**

*Ninth Edition*

Doane and Seward

**Applied Statistics in Business and Economics**
*Seventh Edition*

Doane and Seward
**Essential Statistics in Business and Economics**
*Third Edition*

Lind, Marchal, and Wathen
**Basic Statistics for Business and Economics**
*Tenth Edition*

Lind, Marchal, and Wathen
**Statistical Techniques in Business and Economics**
*Eighteenth Edition*

Jaggia and Kelly
**Business Statistics: Communicating with Numbers**
*Fourth Edition*

Jaggia and Kelly
**Essentials of Business Statistics: Communicating with Numbers**
*Second Edition*

## BUSINESS ANALYTICS

Jaggia, Kelly, Lertwachara, and Chen
**Business Analytics: Communicating with Numbers**
*Second Edition*

## BUSINESS MATH

Slater and Wittry
**Practical Business Math Procedures**
*Fourteenth Edition*

Slater and Wittry

**Math for Business and Finance: An Algebraic Approach**

*Second Edition*

**Seventh Edition**

# Introduction to Management Science and Business Analytics

## A Modeling and Case Studies Approach with Spreadsheets

**Frederick S. Hillier**
*Stanford University*

**Mark S. Hillier**
*University of Washington*

*Cases developed by*

**Karl Schmedders**
*IMD Business School for Management and Leadership*

**Molly Stephens**
*Quinn, Emanuel, Urquhart & Sullivan, LLP*


Mc
Graw
Hill

INTRODUCTION TO MANAGEMENT SCIENCE AND BUSINESS ANALYTICS



Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 27 26 25 24 23 22

ISBN 978-1-265-04005-5

MHID 1-265-04005-2

Cover Image: *whiteMocca/Shutterstock*

The Internet addresses listed in the text were accurate at the time of publication. The inclusion of a website does not indicate an endorsement by the authors or McGraw Hill LLC, and McGraw Hill LLC does not guarantee the accuracy of the information presented at these sites

mheducation.com/highered

To the memory of

**Christine Phillips Hillier**
a beloved wife and daughter-in-law

**Gerald J. Lieberman**
an admired mentor and one of the true giants of our field

# About the Authors

**Frederick S. Hillier** is professor emeritus of operations research at Stanford University. Dr. Hillier is especially known for his classic, award-winning text, *Introduction to Operations Research,* co-authored with the late Gerald J. Lieberman. This book, which is closely related to management science, has been the dominant textbook of its kind for several decades. It has been translated into well over a dozen languages and is currently in its 11th edition. The sixth edition won honorable mention for the 1995 Lanchester Prize (best English-language publication of any kind in the field), and Dr. Hillier also was awarded the 2004 INFORMS Expository Writing Award for the eighth edition. He also is a Fellow of The Institute for Operations Research and the Management Sciences (INFORMS). In 2018, he was awarded the INFORMS Kimball Medal for his distinguished lifetime achievements, including especially for both the Hillier-Lieberman textbook and this Hillier-Hillier textbook. His other books include *The Evaluation of Risky Interrelated Investments, Queueing Tables and Graphs, Introduction to Stochastic Models in Operations Research,* and *Introduction to Mathematical Programming.*

Dr. Hillier received his BS in industrial engineering and doctorate specializing in operations research and management science from Stanford University. As an undergraduate, he became a member of the Stanford Woodwind Quintet as a freshman and then won the Outstanding Sophomore Debater the next year. He won the McKinsey Prize for technical writing his junior year, and then, as a senior, won the Hamilton Award for combining excellence in engineering with

notable achievements in the humanities and social sciences. He ranked first in his undergraduate engineering class of over 300 students and was awarded three national fellowships (National Science Foundation, Tau Beta Pi, and Danforth) for graduate study. During his three years as a graduate student, he took many courses in mathematics, statistics, and economics outside his department while also teaching both a course in engineering economics and a course in operations research. After receiving his PhD degree, he immediately joined the faculty of Stanford University, where he earned tenure at the age of 28 and the rank of full professor at 32.

Dr. Hillier's research has extended into a variety of areas, including integer programming, queueing theory and its application, statistical quality control, and production and operations management. He also has won a major prize co-sponsored by The Institute of Management Sciences for research in the finance area. His seminal papers have been republished in books of selected readings 11 times. Another paper won a McKinsey Foundation award for best papers appearing in the *California Management Review.*

In addition to his distinguished academic career at Stanford, Dr. Hillier devoted considerable time to other forms of service both in the community and at Stanford. For example, he served multiple years as the President of the Council of Churches for Santa Clara County, in the midst of Silicon Valley. He also served for four years as the chair of Stanford's Commission on Investment Responsibility focusing on how Stanford could more effectively combat apartheid in South Africa.

Twice elected a national officer of professional societies, he has served in many important professional and editorial capacities. For example, he served The Institute of Management Sciences as vice president for meetings, chairman of the publications committee, associate editor of *Management Science,* and co-general chairman of an international conference on management science in Japan. He also is a Fellow of the Institute for Operations Research and the Management Sciences (INFORMS). He served for 20 years (until 2013) as the founding series editor for a prominent book series, Springer's International Series in Operations Research and

Management Science, where he helped to add 200 high-quality books to the field's literature. He has had visiting appointments at Cornell University, the Graduate School of Industrial Administration of Carnegie-Mellon University, the Technical University of Denmark, the University of Canterbury (New Zealand), and the Judge Institute of Management Studies at the University of Cambridge (England).



When his beloved mentor and co-author, Jerry Lieberman, contracted a fatal illness in the mid-1990s, Dr. Hillier reluctantly concluded that he needed to retire as a regular faculty member in order to maximize his impact on the field by becoming a full-time textbook author. He now publishes a new edition of either the Hillier-Lieberman textbook or this Hillier-Hillier textbook every couple years or so. This 7th edition becomes his 23rd edition of all his books. There have been dozens of translations of these editions into other languages, which has helped introduce well over a million students around the world to the field. Dr. Hillier's current academic home as an emeritus professor is with the Department of Management Science and Engineering at Stanford.

**Mark S. Hillier,** son of Fred Hillier, is associate professor of quantitative methods at the Michael G. Foster School of Business at the University of Washington. Dr. Hillier received his BS in engineering (plus a concentration in computer science) from Swarthmore College. He then received his MS with distinction in operations research and PhD in industrial engineering and engineering management from Stanford University. As an undergraduate, he won the McCabe Award for ranking first in his engineering class, won election to Phi Beta Kappa based on his work in mathematics, set school records on the men's swim team, and was awarded two national fellowships (National Science Foundation and Tau Beta Pi) for graduate study.

While still a student, he developed a comprehensive software tutorial package, *OR Courseware,* for the Hillier–Lieberman textbook, *Introduction to Operations Research.* (He also has prepared the solutions manual for recent editions of that textbook.) As a graduate

student, he taught a PhD-level seminar in operations management at Stanford and won a national prize for work based on his PhD dissertation.

At the University of Washington, Dr. Hillier currently teaches courses in management science and spreadsheet modeling. He is widely acclaimed as a master teacher, having won a total of 29 teaching awards. These include over twenty MBA teaching awards for the core course in management science and his elective course in spreadsheet modeling, as well as a universitywide teaching award for his work in teaching undergraduate classes in operations management. He was chosen by MBA students in 2007, 2013, and 2021 as the winner of the School's most prestigious teaching award, namely, the PACCAR award for Teacher of the Year (reputed to provide the largest monetary award for MBA teaching in the nation). (A winner of the PACCAR Award is ineligible for the next five years, so only one other faculty member has won it three times and only one other has won it twice.) In 2021, he also won the Charles E. Summer Memorial Teaching Award, which is given to the faculty member voted the best by *all* graduate students. Other awards include for the most outstanding faculty member in the Global Executive MBA program and MBA Elective Professor of the Year voted on by full-time MBA students. Another is the Ron Crocket Award for Innovation in Education in honor of innovations in online teaching for the development of an online course in Excel for Business. The list goes on and on. His research interests include issues in component commonality, inventory, manufacturing, and the design of production systems. A paper by Dr. Hillier on component commonality won an award for best paper of 2000–2001 in *IIE Transactions.* He also has served as principal investigator on a grant from the Bill and Melinda Gates Foundation to lead student research projects that apply spreadsheet modeling to various issues in global health being studied by the foundation.

# About the Case Writers

**Karl Schmedders** has been a Professor of Finance at the IMD Business School for Management and Leadership in Lausanne, Switzerland, since August, 2020. He previously was professor of quantitative business administration at the University of Zurich in Switzerland and a visiting professor of executive education at the Kellogg School of Management of Northwestern University. His research interests include management science, business analytics, and computational economics and finance. He received his PhD in operations research from Stanford University, where he taught both undergraduate and graduate classes in management science, including a case studies course. He received several teaching awards at Stanford, including the universitywide Walter J. Gores Teaching Award. After a post-doc at the Hoover Institution, a think tank on the Stanford campus, he became assistant professor of managerial economics and decision sciences at the Kellogg School. He was promoted to associate professor in 2001 and received tenure in 2005. In 2008 he joined the University of Zurich, where he taught courses in management science, business analytics, and computational economics and finance. He has published research articles in international academic journals such as *Management Science, Operations Research, Econometrica, The Review of Economic Studies,* and *The Journal of Finance,* among others. At Kellogg he received several teaching awards, including the L. G. Lavengood Professor of the Year Award. More recently he won the best professor award of the Kellogg School's European EMBA program and its

EMBA program in Hong Kong many times.

**Molly Stephens** is a partner in the Los Angeles office of Quinn, Emanuel, Urquhart & Sullivan, LLP. She graduated from Stanford with a BS in industrial engineering and an MS in operations research. Ms. Stephens taught public speaking in Stanford's School of Engineering and served as a teaching assistant for a case studies course in management science. As a teaching assistant, she analyzed management science problems encountered in the real world and transformed these into classroom case studies. Her research was rewarded when she won an undergraduate research grant from Stanford to continue her work and was invited to speak at INFORMS to present her conclusions regarding successful classroom case studies. Following graduation, Ms. Stephens worked at Andersen Consulting as a systems integrator, experiencing real cases from the inside, before resuming her graduate studies to earn a JD degree with honors from the University of Texas School of Law at Austin. She is a partner in the largest law firm in the United States devoted solely to business litigation, where her practice focuses on complex financial and securities litigation. She also has been ranked as a leading securities litigator by Chambers USA, which acknowledged "praise for her powerful and impressive securities litigation practice" and noted that she is "phenomenally bright, a critical thinker and great listener."

# Preface

We have been very gratified by the warm reception to the first six editions of our textbook. It seems clear that instructors do not want major changes in the material in the sixth edition, except for the usual updates and refinements. We have heard and honor this message.

However, we also have concluded that the time has come to add some important new material as a complement to the current contents. The nature and rationale for this new material is described below.

## ADDING BUSINESS ANALYTICS AS A COMPLEMENT TO MANAGEMENT SCIENCE

For well over a decade now, we have seen a growing analytics revolution. As we have entered the era of big data, analytics (including data science) now plays a key role in dealing with numerous managerial concerns. Business analysts who analyze these problems no longer can depend primarily on using the techniques of management science. The discipline of business analytics now needs to be used as well. To meet this need, business schools now have substantially increased their coverage of business analytics. In fact, many business schools now offer a master's program in business analytics.

Therefore, without reducing the coverage of management science, we now are providing an introduction to business analytics as well to clarify the close relationship between these two disciplines. This is

done mainly in the first three chapters (plus Chapter 4, which was Chapter 10 in the sixth edition). Chapter 1 is partially new in describing business analytics and its relationship to management science. Chapter 2 is completely new in providing an overview of a major study that draws on the techniques of business analytics and management science working together. Chapter 3 is completely new in presenting some basic kinds of models for performing predictive analytics. Just as in the sixth edition, Chapter 4 (formerly Chapter 10) presents another type of predictive analytics, namely, using historical data to make a forecast of what the value of some future quantity will turn out to be. Therefore, students now can gain a much better understanding of how business analytics and management science complement each other.

However, Chapter 5–15 (plus the Web chapters) present essentially all of the management science material that was in the sixth edition. Therefore, this gives management science instructors considerable flexibility in how to use this book. If they don't have the space or inclination to provide a significant coverage of business analytics, they can go directly from Chapter 1 to Chapter 5–15. If they want to include an overview of how business analytics and management science can work together, Chapter 2 can be included as well. If they want a fuller introduction to business analytics while still providing a more thorough introduction to management science, Chapter 3 and perhaps Chapter 4 can be included as well.

Master's programs in business analytics typically include a course that is devoted mainly to presenting the techniques of management science and operations research. This textbook should be well suited for such a course.

As discussed in the following three subsections, we continue to believe that a modern introductory management science textbook should have three key elements. As summarized in the subtitle of this book, these elements are a *modeling* and *case studies* approach with *spreadsheets.*

## SPREADSHEETS

The modern approach to the teaching of management science clearly is to use *spreadsheets* as a primary medium of instruction. Both business students and managers now live with spreadsheets, so they provide a comfortable and enjoyable learning environment. Modern spreadsheet software, including Microsoft Excel used in this book, now can be used to do real management science. For student-scale models (which include many practical real-world models), spreadsheets are a much better way of implementing these models than traditional algebraic solvers. This means that the algebraic curtain that used to be prevalent in traditional management science courses and textbooks now can be lifted.

page x

However, with the current enthusiasm for spreadsheets, there is a danger of going overboard. Spreadsheets are not the only useful tool for performing management science analyses. Occasional modest use of algebraic and graphical analyses still have their place and we would be doing a disservice to the students by not developing their skills in these areas when appropriate. Furthermore, the book should not be mainly a spreadsheet cookbook that focuses largely on spreadsheet mechanics. Spreadsheets are a means to an end, not an end in themselves.

## A MODELING APPROACH

This brings us to the second key feature of the book, a *modeling approach.* Model formulation lies at the heart of management science methodology and also plays a basic role when applying business analytics. Therefore, we heavily emphasize the art of model formulation, the role of a model, and the analysis of model results. We primarily (but not exclusively) use a spreadsheet format rather than algebra for formulating and presenting a model.

Some instructors have many years of experience in teaching modeling in terms of formulating algebraic models. Some of these instructors feel that students should do their modeling in this way and then transfer the model to a spreadsheet simply to use the Excel

Solver to solve the model. We disagree with this approach. Our experience (and the experience reported by many others) is that most business students find it more natural and comfortable to do their modeling directly in a spreadsheet. Furthermore, by using the best spreadsheet modeling techniques (as presented in this edition), formulating a spreadsheet model tends to be considerably more efficient and transparent than formulating an algebraic model. Another benefit is that the spreadsheet model includes all the relationships that can be expressed in an algebraic form and we often will summarize the model in this format as well.

Another break from past tradition in this book (and several contemporary textbooks) is to virtually ignore the algorithms that are used to solve the models. We feel that there is no good reason why typical business students should learn the details of algorithms executed by computers. Within the time constraints of a one-term management science course, there are far more important lessons to be learned. Therefore, the focus in this book is on what we believe are these far more important lessons. High on this list is the art of modeling managerial problems on a spreadsheet.

We believe that training business students in spreadsheet modeling will provide them with two key benefits when they later become managers. First, this will give them a powerful tool for analyzing small managerial problems without requiring outside help. Second, this will enable them to recognize when a team of business analysts could be very helpful for analyzing more complicated managerial problems.

Formulating a spreadsheet model of a real problem typically involves much more than designing the spreadsheet and entering the data. Therefore, we work through the process step by step: understand the unstructured problem, verbally develop some structure for the problem, gather the data, express the relationships in quantitative terms, and then lay out the spreadsheet model. The structured approach highlights the components of the model and the different types of spreadsheet cells used for each. Consequently, the emphasis is on the modeling rather than spreadsheet mechanics.

## A CASE STUDIES APPROACH

However, all this still would be quite sterile if we simply presented a long series of brief examples with their spreadsheet formulations. This leads to the third key feature of this book—a *case studies* approach. In addition to examples, every chapter includes a case study patterned after actual applications to convey the whole process of applying management science and business analytics. In a few instances, the entire chapter revolves around a case study. By drawing the student into the story, we have designed each case study to bring that chapter's technique to life in a context that vividly illustrates the relevance of the technique for aiding managerial decision making. This storytelling, case-centered approach should make the material more enjoyable and stimulating while also conveying the practical considerations that are key factors in applying these kinds of techniques.

page xi

We have been pleased to have several reviewers of the first six editions express particular appreciation for our case study approach. Even though this storytelling approach has received little use in some other management science textbooks, we feel that it is a real key to preparing students for the practical application of the relevant techniques. Some of the reviewers have highlighted the effectiveness of the dialogue/scenario enactment approach used in some of the case studies. Although unconventional, this approach provides a way of demonstrating the process of managerial decision making with the help of management science and business analytics. It also enables previewing some key concepts in the language of management.

Every chapter also contains full-fledged cases following the problems at the end of the chapter. These cases usually continue to employ a stimulating storytelling approach, so they can be assigned as interesting and challenging projects. Many of these cases were developed jointly by two talented case writers, Karl Schmedders (a faculty member at the IMD Business School for Management and Leadership in Switzerland) and Molly Stephens (formerly a management science consultant with Andersen Consulting). The authors also have added some cases, including several shorter ones.

We are, of course, not the first to incorporate any of these key features into a management science textbook. However, we believe that the book currently is unique in the way that it fully incorporates all three key features together.

## OTHER SPECIAL FEATURES

We also should mention some additional special features of the book that are continued from the sixth edition.

- Diverse examples, problems, and cases convey the pervasive relevance of management science and business analytics.
- A strong managerial perspective.
- Learning objectives at the beginning of each chapter.
- Numerous margin notes that clarify and highlight key points.
- Excel tips interspersed among the margin notes.
- Review questions at the end of each section.
- A glossary at the end of each chapter.
- Solved problems (problems with complete solutions provided) at the end of each chapter.
- Partial answers to selected problems in the back of the book.
- Extensive supplementary text materials (10 supplements to book chapters and 7 additional chapters) are available on the website, **www.mhhe.com/Hillier7e**.

## A SPECIAL SOFTWARE PACKAGE

This edition continues to integrate Excel and an impressive more recent product of Frontline Systems called **Analytic Solver®**. The downloaded software works only with Excel for Windows. However, a cloud-based version of this software is also available at **AnalyticSolver.com**. The cloud-based version works along with Excel (on either Mac or Windows) and is designed to look and feel as much as possible like the downloaded Analytic Solver add-in for Excel. It offers comprehensive features for prescriptive analytics (optimization,

simulation, decision analysis) and predictive analytics (forecasting, data mining, text mining). Its optimization features are upward compatible from the standard Solver in Excel. Analytic Solver includes:



- A more interactive user interface, with the model parameters always visible alongside the main spreadsheet, rather than only in the Solver dialog box.
- Parameter analysis reports that provide an easy way to see the effect of varying data in a model in a systematic way.
- A model analysis tool that reveals the characteristics of a model (e.g., whether it is linear or nonlinear, smooth or nonsmooth).
- Tools to build and solve decision trees within a spreadsheet.
- A full range of time series forecasting and data mining models.
- The ability to build and run sophisticated Monte Carlo simulation models.
- An interactive simulation mode that allows simulation results to be shown instantly whenever a change is made to a simulation model.
- The Solver in Analytic Solver can be used in combination with computer simulation to perform simulation optimization.
- **If interested in having students get individual licenses for class use, instructors should send an email to support@solver.com to get their course code and receive student pricing and access information as well as their own access information.** Note that this software is not free with the purchase of this text, but low-cost student licenses are available.

## A CONTINUING FOCUS ON EXCEL AND ITS SOLVER

As with all the preceding editions, this edition continues to focus on spreadsheet modeling in an Excel format. Although it lacks some of the functionalities of Analytic Solver, the Excel Solver continues to provide a completely satisfactory way of solving most of the

spreadsheet models encountered in this book. This edition continues to feature this use of the Excel Solver whenever either it or the Analytic Solver could be used.

Many instructors prefer this focus because it avoids introducing other complications that might confuse their students. We agree.

However, the key advantage of introducing Analytic Solver is that it provides an all-in-one complement to the Excel Solver. There are some important topics in the book (including decision analysis and computer simulation) where the Excel Solver lacks the functionalities needed to deal fully with these kinds of problems. Multiple Excel add-ins—Solver Table, TreePlan, SensIt, RiskSim, Crystal Ball, and OptQuest (a module of Crystal Ball)—were introduced in previous editions to provide the needed functionalities. Analytic Solver alone now replaces all of these add-ins.

To further enhance a continuing focus on Excel and its Solver, McGraw Hill's **Connect**® Instructor Resources includes all the Excel files that provide the live spreadsheets for all the various examples and case studies throughout the book. In addition to further investigating the examples and case studies, these spreadsheets can be used by either the student or instructor as templates to formulate and solve similar problems. This website also includes dozens of Excel templates for solving various models in the book as well as a Queueing Simulator for performing computer simulations of queueing systems (used in Chapter 14).

## NEW FEATURES IN THIS EDITION

We have made some important enhancements to the current edition.

**A New Section Introduces Business Analytics** The business world has come to recognize the key role that business analytics can play in managerial decision making. This new Section 1.2 describes the three categories of business analytics and also introduces the role of data science, machine learning, and artificial intelligence.

**A Largely New Section Describes the Relationship Between**

**Management Science and Business Analytics** Both management science and business analytics are disciplines that provide a scientific approach to guiding managerial decision making by using sophisticated techniques that draw on the mathematical sciences, including data science. Section 1.3 describes how these are overlapping disciplines that complement each other extremely well.



**A New Chapter Provides an Overview of the Analysis Process When Using Business Analytics and Management Science** Chapter 2 describes the overall process when teams of business analysts apply business analytics and management science to conduct major studies for management. After emphasizing the need to work with management to carefully define the problem of concern to management, the chapter describes and illustrates the several steps needed to perform each of the three stages of analytics (descriptive, predictive, and prescriptive). Business analytics and management science play complementary roles throughout this overall process.

**A New Chapter Presents Several Popular Models for Performing Predictive Analytics** A considerable number of models have been developed for performing predictive analytics. Some of these are *classification models,* which expresses its prediction of an outcome simply by classifying it as likely to fit a particular class of outcomes. Others are *prediction models,* which actually predict a numerical value for the outcome. Chapter 3 presents several popular models of both types.

**A New Section Extends Queueing Models to Consider Human Behavior** When customers join a waiting line to receive some service from a server, queueing models (the subject of Chapter 13) can be used to predict how long the customers will need to wait. However, these models are based on simplifying mathematical assumptions about how the customers and the server will behave. Recent research has been developing an alternative approach called *behavioral queueing theory* that instead considers the typical behavior of human servers and customers. The new Section 13.10

presents this alternative approach.

**New Introductions to the Five Parts of the Book Provide Better Perspective** Now that the book occasionally goes back and forth in discussing management science and business analytics, we have broken the book into five parts, where each part consists of a few chapters that have a common theme. To help maintain perspective about the current theme, we have provided an introduction to each part at the beginning of the first of its chapters.

**We Now Are a Multi-Color Book to Further Illuminate the Material** Past editions have been one-color books. We now are delighted to have full color available to better highlight the material. For example, descriptive analytics makes heavy use of color and we now can fully illustrate this. Color also will highlight the different components of spreadsheet models.

**A Thorough Updating Throughout the Book.** Given that the writing of the first edition occurred more than 20 years ago, it is inevitable that some of that writing now is somewhat outdated. Even though the descriptions of management science techniques may still be accurate, the numbers and other details describing their application in certain problems, cases, and examples may now seem quite obsolete. Wage standards have changed. Prices have changed. Technologies have changed. Dates have changed. We have done some updating with each new edition and we again made a real effort this time to thoroughly update numbers and other details as needed to reflect conditions in 2022.

**Additional Links to Articles that Describe Dramatic Real Applications.** The sixth edition included 26 application vignettes that described in a few paragraphs how an actual application of management science had a powerful effect on a company or organization by using techniques like those being studied in that portion of the book. The current edition adds eight more vignettes based on recent applications of management science and/or business analytics (while deleting four outdated ones). We continue the practice of adding a link to the journal articles that fully describe these applications (except that the vignette for Section 1.5 doesn’t

require a link), through a special arrangement with the Institute for Operations Research and the Management Sciences (INFORMS®). Thus, the instructor now can motivate his or her lectures by having the students delve into real applications that dramatically demonstrate the relevance of the material being covered in the lectures. The end-of-chapter problems also include an assignment after reading each of these articles.



We continue to be excited about this partnership with INFORMS, our field's preeminent professional society, to provide a link to each of these articles describing spectacular applications of management science and/or business analytics. INFORMS is a professional society for students, academics, and practitioners in analytics, operations research, and management science. Information about INFORMS journals, meetings, job bank, scholarships, awards, and teaching materials is available at **www.informs.org**.

**A Word-by-Word Review to Further Increase Clarity in Each Chapter.** A hallmark of each edition has been a particularly heavy use of certain techniques to maximize the clarity of the material: use cases to bring the material to life, divide sections into smaller subsections, use short paragraphs, use bullet points, set off special conclusions, use italics or boldface to highlight key points, add margin notes, never assume too much about understanding preceding material, etc. However, we have doubled down with this approach in the current edition by using a word-by-word review of each chapter to further increase clarity while also taking into special account the input provided by reviewers and others.

## REFLECTING THE DIVERSE WORLD AROUND US

McGraw Hill believes in unlocking the potential of every learner at every stage of life. To accomplish that, we are dedicated to creating products that reflect, and are accessible to, all the diverse, global customers we serve. Within McGraw Hill, we foster a culture of belonging, and we work with partners who share our commitment to

equity, inclusion, and diversity in all forms. In McGraw Hill Higher Education and for *Introduction to Management Science and Business Analytics,* this includes, but is not limited to the following:

- Refreshing and implementing inclusive content guidelines around topics including generalizations and stereotypes, gender, abilities/disabilities, race/ethnicity, sexual orientation, diversity of names, and age.
- Enhancing best practices in assessment creation to eliminate cultural, cognitive, and affective bias.
- Including more diverse voices in the development and review of our content.

## THIS EDITION ALSO INCLUDES A SPECIAL TEACHING AND LEARNING PLATFORM

McGraw Hill's **Connect**® is a teaching and learning platform that is proven to deliver better results for students and instructors. It empowers students by continually adapting to deliver precisely what is needed when they need it, and how they need it, so their class time is both engaging and effective.

Available with this edition, Connect includes multiple-choice questions for each chapter to be used as practice or homework for students. It also includes SmartBook® (described in the next section) as a personal tutor for students, as well as instrucstor resources (including a test bank) and student resources. For access, visit **connect.mheducation.com**. Instructors also can contact their McGraw Hill sales representative.

After describing SmartBook, various details about Connect are presented next and then later as well.

## SMARTBOOK®

Proven to help students improve grades and study more efficiently, SmartBook contains the same content within the print book, but

actively tailors that content to the needs of the individual. SmartBook's adaptive technology provides precise, personalized instruction on what the student should do next, guiding the student to master and remember key concepts, targeting gaps in knowledge and offering customized feedback, and driving the student toward comprehension and retention of the subject matter. Available on desktops and tablets, SmartBook puts learning at the student's fingertips—anywhere, anytime.



## PROCTORIO
## REMOTE PROCTORING & BROWSER-LOCKING CAPABILITIES

Remote proctoring and browser-locking capabilities, hosted by Proctorio within Connect, provide control of the assessment environment by enabling security options and verifying the identity of the student.

Seamlessly integrated within Connect, these services allow instructors to control students' assessment experience by restricting browser activity, recording students' activity, and verifying students are doing their own work.

Instant and detailed reporting gives instructors an at-a-glance view of potential academic integrity concerns, thereby avoiding personal bias and supporting evidence-based claims.

## READANYWHERE

Read or study when it's convenient for you with McGraw Hill's free ReadAnywhere app. Available for iOS or Android smartphones or

tablets, ReadAnywhere gives users access to McGraw Hill tools including the eBook and SmartBook 2.0 or Adaptive Learning Assignments in Connect. Take notes, highlight, and complete assignments offline—all of your work will sync when you open the app with WiFi access. Log in with your McGraw Hill Connect username and password to start learning—anytime, anywhere!

## OLC-ALIGNED COURSES IMPLEMENTING HIGH-QUALITY ONLINE INSTRUCTION AND ASSESSMENT THROUGH PRECONFIGURED COURSEWARE

In consultation with the Online Learning Consortium (OLC) and our certified Faculty Consultants, McGraw Hill has created pre-configured courseware using OLC's quality scorecard to align with best practices in online course delivery. This turnkey courseware contains a combination of formative assessments, summative assessments, homework, and application activities, and can easily be customized to meet an individual's needs and course outcomes. For more information, visit **https://www.mheducation.com/highered/olc**.

## TEGRITY: LECTURES 24/7

Tegrity in Connect is a tool that makes class time available 24/7 by automatically capturing every lecture. With a simple one-click start-and-stop process, you capture all computer screens and corresponding audio in a format that is easy to search, frame by frame. Students can replay any part of any class with easy-to-use, browser-based viewing on a PC, Mac, iPod, or other mobile devices.

Educators know that the more students can see, hear, and experience class resources, the better they learn. In fact, studies prove it. Tegrity's unique search feature helps students efficiently find what they need, when they need it, across an entire semester of class recordings. Help turn your students' study time into learning moments immediately supported by your lecture. With Tegrity, you also increase

intent listening and class participation by easing students' concerns about note-taking. Using Tegrity in Connect will make it more likely you will see students' faces, not the tops of their heads.

## TEST BUILDER IN CONNECT

Available within Connect, Test Builder is a cloud-based tool that enables instructors to format tests that can be printed, administered within a Learning Management System, or exported as a Word document of the test bank. Test Builder offers a modern, streamlined interface for easy content configuration that matches course needs, without requiring a download.



Test Builder allows you to:

- access all test bank content from a particular title.
- easily pinpoint the most relevant content through robust filtering options.
- manipulate the order of questions or scramble questions and/or answers.
- pin questions to a specific location within a test.
- determine your preferred treatment of algorithmic questions.
- choose the layout and spacing.
- add instructions and configure default settings.

Test Builder provides a secure interface for better protection of content and allows for just-in-time updates to flow directly into assessments.

## WRITING ASSIGNMENT

Available within Connect and Connect Master, the Writing Assignment tool delivers a learning experience to help students improve their written communication skills and conceptual understanding. As an

instructor you can assign, monitor, grade, and provide feedback on writing more efficiently and effectively.

## CREATE YOUR BOOK, YOUR WAY

McGraw Hill's Content Collections Powered by Create® is a self-service website that enables instructors to create custom course materials—print and eBooks—by drawing upon McGraw Hill's comprehensive, cross-disciplinary content. Choose what you want from our high-quality textbooks, articles, and cases. Combine it with your own content quickly and easily, and tap into other rights-secured, third-party content such as readings, cases, and articles. Content can be arranged in a way that makes the most sense for your course and you can include the course name and information as well. Choose the best format for your course: color print, black-and-white print, or eBook. The eBook can be included in your Connect course and is available on the free ReadAnywhere app for smartphone or tablet access as well. When you are finished customizing, you will receive a free digital copy to review in just minutes! Visit McGraw Hill Create® —**www.mcgrawhillcreate.com**—today and begin building!

## INSTRUCTOR RESOURCES

The Instructor Resource Library within Connect is password-protected and a convenient place for instructors to access course supplements that include ten supplements to chapters in the print book and 7 supplementary chapters. Resources for instructors include the complete solutions to all problems and cases, PowerPoint slides which include both lecture materials for nearly every chapter and nearly all the figures (including all the spreadsheets) in the book, and an expanded Test Bank. The test bank contains almost 1,000 multiple-choice and true-false questions, all tagged according to learning objective, topic, level of difficulty, Bloom's taxonomy and AACSB category for filtering and reporting, and in delivered in the following ways:

– As a Connect assignment for online testing and automatic

grading; can be used for actual exams or assigned as quizzes or practice;

– In TestGen, a desktop test generator and editing application for instructors to provide printed tests that can incorporate both McGraw Hill's and instructors' questions;

– As Word files, with both question-only and answer files.

## STUDENT RESOURCES

As described above, SmartBook provides a powerful tool to students for personalized instruction. For the additional convenience of students, we also are providing the website, **www.mhhe.com/Hillier7e**, to provide the full range of resources of interest to students. In addition to providing access to supplementary text material (both supplements to book chapters and additional chapters), this website provides solutions to the "solved problems" (additional examples) that are included at the end of each chapter. For each spreadsheet example in the book, a live spreadsheet that shows the formulation and solution for the example also is provided in the website for easy reference and for use as a template. (At the end of each chapter, the page entitled "Learning Aids for This Chapter" lists the Excel files and other resources that are relevant for that chapter.) Information about accessing the book's software is provided. In addition, the website includes a tutorial with sample test questions (different from those in the instructor's test bank) for self-testing quizzes on the various chapters. It also provides access to the INFORMS articles cited in the application vignettes as well as updates about the book, including errata.



## AN INVITATION

We invite your comments, suggestions, and errata. You can contact either one of us at the e-mail addresses given below. While giving these addresses, let us also assure instructors that *we will continue our policy of not providing solutions to problems and cases in the book to anyone* (including your students) who contacts us. We hope that

you enjoy the book.

Frederick S. Hillier
*Stanford University* (fhillier@stanford.edu)

Mark S. Hillier
*University of Washington* (mhillier@uw.edu)

*January 2022*

# Acknowledgments

This new edition has benefited greatly from the sage advice of many individuals. To begin, we would like to express our deep appreciation to the following individuals who provided formal reviews of the sixth edition and some preliminary drafts for the seventh edition.

**George Joseph Cooper**
*Wilmington University*
**Phillip Fry**
*Boise State University*
**Arpita Jadav**
*Jacksonville University*
**Dr. Michael A. King**
*George Mason School of Business*
**Layek Abdel-Malek**
*New Jersey Institute of Technology*
**Jomon A. Paul**
*KennesawState University*
**Jim Samuel**
*University of Charleston*
**Shane Schartz**
*Fort Hays State University*
**Laurent Tchommo**
*James Madison University*

We also are grateful for the valuable input provided by many of our students as well as various other students and instructors who contacted us via e-mail.

In addition, we want to give a special commendation to Professor

Vijay Mehrotra, Professor of Business Analytics at the University of San Francisco, and a regular columnist for the *Analytics* magazine. His expert advice was invaluable to us for better understanding the viewpoint and terminology of the business analytics community.

This book has continued to be a team effort involving far more than the two co-authors. As a third co-author for the first edition, the late Gerald J. Lieberman provided important initial impetus for this project. We also are indebted to our case writers, Karl Schmedders and Molly Stephens, for their invaluable contributions. Ann Hillier (our wife or mother who is a Stanford M.S. graduate in Statistics with a concentration in Operations Research) again devoted numerous hours to proofreading and dealing with computer issues. They all were vital members of the team.

McGraw Hill/Irwin's editorial and production staff provided the other key members of the team, including Eric Weber, Portfolio Manager; Michele Janicek, Product Development Manager, Barbara Hari, Product Developer Harper Christopher, Executive Marketing Manager, Jolynn Kilburg, Program Manager, and Melissa Leick, Senior Core Content Project Manager. This book is a much better product because of their guidance and hard work. It has been a real pleasure working with such a thoroughly professional staff.

# **Instructors:** Student Success Starts with You

## Tools to enhance your unique voice

Want to build your own course? No problem. Prefer to use an OLC-aligned, prebuilt course? Easy. Want to make changes throughout the semester? Sure. And you'll save time with Connect's auto-grading too.


## Study made personal

Incorporate adaptive study resources like SmartBook® 2.0 into your course and help your students be better prepared in less time. Learn more about the powerful personalized learning experience available in SmartBook 2.0 at **www.mheducation.com/highered/connect/smartbook**

Laptop: McGraw Hill; Woman/dog: George Doyle/Getty Images

## Affordable solutions, added value

Make technology work for you with LMS integration for single sign-on access, mobile access to the digital textbook, and reports to quickly show you how each of your students is doing. And with our Inclusive Access program you can provide all these tools at a discount to your students. Ask your McGraw Hill representative for more information.

Padlock: Jobalou/Getty Images

## Solutions for your challenges 

A product isn’t a solution. Real solutions are affordable, reliable, and come with training and ongoing support when you need it and how you want it. Visit **www.supportateverystep.com** for videos and resources both you and your students can use

throughout the semester.

Checkmark: Jobalou/Getty Images




# **Students:** Get Learning that Fits You

## Effective tools for efficient studying

Connect is designed to help you be more productive with simple, flexible, intuitive tools that maximize your study time and meet your individual learning needs. Get learning that works for you with Connect.

## Study anytime, anywhere

Download the free ReadAnywhere app and access your online eBook, SmartBook 2.0, or Adaptive Learning Assignments when it's convenient, even if you're offline. And since the app automatically

syncs with your Connect account, all of your work is available every time you open it. Find out more at **www.mheducation.com/readanywhere**

> ***"I really liked this app—it made it easy to study when you don't have your text-book in front of you."***
>
> - Jordan Cunningham, Eastern Washington University

# Everything you need in one place

Your Connect course has everything you need—whether reading on your digital eBook or completing assignments for class, Connect makes it easy to get your work done.


Calendar: owattaphotos/Getty Images

# Learning for everyone

McGraw Hill works directly with Accessibility Services Departments and faculty to meet the learning needs of all students. Please contact your Accessibility Services Office and ask them to email accessibility@mheducation.com, or visit **www.mheducation.com/about/accessibility** for more information.

Top: Jenner Images/Getty Images, Left: Hero Images/Getty Images, Right: Hero Images/Getty Images

# Brief Contents

**Part 1 The Essence of Management Science and Business Analytics**

1 Introduction 1
2 Overview of the Analysis Process 36

**Part 2 Models for Predictive Analytics**

3 Classification and Prediction Models for Predictive Analytics 87
4 Predictive Analytics Based on Traditional Forecasting Methods 139

**Part 3 Using Linear Programming to Perform Prescriptive Analytics**

5 Linear Programming: Basic Concepts 187
6 Linear Programming: Formulation and Applications 230
7 The Art of Modeling with Spreadsheets 289
8 What-If Analysis for Linear Programming 317
9 Network Optimization Problems 369

**Part 4 Using Integer or Nonlinear Programming to Perform Prescriptive Analytics**

10 Integer Programming 409
11 Nonlinear Programming 447

**Part 5 Traditional Uncertainty Models for Performing Predictive or Prescriptive Analytics**

12 Decision Analysis 501
13 Queueing Models 564
14 Computer Simulation: Basic Concepts 619
15 Computer Simulation with Analytic Solver 657

**APPENDIXES**

A Tips for Using Microsoft Excel for Modeling 725
B Partial Answers to Selected Problems 731

**INDEX 736**

**SUPPLEMENTS available on the text website www.mhhe.com/Hillier7e**

| | |
|---|---|
| **Supplement to Chapter 1** | An Illustration of the Management Science Approach to Break-Even Analysis |
| **Supplement to Chapter 5** | More About the Graphical Method for Linear Programming |
| **Supplement to Chapter 8** | Reduced Costs |
| **Supplement to Chapter 9** | Minimum Spanning-Tree Problems |
| **Supplement 1 to Chapter 10** | Advanced Formulation Techniques for Binary Integer Programming |

| | |
|---|---|
| **Supplement 2 to Chapter 10** | Some Perspectives on Solving Binary Integer Programming Problems |
| **Supplement 1 to Chapter 12** | Decision Criteria |
| **Supplement 2 to Chapter 12** | Using TreePlan Software for Decision Trees |
| **Supplement to Chapter13** | Additional Queueing Models |
| **Supplement to Chapter14** | The Inverse Transformation Method for Generating Random Observations |
| **Chapter 16** | Solution Concepts for Linear Programming |
| **Chapter 17** | Transportation and Assignment Problems |
| **Chapter 18** | PERT/CPM Models for Project Management |
| **Chapter 19** | Goal Programming |
| **Chapter 20** | Inventory Management with Known Demand |
| **Chapter 21** | Inventory Management with Uncertain Demand |
| **Chapter 22** | Computer Simulation with Crystal Ball |


# Contents

**PART 1 The Essence of Management Science and Business Analytics**

## Chapter 1

## Introduction 1

**1.1** The Nature of Management Science 4

**1.2** What is Business Analytics? 6

**1.3** The Relationship Between Management Science and Business Analytics 10

**1.4** A Case Study: The VRX Company Advertising Budget Problem 13

**1.5** The Impact of Management Science and Business Analytics 26

**1.6** Some Special Features of This Book 29

**1.7** Summary 31

Glossary 32

Learning Aids for This Chapter 33

Solved Problem 33

Problems 34

**Case 1-1** VRX Revisited: Updating the Model with New Data Over Time 35

## Chapter 2

## Overview of the Analysis Process 36

**2.1** A Case Study: First Bank Evaluates Applications for Unsecured Loans 37

**2.2** Define the Problem 37

**2.3** Performing Descriptive Analytics 40

**2.4** Performing Predictive Analytics 58

**2.5** Performing Prescriptive Analytics 71

**2.6** Summary 80

Glossary 80

Learning Aids for This Chapter 82

Solved Problems 82

Problems 82

**Case 2-1** Vacations at Vegas Villas 85

# PART 2 Models for Predictive Analytics

## Chapter 3

## Classification and Prediction Models for Predictive Analytics 87

**3.1** A Case Study: The Evergreen Solar Predictive Analytics Problem 89

**3.2** Models Based on The *k*-Nearest-Neighbors (KNN) Algorithm 92

**3.3** Models Based on Classification Tree and Regression Tree Algorithms 104

**3.4** Other Models Based on Algorithms for Classification and Prediction 117

**3.5** Revisiting the Case Study: Refining and Testing the Models 126

**3.6** Affinity Analysis and Recommendation Systems 130
**3.7** Summary 131

Glossary 132
Learning Aids for This Chapter 133
Solved Problems 133
Problems 134
**Case 3-1** Evergreen Solar Decides to Use Naïve Bayes 137
**Case 3-2** Revisiting Vacations at Vegas Villas 138

## Chapter 4

## Predictive Analytics Based on Traditional Forecasting Methods 139

**4.1** An Overview of the Techniques of Time Series Forecasting 140
**4.2** A Case Study: The Computer Club Warehouse (CCW) Problem 142
**4.3** Applying Time Series Forecasting Methods To the Case Study 146
**4.4** The Time Series Forecasting Methods In Perspective 165
**4.5** Causal Forecasting with Linear Regression 168
**4.6** Judgmental Forecasting Methods 173
**4.7** Summary 174

Glossary 175
Summary of Key Formulas 176
Learning Aids for This Chapter 176
Solved Problems 176
Problems 176
**Case 4-1** Finagling the Forecasts 184

## PART 3 Using Linear Programming to Perform

## Prescriptive Analytics

### Chapter 5

### Linear Programming: Basic Concepts 187

**5.1** A Case Study: The Wyndor Glass Co. Product-Mix Problem 189
**5.2** Formulating the Wyndor Problem on a Spreadsheet 192
**5.3** The Mathematical Model in the Spreadsheet 198
**5.4** The Graphical Method for Solving Two-Variable Problems 200
**5.5** Using Excel's Solver to Solve Linear Programming Problems 205
**5.6** Analytic Solver 209
**5.7** A Minimization Example—The Profit & Gambit Co. Advertising-Mix Problem 213
**5.8** Linear Programming From a Broader Perspective 218
**5.9** Summary 219

Glossary 219
Learning Aids for This Chapter 220
Solved Problems 220
Problems 221



**Case 5-1** Auto Assembly 226
**Case 5-2** Cutting Cafeteria Costs 227
**Case 5-3** Staffing a Call Center 228

### Chapter 6

### Linear Programming: Formulation and Applications 230

**6.1** A Case Study: The Super Grain Corp. Advertising-Mix Problem

231
**6.2** Resource-Allocation Problems 237
**6.3** Cost–Benefit–Trade-Off Problems 247
**6.4** Mixed Problems 253
**6.5** Transportation Problems 261
**6.6** Assignment Problems 265
**6.7** Model Formulation From a Broader Perspective 268
**6.8** Summary 270

Glossary 270
Learning Aids for This Chapter 271
Solved Problems 271
Problems 272
**Case 6-1** Shipping Wood to Market 280
**Case 6-2** Capacity Concerns 281
**Case 6-3** Fabrics and Fall Fashions 282
**Case 6-4** New Frontiers 284
**Case 6-5** Assigning Students to Schools 285
**Case 6-6** Reclaiming Solid Wastes 286
**Case 6-7** Project Pickings 287

## Chapter 7

## The Art of Modeling with Spreadsheets 289

**7.1** A Case Study: The Everglade Golden Years Company Cash Flow Problem 290
**7.2** Overview of the Process of Modeling with Spreadsheets 291
**7.3** Some Guidelines for Building “Good” Spreadsheet Models 302
**7.4** Debugging a Spreadsheet Model 308
**7.5** Summary 311

Glossary 312

Learning Aids for This Chapter 312
Solved Problem 312
Problems 313
Case 7-1 Prudent Provisions for Pensions 316

## Chapter 8

## What-If Analysis for Linear Programming 317

**8.1** The Importance of What-if Analysis to Managers 318
**8.2** Continuing the Wyndor Case Study 320
**8.3** The Effect of Changes in One Objective Function Coefficient 322
**8.4** The Effect of Simultaneous Changes in Objective Function Coefficients 328
**8.5** The Effect of Single Changes In a Constraint 335
**8.6** The Effect of Simultaneous Changes in the Constraints 341
**8.7** Robust Optimization 345
**8.8** Chance Constraints with Analytic Solver 348
**8.9** Summary 352

Glossary 352
Learning Aids for This Chapter 353
Solved Problem 353
Problems 354
Case 8-1 Selling Soap 363
Case 8-2 Controlling Air Pollution 364
Case 8-3 Farm Management 366
Case 8-4 Assigning Students to Schools (Revisited) 368

## Chapter 9

## Network Optimization Problems 369

**9.1** Minimum-Cost Flow Problems 370

**9.2** A Case Study: The BMZ Co. Maximum Flow Problem 379
**9.3** Maximum Flow Problems 382
**9.4** Shortest Path Problems 386
**9.5** Summary 395

Glossary 396
Learning Aids for This Chapter 396
Solved Problems 397
Problems 397
**Case 9-1** Aiding Allies 402
**Case 9-2** Money in Motion 405
**Case 9-3** Airline Scheduling 406
**Case 9-4** Broadcasting the Olympic Games 407

**PART 4 Using Integer or Nonlinear Programming to Perform Prescriptive Analytics**

## Chapter 10

## Integer Programming 409

**10.1** The Nature of Integer Programming 410
**10.2** A Case Study: The California Manufacturing Co. Problem 412
**10.3** Using BIP for Project Selection: The Tazer Corp. Problem 419
**10.4** Using BIP for the Selection of Sites for Emergency Services Facilities: The Caliente City Problem 421
**10.5** Using BIP for Crew Scheduling: The Southwestern Airways Problem 425
**10.6** Using Mixed BIP to Deal with Setup Costs for Initiating Production: The Revised Wyndor Problem 429
**10.7** Summary 434

Glossary 434
Learning Aids for This Chapter 435
Solved Problems 435
Problems 436
**Case 10-1** Assigning Art 441
**Case 10-2** Stocking Sets 442
**Case 10-3** Assigning Students to Schools (Revisited) 446
**Case 10-4** Broadcasting the Olympic Games (Revisited) 446



## Chapter 11

## Nonlinear Programming 447

**11.1** The Challenges of Nonlinear Programming 449
**11.2** Continuing the Wyndor Case Study to Deal with Decreasing Marginal Returns 457
**11.3** Applying Nonlinear Programming to Portfolio Selection 463
**11.4** Separable Programming 467
**11.5** Difficult Nonlinear Programming Problems 477
**11.6** Evolutionary Solver and Genetic Algorithms 478
**11.7** Using Analytic Solver to Analyze a Model and Choose a Solving Method 486
**11.8** Summary 490
Glossary 491
Learning Aids for This Chapter 491
Solved Problem 492
Problems 492
**Case 11-1** Continuation of the Super Grain Case Study 497
**Case 11-2** Savvy Stock Selection 498

Case 11-3 International Investments 499

PART 5 Traditional Uncertainty Models for Performing Predictive or Prescriptive Analytics

Chapter 12

Decision Analysis 501

12.1 A Case Study: The Goferbroke Company Problem 503
12.2 Decision Criteria 506
12.3 Decision Trees 511
12.4 Sensitivity Analysis with Decision Trees 514
12.5 Checking Whether to Obtain More Information 519
12.6 Using New Information to Update the Probabilities 521
12.7 Using a Decision Tree to Analyze the Problem with a Sequence of Decisions 525
12.8 Performing Sensitivity Analysis on the Problem with a Sequence of Decisions 532
12.9 Using Utilities to Better Reflect the Values of Payoffs 535
12.10 The Practical Application of Decision Analysis 546
12.11 Summary 547

Glossary 548
Learning Aids for This Chapter 549
Solved Problems 549
Problems 550
Case 12-1 Who Wants to Be a Millionaire? 559
Case 12-2 University Toys and the Business Professor Action Figures 560
Case 12-3 Brainy Business 560
Case 12-4 Smart Steering Support 562

## Chapter 13

## Queueing Models 564

**13.1** Elements of a Queueing Model 565
**13.2** Some Examples of Queueing Systems 571
**13.3** Measures of Performance for Queueing Systems 573
**13.4** A Case Study: the Dupit Corp. Problem 576
**13.5** Some Single-Server Queueing Models 579
**13.6** Some Multiple-Server Queueing Models 587
**13.7** Priority Queueing Models 592
**13.8** Some Insights About Designing Queueing Systems 597
**13.9** Economic Analysis of the Number of Servers to Provide 603
**13.10** Behavioral Queueing Theory 606
**13.11** Summary 608

Glossary 608
Key Symbols 609
Learning Aids for This Chapter 609
Solved Problem 610
Problems 610

**Case 13-1** Queueing Quandary 616

**Case 13-2** Reducing In-Process Inventory 617

## Chapter 14

## Computer Simulation: Basic Concepts 619

**14.1** The Essence of Computer Simulation 620
**14.2** A Case Study: Herr Cutter's Barber Shop (Revisited) 633
**14.3** Analysis of the Case Study 640
**14.4** Outline of a Major Computer Simulation Study 647
**14.5** Summary 650

Glossary 650

Learning Aids for This Chapter 651
Solved Problem 651
Problems 651
**Case 14-1** Planning Planers 655
**Case 14-2** Reducing In-Process Inventory (Revisited) 656

## Chapter 15

## Computer Simulation with Analytic Solver 657

**15.1** A Case Study: Freddie the Newsboy's Problem 658
**15.2** Bidding for a Construction Project: A Prelude to the Reliable Construction Co. Case Study 668
**15.3** Project Management: Revisiting the Reliable Construction Co. Case Study 672
**15.4** Financial Risk Analysis: Revisiting the Think-Big Development Co. Problem 678
**15.5** Revenue Management In the Travel Industry 683
**15.6** Choosing the Right Distribution 688
**15.7** Decision Making with Parameter Analysis Reports and Trend Charts 699
**15.8** Optimizing with Computer Simulation Using the Solver in Analytic Solver 707
**15.9** Summary 715



Glossary 716
Learning Aids for This Chapter 716
Solved Problem 716
Problems 717
**Case 15-1** Action Adventures 721
**Case 15-2** Pricing under Pressure 722

Case 15-3 Financial Planning for Retirement 724

Appendix A: Tips for Using Microsoft Excel for Modeling 725

Appendix B: Partial Answers to Selected Problems 731

Index 736

**SUPPLEMENTS available on the text website www.mhhe.com/Hillier7e**

**Supplement to Chapter 1** An Illustration of the Management Science Approach to Break-Even Analysis

**Supplement to Chapter 5** More About the Graphical Method for Linear Programming

**Supplement to Chapter 8** Reduced Costs

**Supplement to Chapter 9** Minimum Spanning-Tree Problems

**Supplement 1 to Chapter 10** Advanced Formulation Techniques for Binary Integer Programming

**Supplement 2 to Chapter 10** Some Perspectives on Solving Binary Integer Programming Problems

**Supplement 1 to Chapter 12** Decision Criteria

**Supplement 2 to Chapter 12** Using TreePlan Software for Decision Trees

**Supplement to Chapter 13** Additional Queueing Models

**Supplement to Chapter 14** The Inverse Transformation Method for Generating Random Observations

**CHAPTERS available at www.mhhe.com/Hillier7e**

## Chapter Sixteen

## Solution Concepts for Linear Programming

**16.1** Some Key Facts about Optimal Solutions
**16.2** The Role of Corner Points in Searching for an Optimal Solution
**16.3** Solution Concepts for the Simplex Method
**16.4** The Simplex Method with Two Decision Variables
**16.5** The Simplex Method with Three Decision Variables
**16.6** The Role of Supplementary Variables
**16.7** Some Algebraic Details for the Simplex Method
**16.8** Computer Implementation of the Simplex Method
**16.9** The Interior-Point Approach to Solving Linear Programming Problems
**16.10** Summary

Glossary
Learning Aids for This Chapter
Problems Partial Answers to Selected Problems

## Chapter Seventeen

## Transportation and Assignment Problems

**17.1** A Case Study: The P & T Company Distribution Problem
**17.2** Characteristics of Transportation Problems
**17.3** Modeling Variants of Transportation Problems
**17.4** Some Other Applications of Variants of Transportation Problems
**17.5** A Case Study: The Texago Corp. Site Selection
**17.6** Characteristics of Assignment Problems
**17.7** Modeling Variants of Assignment Problems
**17.8** Summary

Glossary
Learning Aids for This Chapter

Problems Partial Answers to Selected Problems
**Case 17-1** Continuation of the Texago Case Study

## Chapter Eighteen

## PERT/CPM Models for Project Management

**18.1** A Case Study: The Reliable Construction Co. Project
**18.2** Using a Network to Visually Display a Project
**18.3** Scheduling a Project with PERT/CPM
**18.4** Dealing with Uncertain Activity Durations
**18.5** Considering Time–Cost Trade-Offs
**18.6** Scheduling and Controlling Project Costs
**18.7** An Evaluation of PERT/CPM from a Managerial Perspective
**18.8** Summary

Appendix 18.1: Table for the Normal Distribution
Glossary
Learning Aids for This Chapter
Problems Partial Answers to Selected Problems
**Case 18-1** Steps to Success
**Case 18-2** "School's Out Forever . . ."



## Chapter Nineteen

## Goal Programming

**19.1** A Case Study: The Dewright Co. Goal-Programming Problem
**19.2** Weighted Goal Programming
**19.3** Preemptive Goal Programming
**19.4** Summary

Glossary
Learning Aids for This Chapter

Problems Partial Answers to Selected Problems
Case 19-1 A Cure for Cuba
Case 19-2 Remembering September 11

## Chapter Twenty

## Inventory Management with Known Demand

**20.1** A Case Study: The Atlantic Coast Tire Corp. (ACT) Problem
**20.2** Cost Components of Inventory Models
**20.3** The Basic Economic Order Quantity (EOQ) Model
**20.4** The Optimal Inventory Policy for the Basic EOQ Model
**20.5** The EOQ Model with Planned Shortages
**20.6** The EOQ Model with Quantity Discounts
**20.7** The EOQ Model with Gradual Replenishment
**20.8** Summary

Glossary
Learning Aids for This Chapter
Problems Partial Answers to Selected Problems
Case 20-1 Brushing Up on Inventory Control

## Chapter Twenty One

## Inventory Management with Uncertain Demand

**21.1** A Case Study for Perishable Products: Freddie the Newsboy's Problem
**21.2** An Inventory Model for Perishable Products
**21.3** A Case Study for Stable Products: The Niko Camera Corp. Problem
**21.4** The Management Science Team's Analysis of the Case Study
**21.5** A Continuous-Review Inventory Model for Stable Products
**21.6** Larger Inventory Systems in Practice
**21.7** Summary

Glossary
Learning Aids for This Chapter
Problems Partial Answers to Selected Problems
**Case 21-1** TNT: Tackling Newsboy's Teachings
**Case 21-2** Jettisoning Surplus Stock

## Chapter Twenty Two

## Computer Simulation with Crystal Ball

**22.1** A Case Study: Freddie the Newsboy's Problem
**22.2** Bidding for a Construction Project: A Prelude to the Reliable Construction Co. Case Study
**22.3** Project Management: Revisiting the Reliable Construction Co. Case Study
**22.4** Financial Risk Analysis: Revisiting the Think-Big Development Co. Problem
**22.5** Revenue Management in the Travel Industry
**22.6** Choosing the Right Distribution
**22.7** Decision Making with Decision Tables
**22.8** Optimizing with OptQuest
**22.9** Summary

Glossary
Learning Aids for This Chapter
Solved Problem
Problems Partial Answers to Selected Problems
**Case 22-1** Action Adventures
**Case 22-2** Pricing under Pressures

PART 1 (Chapters 1–2

Science and Business Analytics

# CHAPTER 1

# Introduction

This book has five parts. Chapters 1 and 2 comprise Part 1, which has the theme of presenting the essence of management science and business analytics. To clarify the role of Chapter 1 in this endeavor, we begin by providing an introduction to Part 1, after which we will focus on presenting Chapter 1.

## Introduction to Part 1 (Chapters 1 and 2) | The Essence of Management Science and Business Analytics

This book provides an introduction to two closely related disciplines—management science and business analytics—that provide a scientific approach to improving the management of business firms around the world. The greater emphasis will be on management science, and indeed, the final 11 chapters (Chapters 5–15) will present its major

techniques. However, before focusing on management science, the first four chapters will include significant coverage of the complementary roles of management science and business analytics, followed by presenting some key techniques of business analytics (including those that are sometimes given different names such as data science, data mining, machine learning, and so forth).

Because of the dual coverage of management science and business analytics, we have divided the book into five parts to clarify the focus within each part and to provide perspective about how this focus relates to the rest of the book. Thus, Parts 3, 4, and 5 will focus on three different categories of the techniques of management science. Part 2 (Chapters 3 and 4) will be devoted to presenting the techniques of business analytics for performing predictive analytics. To lay the groundwork for all of this, Part 1 (Chapters 1 and 2) will focus on describing the essence of management science and business analytics, as discussed below.

**Management science** (often called **operations research** outside of business schools) was first developed in the middle of the 20th century and has had a major impact ever since. **Business analytics** is much younger, dating back to near the turn of the century, but now is riding high as a prominent part of the **analytics revolution.** Both disciplines have their own unique strengths but also share some major strengths as well. They complement each other extremely well. When a major study is needed to aid managerial decision making, the combination of the two disciplines provides real strength at every stage of the study.

**business analytics**

The art and the science of transforming data into insights for making better business decisions. (Section 1.2)

**Chapter 1** describes the special features of management science and business analytics separately and then emphasizes the close relationship between these two disciplines. The chapter includes a description of the three stages of analytics: (1) **descriptive analytics**

(analyzing data to create informative *descriptions* of what has happened so far), (2) **predictive analytics** (using models to create *predictions* of what is likely to happen in the future), and (3) **prescriptive analytics** (using decision models, including the optimization models of management science, to *prescribe* the best options for managerial decision making). The business analytics discipline has special strength for the first two stages. The management science discipline also has considerable strength for performing predictive analytics, but its special strength is for performing prescriptive analytics. Since teams of business analysts performing a major study for management frequently need to include all three stages of analytics, such teams often make heavy use of the techniques of both business analytics and management science. Chapter 1 also describes how this kind of approach has had an impressive impact on improving the efficiency and profitability of numerous businesses around the world.



**descriptive analytics**

Analyzing data to create informative *descriptions* of what has happened so far. (Section 1.2)

**predictive analytics**

Using models to create *predictions* of what is likely to happen in the future. (Section 1.2)

**Chapter 2** further emphasizes this close relationship between business analytics and management science. The chapter provides a thorough overview of the analysis process for conducting major projects to study complex business problems by using both disciplines. Section 2.3 is of special interest because it is the one place in the book that provides a detailed step-by-step description and illustration of how descriptive analytics is performed. Some tools are illustrated for reframing raw data to enable clearly visualizing the message being conveyed by the data. Sections 2.4 and 2.5 also provide detailed step-by-step descriptions and illustrations of what is needed to be ready to perform predictive analytics and prescriptive analytics, respectively.

What this overview of the analysis process does not do is provide much detail about the specific techniques that then are needed to actually perform predictive analytics and prescriptive analytics. In particular, it is necessary to develop a **model** that fully defines the problem and provides an **algorithm** (a systematic solution procedure) for applying the model. Part 2 will focus on some popular models for performing *predictive* analytics. Parts 3 and 4 then will focus on some models needed for performing *prescriptive* analytics. Part 5 will present some traditional *uncertainty models* for performing predictive analytics or prescriptive analytics when future events are particularly uncertain.

**model**

An approximate representation of something. (Section 1.1)

Before focusing on these models, one goal of Part 1 is to provide the broader context of the work that needs to be done first to prepare for applying these models. Another goal is to provide future managers and future business analysts with a good understanding of the great impact that management science and business analytics together can have.

The book's website also includes additional information about Part 1. In particular, Chapter 1 has a supplement there entitled "An Illustration of the Management Science Approach: Break-Even Analysis."

**Resumption of Chapter One**

## Learning Objectives

After completing this chapter, you should be able to

- Define the term *management science*.
- Describe the nature of management science.
- Describe mathematical models and spreadsheet models.
- Define the term *business analytics.*

Describe the nature of business analytics.

Describe the three categories of business analytics.

Describe the relationship between management science and business analytics.

Identify the levels of annual savings that management science sometimes can provide to organizations.

Identify some special features of this book.

The introduction to Part 1 points out that the focus of this book is on providing a thorough introduction to management science while also introducing the basic concepts of business analytics that play a complementary role. This chapter begins this process by describing the general nature of these closely related disciplines.

The reason for introducing these two disciplines together is that they complement each other very well. They both use a scientific approach to improving the management of business firms. They both use basic tools from such fields as mathematics, statistics, computer science, and information technology. They both are dedicated to aiding managerial decision making. Indeed, any major study being conducted to aid managerial decision making commonly draws from the special techniques of both disciplines. As the toolkits of the two disciplines continue to merge, the distinction between these disciplines continues to diminish. Therefore, it now makes sense to provide an introduction to these complementary disciplines together.

A specialist in either or both of these disciplines requires having a good background in mathematics and related fields. This can cause anxiety to some students who fear that they may not have an adequate mathematical background for this kind of course. However, rest easy. We realize that most readers of this book are aspiring to become managers, not mathematicians. Therefore, the emphasis throughout is on conveying what a future manager needs to know about management science and business analytics. Yes, this means including a little mathematics here and there, because it is a major language of the field. The mathematics you do see will be at the level of high school algebra plus (in the later chapters) basic concepts

of elementary probability theory. We think you will be pleasantly surprised by the new appreciation you gain for how useful and intuitive mathematics at this level can be. However, managers do not need to know any of the heavy mathematical theory that underlies the various techniques of management science and business analytics. Therefore, the use of mathematics plays only a strictly secondary role in the book.

One reason we can deemphasize mathematics is that powerful *spreadsheet software* is available for applying management science and business analytics. Spreadsheets provide a comfortable and familiar environment for formulating and analyzing managerial problems. The spreadsheet takes care of applying the necessary mathematics automatically in the background with only a minimum of guidance by the user. This has revolutionized the use of management science and business analytics. In the past, business analysts with substantial training in management science and/or business analytics were needed to carry out significant studies for management. Now spreadsheets are bringing many of the tools and concepts of these disciplines within the reach of managers for conducting their own analyses. Although busy managers will continue to call upon business analysts with extensive training in management science and/or business analytics to conduct major studies for them, they are increasingly becoming direct users themselves through the medium of spreadsheet software. Therefore, since this book is largely aimed at future managers and business analysts, we will emphasize the use of spreadsheets for applying management science and business analytics.

This book maintains a primary focus on management science, while also introducing the complementary role of business analytics. What does an enlightened future manager need to learn about these topics?

Gain an appreciation for the relevance and power of management science and business analytics. (Therefore, we include many *application vignettes* throughout the book that give examples of *actual applications* of these disciplines and the *impact* they had on

the organizations involved.)

Learn to recognize when these disciplines can (and cannot) be fruitfully applied. (Therefore, we will emphasize the *kinds of problems* to which the various techniques can be applied.)

Learn how to apply the major techniques of management science and business analytics to analyze a variety of managerial problems. (Therefore, we will focus largely on how spreadsheets enable many such applications with no more background in these disciplines than provided by this book.)

Develop an understanding of how to interpret the results of a management science and business analytics study. (Therefore, we will present many *case studies* that illustrate such studies and how their results depend on the assumptions and data that were used.)

Obtain a thorough introduction to the major techniques of management science while also introducing a few key techniques of business analytics that illustrate how this discipline complements management science.

The objectives just described are the key teaching goals of this book.

We begin this process in the next five sections by introducing the nature of management science and business analytics, as well as the impact that these disciplines are having on many organizations. (This process will continue throughout the remaining chapters as well.) In particular, Section 1.1 describes the nature of management science and Section 1.2 does the same for business analytics. Section 1.3 then discusses the relationship between management science and business analytics. Section 1.4 provides an illustration of a typical application of business analytics and management science (choosing an advertising budget). Section 1.5 focuses on the impact of management science and business analytics. Section 1.6 then points out some of the special features of this book that you can look forward to seeing in the subsequent chapters.

# 1.1 THE NATURE OF MANAGEMENT SCIENCE

What is the name *management science* (sometimes abbreviated MS) supposed to convey? It does involve *management* and *science* or, more precisely, *the science of management,* but this still is too vague. Here is a more suggestive definition.

> **Management science** is a *discipline* that attempts to *aid managerial decision making* by applying a *scientific approach* to managerial problems that involve *quantitative factors.*

**management science**

A discipline that attempts to aid managerial decision making by applying a scientific approach to managerial problems that involve quantitative factors.

Now let us see how elaborating upon each of the italicized terms in this definition conveys much more about the nature of management science.

## Management Science Is a Discipline

As a discipline, management science is a whole body of knowledge and techniques that are based on a scientific foundation. For example, it is analogous in some ways to the medical field. A *medical doctor* has been trained in a whole body of knowledge and techniques that are based on the scientific foundations of the medical field. After receiving this training and entering practice, the doctor must diagnose a patient's illness and then choose the appropriate medical procedures to apply to the illness. The patient then makes the final decision on which medical procedures to accept. For less serious cases, the patient may choose not to consult a doctor and instead use his own basic knowledge of medical principles to treat himself. Similarly, a *management scientist* must receive substantial training

(albeit considerably less than for a medical doctor). This training also is in a whole body of knowledge and techniques that are based on the scientific foundations of the discipline. After entering practice, the management scientist must diagnose a managerial problem and then choose the appropriate management science techniques to apply in analyzing the problem. The cognizant manager then makes the final decision as to which conclusions from this analysis to accept. For less extensive managerial problems where management science can be helpful, the manager may choose not to consult a management scientist and instead use his or her own basic knowledge of management science principles to analyze the problem.

Although it has considerably longer roots, the rapid development of the discipline began in the 1940s and 1950s. The initial impetus came early in World War II, when large numbers of scientists were called upon to apply a scientific approach to the management of the war effort for the allies. When the war ended, the success of this approach in the war effort spurred interest in applying it outside the military as well. By the early 1950s, substantial applications of management science were being seen in a variety of organizations in business, industry, and government. Courses presenting the techniques of management science also began to be introduced in some colleges and universities.

Another landmark event in the history of management science was the discovery by George Dantzig in 1947 of the *simplex method* for solving linear programming problems. (Linear programming is the subject of several chapters.) Considerable progress in developing the other techniques of management science also occurred throughout the middle of the 20th century. However, the very limited computational power available at that time (whether when doing the computations by hand or with the relatively primitive electronic computers of the day) prevented applying these techniques except to small problems. Fortunately, another factor that gave great impetus to the growth of the discipline ever since that time was the onslaught of the computer revolution. Even massive problems usually can be solved now with today’s powerful computers.

The traditional name given to the discipline (and the one that still is widely used today outside of business schools) is **operations research.** This name was applied because the teams of scientists in World War II were doing *research* on how to manage military *operations.* The abbreviation OR also is widely used. This abbreviation often is combined with the one for management science (MS), thereby referring to the discipline as OR/MS. According to estimates from the U.S. Bureau of Labor Statistics in 2021, there were approximately 105,000 individuals at that time working as operations research analysts in the United States (some with just a B.S. degree) with a median annual salary of about $85,000. The Bureau also forecasted that this number of individuals working as operations research analysts would grow by 25 percent over the subsequent decade.

**operations research**

The traditional name for management science that still is widely used outside of business schools.



As discussed in the next two sections, another discipline that is closely related to management science is **business analytics**. Like management science, business analytics attempts to aid managerial decision making but with particular emphasis on three types of analysis: (1) *descriptive analytics*—the use of data (sometimes massive amounts of data) to analyze trends to date (perhaps using some of the techniques described in Section 2.3), (2) *predictive analytics*—the use of data to predict what will happen in the future (perhaps by using the forecasting techniques described in Chapters 3 and 4), and (3) *prescriptive analytics*—the use of data to prescribe the best course of action (frequently by using the optimization techniques described in many chapters of this book). Broadly speaking, the techniques of the management science discipline provide the firepower for prescriptive analytics and, to a lesser extent, for predictive analytics, but not so much for descriptive analytics. (Section

1.3 will further describe the relationship between management science and business analytics.)

One major international professional society for the management science discipline (as well as for business analytics) is the *Institute for Operations Research and the Management Sciences* (INFORMS). Headquartered in the United States, with well over 12,000 members, this societyholds major conferences in the United States each year (including a Business Analytics Conference and the annual INFORMS Meeting) plus occasional conferences elsewhere. It also publishes several prominent journals, including *Management Science, Operations Research, Analytics,* and *INFORMS Journal on Applied Analytics* (formerly entitled *Interfaces* before 2019). (Articles describing actual applications of management science are featured in this last journal, so you will see many references and links to this journal throughout the book.) In addition, a few dozen countries around the world have their own national operations research societies.

Thus, operations research/management science (OR/MS) is a truly international discipline. (We hereafter will normally just use the name *management science*.)

## Management Science Aids Managerial Decision Making

The key word here is that management science *aids* managerial decision making. Business analysts employing management science don't make managerial decisions. Managers do. A management science study only provides an analysis and recommendations, based on the quantitative factors involved in the problem, as input to the cognizant managers. Managers must also take into account various intangible considerations that are outside the realm of management science and then use their best judgment to make the decision. Sometimes managers find that qualitative factors are as important as quantitative factors in making a decision.

When business analysts employ management science and other techniques to make

recommendations to management, it is managers (not the business analysts) who make the decisions.

A small informal management science study (or management science and business analytics study) might be conducted by just a single individual, who may be the cognizant manager. However, management science *teams* normally are used for larger studies. (We often will use the term *team* to cover both cases throughout the book.) Such a team often includes some members who are not management scientists but who provide other types of expertise (such as specialists in business analytics) needed for the study. Although a management science team often is entirely *in-house* (employees of the company), part or all of the team may instead be *consultants* who have been hired for just the one study. Consulting firms that partially or entirely specialize in management science and related techniques (such as business analytics) currently are a growing industry.

Although we use the word *study* throughout the book to describe the work being done by teams of business analysts who are applying management science and other techniques, these teams often are engaged in full-fledged *projects* being guided by management. Rather than simply presenting a report or presentation to a manager, the team often works closely with management and the managerial staff to gather the needed data and define management's objectives for the project. Once management has used the team's input to guide its decisions about a new system, the team may then be heavily involved with making sure that management's desires are being implemented properly.

## Management Science Uses a Scientific Approach

Management science is based strongly on some scientific fields, including mathematics, statistics, and computer science. It also draws on the social sciences, especially economics. Since the field is concerned with the practical management of organizations, a management scientist should have solid training in business

administration, including its various functional areas, as well.

To a considerable extent, a management science team will attempt to use the *scientific method* in conducting its study. This means that the team will emphasize conducting a *systematic investigation* that includes careful data gathering, developing and testing hypotheses about the problem (typically in the form of a mathematical model), and then applying sound logic in the subsequent analysis.

When conducting this systematic investigation, the management science team typically would follow several (overlapping) steps that include defining the problem, gathering relevant data, formulating a mathematical model, determining how to solve the model, testing and refining the model, applying the model to develop recommendations for management, and then helping to implement the recommendations adopted by management. Chapter 2 is devoted to fully describing each of the steps for conducting a complete study, including performing descriptive analytics, predictive analytics, and prescriptive analytics (the latter is where management science plays a particularly key role).

## Management Science Considers Quantitative Factors

Many managerial problems revolve around such quantitative factors as production quantities, revenues, costs, the amounts available of needed resources, and so on. By incorporating these quantitative factors into a **mathematical model** and then applying mathematical procedures to solve the model, management science provides a uniquely powerful way of analyzing such managerial problems. Although management science is concerned with the practical management of organizations, including taking into account relevant qualitative factors, its special contribution lies in this unique ability to deal with the quantitative factors.

### mathematical model

An approximate representation of, for example, a business problem that is expressed in

terms of mathematical symbols and expressions.

The supplement to this chapter at **www.mhhe.com/Hillier7e** provides a case study that illustrates the management science approach to considering quantitative factors. The specific problem being addressed involves *break-even analysis,* which leads to determining the **break-even point** of a new product, defined as the minimum sales level required before the product becomes profitable. Both a spreadsheet model and a mathematical model are formulated to conduct the analysis. Several problems and a case requiring break-even analysis also are included.

### Review *Questions*

When did the rapid development of the management science discipline begin?

What is the traditional name given to this discipline outside of business schools?

What does a management science study provide to managers to aid their decision making?

Upon which scientific fields and social sciences is management science especially based?

What are some quantitative factors around which many managerial problems revolve?

## 1.2 WHAT IS BUSINESS ANALYTICS?

There has been great buzz throughout the business world over the last couple decades about *business analytics* and the importance of incorporating it into managerial decision making. The primary impetus for this buzz was a series of articles and books by Thomas H. Davenport, a renowned thought-leader who has helped hundreds of companies worldwide to revitalize their business practices. He initially introduced the concept of analytics in the January 2006 issue of the

*Harvard Business Review* with an article, “Competing on Analytics,” that now has been named as one of the 10 must-read articles in that magazine’s 90-year history. Thomas Davenport soon followed up this article with two best-selling books entitled *Competing on Analytics: The New Science of Winning* (published in 2007 with a new edition published in 2017) and *Analytics at Work: Smarter Decisions, Better Results* (published in 2011). (Jeanne Harris also was a co-author of both books and Robert Morison was an additional co-author of the second book.)

So, what is business analytics? Here is a succinct definition.

By using a variety of innovative techniques to analyze the available data, **business analytics** can be defined as the art and the science of transforming data into insight for making better business decisions.



While developing a considerable number of its own innovative techniques in its relatively short history, business analytics also has drawn on various other *quantitative decision sciences,* including management science, mathematics, statistics, computer science, information technology, industrial engineering, etc. For example, it draws heavily on statistics and computer science when the focus is on making sense of vast amounts of data while also exploiting an explosion in computational capability needed to do this.

Business analytics draws on management science and various other quantitative decision sciences.

Thus, any application of business analytics draws on any of the quantitative decision sciences that can be helpful in analyzing a given problem. Therefore, a company’s business analytics group might include members who collectively have considerable training in all of the quantitative decision sciences listed above, as well as the solid

background in business administration needed by any business analyst.

Business analytics has grown in prominence over the past couple decades largely because we have entered into the era of **big data** where massive amounts of data (accompanied by massive amounts of computational power) are now commonly available to many businesses to help guide managerial decision making. The current data surge is coming from sophisticated computer tracking of shipments, sales, suppliers, and customers, as well as e-mail, web - traffic, social networks, images, and video. A primary focus of business analytics is on how to make the most effective use of all these data.

### big data

Refers to the era of big data we have entered in recent decades where enormous and increasing amounts of transactional data commonly are available for analysis.

The era of *big data* has created new challenges that require the use of business analytics.

## The Three Categories of Business Analytics

The application of business analytics can be divided into three overlapping categories. Each of these categories will be discussed in depth in subsequent chapters. Meanwhile, here are the traditional names and brief descriptions of these categories:

Category 1: **Descriptive analytics** (analyzing data to create informative *descriptions* of what has happened so far)

Category 2: **Predictive analytics** (using models to create *predictions* of what is likely to happen in the future)

Category 3: **Prescriptive analytics** (using decision models, including the optimization models of management science, to *prescribe* the best options for managerial decision making)

### prescriptive analytics

Using decision models to *prescribe* the best options for managerial decision making.

The first of these categories, *descriptive analytics,* requires dealing

with perhaps massive amounts of data. Information technology is used to store and access the data on what has happened in the past, as well as to record what is happening now. Descriptive analytics then uses innovative techniques (including algorithms) to explore the data, locate and extract the data that are relevant, and then identify the interesting patterns and summary data. Innovative *performance metrics* also may be calculated to more vividly describe performance to date. A key tool of descriptive analytics is **data visualization.** After exploring the data to identify the insights, the goal of data visualization is then to *communicate* those insights clearly and efficiently to managers and other users through the careful selection of the most effective visual graphics. (Section 2.3 will focus on descriptive analytics.)

**data visualization**

After exploring the data to identify the insights, the goal of data visualization is then to communicate these insights clearly and efficiently to managers and other users through the careful selection of the most effective visual graphics. (also see Section 1.4)

An important goal of business analytics, including especially descriptive analytics, is to track down and connect the relevant parts of all the available data with the business problems and issues of current interest. This provides guidance into what kinds of data summaries and visualizations (as well as the specific types of predictive and prescriptive models) should be constructed in order to be most valuable for the business.

For all parts of business analytics, but especially for descriptive and predictive models (which typically produce vital inputs for prescriptive models), considerable resources and effort go into data preparation. This is a significant part of every data scientist's job as well.

*Predictive analytics* often involves applying statistical models to predict future events or trends. For example, Chapter 4 (Predictive Analytics Based on Time-Series Forecasting) is devoted to developing various **forecasting models** for predicting a future quantity of some type based on the historical pattern of that quantity. (Management

scientists have used these models from the field of Statistics for many decades and now they also are key tools in the business analytics toolkit.) Chapters 14 and 15 will describe how **computer simulation** (using a computer to simulate the operation of a system) also can be very useful for demonstrating future events that can occur. (Computer simulation is another traditional management science technique.) These powerful management science techniques (with roots in statistics and computer science) have been incorporated into a much larger business analytics toolkit for performing predictive analytics.

### forecasting models

Models for predicting a future quantity of some type based on the historical pattern of that quantity, as described in Chapter 4.

### computer simulation

Using a computer to simulate the operation of an entire process or system, as described in Chapters 14 and 15.



## An Application Vignette

**IBM** (International Business Machines) is an American international technology company with operations in over 170 countries. It is one of the world's largest employers with (as of 2020) over 345,000 employees. It produces and sells computer hardware, middleware, and software, while also providing hosting and consulting services for numerous clients. It also is one of the world's leading research organizations and is a leader in implementing innovative business practices.

IBM Global Technology Services (GTS) operates and manages some of the world's largest data centers for its clients. Because of the high cost and disruption caused by incurring server downtime due to needing maintenance or replacement, special attention

needs to be given to reducing server downtime. A traditional approach for attempting to do this is to automatically replace a server when it reaches a certain age, say, five years. IBM has developed a much better approach by using the innovative techniques of **predictive analytics** to better predict when a server should be upgraded.

IBM's methodology for doing this is called *Predictive Analytics for Server Incident Reduction (PASIR).* PASIR uses a sophisticated version of a popular technique of predictive analytics called *machine learning* (a form of artificial intelligence) to collect, classify, and analyze vast amounts of information (including over 6 million reports of undesirable incidents with some server) about the historical record of the various specific types of servers. High-impact problems involving server outages are correlated with problematic server configurations. This enables developing the best available predictions of future problems and the recommendations of the most appropriate modernization strategy for each server.

Since 2013, IBM has applied PASIR to more than 840,000 client servers in more than 360 client environments, resulting in much more precise upgrade spending, as well as environmental benefits. It is conservatively estimated that this application of predictive analytics is providing IBM's clients with average savings of **$1 billion per year.**

This dramatic application of predictive analytics resulted in IBM winning the prestigious honor of being one of the five worldwide finalists for the 2020 Franz Edelman Award for Achievement in Advanced Analytics, Operations Research, and Management Science.

**Source:** J. Bogojeska, I. Giurgiu, G. Stark, and D. Wiesmann, "IBM Predictive Analytics Reduces Server Downtime," *INFORMS Journal on Applied Analytics* 51, no. 1 (January–February 2021): 63–75. (A link to this article is provided on this book's website at **www.mhhe.com/Hillier7e**.)

In addition, the emergence of the analytics revolution soon after the turn of the century has led the business analytics community to

achieve dramatic advances in further developing and refining techniques for performing predictive analytics. Sometimes, rather than predicting the future *quantity* of some type based on the historical pattern of that quantity (such as when using forecasting models), the goal may be to predict a *yes-or-no* outcome (or perhaps one of a small set of possible outcomes). For example, a business often is interested in predicting the behavior of a prospective customer. Will that customer go ahead and purchase a product that is being offered? How should this kind of question be addressed?

The business analytics community has made great advances in developing powerful techniques for performing predictive analytics after the turn of the century.

When trying to predict a yes-or-no outcome like this, rather than a numeric outcome, it is commonly referred to as **classification** rather than prediction. A basic approach for addressing this kind of classification question is to collect data involving the characteristics and behavior of previous customers. Then, determine a subset of the previous customers whose characteristics are most similar to the prospective customer. Then classify the prospective customer as likely to purchase (or not) the product being offered based on the past behavior of this subset of previous customers.

## classification

Using models to predict a *yes-or-no* outcome (or perhaps one of a small set of possible outcomes).

Although this example of how to classify the likely behavior of a prospective customer may seem quite intuitive, we have not spelled out a number of detailed procedures that are needed to implement this methodology as effectively and efficiently as possible. Much of Chapter 3 revolves around applying or modifying this methodology to fit a variety of situations. Because these and some other methods of predictive analytics are quite sophisticated, this category of analytics tends to be more advanced than the first one (descriptive analytics).

*Prescriptive analytics* uses powerful techniques drawn mainly from management science to prescribe what should be done in the future.

*Prescriptive analytics* is the final (and most advanced) category of analytics. It involves applying decision models to the data to prescribe what should be done in the future. The powerful techniques of *management science* described in many of the chapters of this book (including a wide variety of decision models for finding optimal solutions) commonly are used here. The purpose is to guide managerial decision making, so the name *decision analytics* also could be used to describe this category.



Having introduced some of the basic traditional terminologies of business analytics (descriptive, predictive, and prescriptive analytics), we should point out that the terminology in this young field continues to change at a rapid pace due to innovation and lots of market activity. For example, business analytics is sometimes referred to as *data science* (see below), as well as *data analytics* or *decision analytics.* (*Business intelligence* also is a traditional name for descriptive and predictive analytics.) Additional changes in terminology probably lie ahead.

## The Role of Data Science

Business analytics is sometimes referred to as **data science** because it focuses so much on the science of transforming data into useful insights. However, in fact, business analytics and data science are two distinct, albeit closely related, disciplines. Recall that business analytics was defined at the beginning of this section as the art and the science of transforming data into insight for making better business decisions. Note that the definition of data science below is quite different.

### data science

An interdisciplinary field that uses scientific methods, processes, algorithms, and systems to extract knowledge or insights from even massive amounts of data in various forms.

**Data science** is an interdisciplinary field that uses scientific methods, processes, algorithms, and systems to extract knowledge or insights from even massive amounts of data in various forms.

Although business analytics also is interdisciplinary and uses scientific methods, the important differences in these definitions are that data science is more interdisciplinary, more based on scientific methods, more applicable to various areas in addition to business, and more concerned with how to deal with even massive amounts of data in various forms.

Numerous universities now offer degree programs in either business analytics or data science (or both). There are distinct differences between these two types of programs. The business analytics programs normally are offered in business schools (typically at the master's level) because the focus is on the analysis of mostly structured business data to make key *business* decisions. The data science programs often are in STEM departments and go deeper into the foundational areas such as statistics, computer science, and relevant technologies (such as the two introduced in the next two subsections). This interdisciplinary approach enables applications in a variety of areas rather than just mainly business applications.

Data science is based on a strong background in statistics, computer science, and relevant technologies.

Because of its emphasis on the application of science to the analysis of data, highly trained practitioners of data science frequently are given the title of **data scientists.** Specialists in business analytics occasionally have earned this title, but less often since their emphasis is more on using a deep understanding of business administration to make strategic business decisions. However, business analytics teams often will include at least one data scientist on the team. Although business analysts have a good background in mathematics, statistics, and computer science, the stronger background of a data scientist in these areas frequently can be helpful for a business

analytics team. A stronger background in computer technology also can be helpful when the team wants to apply either of the powerful human-like technologies described below.

### data scientist

A common title given to highly trained practitioners of data science or business analytics who mainly focus on the application of science to the analysis of data.

## The Role of Machine Learning

Computers now are so powerful that they can process enormous amounts of information and calculations in seconds that would be far beyond the capacity of any human being. This gives computer systems (the “machine”) the ability to automatically “learn” from the patterns in the data and thereby do such things as progressively improve performance on a specific task.

The goal of **machine learning** is to allow computers to learn automatically from historical relationships and trends in the data in order to do such things as making data-driven predictions.

### machine learning

A technology that allows computers to learn automatically from historical relationships and trends in the data in order to do such things as making data-driven predictions.

A few of the applications of machine learning include self-driving cars, practical speech recognition, effective web search, image recognition, medical diagnosis, and a vastly improved understanding of the human genome.

To illustrate the machine learning process, consider the case of how specially trained physicians (radiologists) use *pattern recognition* to diagnose a specific disease. They read images from routine x-rays, computed tomography, MRI, ultrasound, and other imaging modalities. This is done only after several years of training in a radiology

residency, plus perhaps additional training in a subspeciality. Progress now is being made with using machine learning to assist radiologists with performing this pattern recognition. This involves approximating the training process of human radiologists by creating a digital “neural net” which can learn to recognize patterns by being fed with huge numbers of training images accompanied by the “correct answer.” The resulting computer application then provides the radiologist with a “second opinion” to help improve the diagnosis (the prediction regarding a specific disease).

What does this radiology example have to do with business analytics? Nothing directly, but a great deal indirectly. Business analytics frequently is involved with using pattern recognition in other contexts. Some examples include looking for patterns in financial histories to detect fraud, looking for patterns in e-mail messages to detect spam, or looking for patterns in the buying behavior of past customers to make additional purchase recommendations to a new customer. (You will see a variety of similar applications of predictive analytics in Chapter 3.)

Machine learning is a popular method for applying predictive analytics by performing pattern recognition.

## The Role of Artificial Intelligence

Although the term artificial intelligence (AI) was first coined way back in 1956, the big buzz about AI came early in the 21st century and is continuing to grow. There were some important breakthroughs in image recognition in the early 2010s and advances in natural language processing came a little later. Exciting research continues, but we still have a long way to go to fully realize the goal of artificial intelligence.

> The goal of **artificial intelligence (AI)** is to build intelligent computer programs and machines that can simulate human thinking capability and behavior.

### artificial intelligence

The goal of artificial intelligence is to build intelligent computer programs and machines that can simulate human thinking capability and behavior.

However, one famous example of artificial intelligence dates back to before the turn of the century. In 1997, a computer called Deep Blue was able to apply artificial intelligence to defeat the world champion chess player (Garry Kasparov) in a match consisting of six chess games. Deep Blue could generate and evaluate about 200 million chess positions per second. Therefore, it was able to look ahead a considerable number of moves to evaluate various combinations of moves by itself and its competitor. Chess players do this all the time, but even Chess Grandmasters cannot do this as well as Deep Blue. Therefore, Deep Blue was simulating human thinking capability and behavior, but doing this more effectively than a world champion because of the power of AI.

Machine learning (ML) and artificial intelligence (AI) are closely related technologies. The terms often are used interchangeably, but ML actually is just one important part of AI. Because its focus is on automatically learning from historical relationships and trends in the data, ML provides an ideal platform for performing AI. The difficult part then is taking the next step to use this platform to truly simulate human thinking capability and behavior.

Machine learning provides an ideal platform for performing artificial intelligence.

Some practitioners (including many consultants) now use AI as a broad umbrella term that encompasses management science, operations research, analytics, machine learning, and so forth. However, the algorithms being used generally have been developed based on human intelligence rather than artificial intelligence. The full promise of AI should gradually come later.

## Review *Questions*

What are some quantitative decision sciences that are drawn upon by business analytics?

What is meant by *the era of big data* and what role did it play in the origin of business analytics?

What does *descriptive analytics* involve doing?

What does *predictive analytics* involve doing?

What does *prescriptive analytics* involve doing?

What is data science and how does it differ from business analytics?

What is machine learning and how does it relate to business analytics?

What is artificial intelligence and how does it relate to machine learning?

## 1.3 THE RELATIONSHIP BETWEEN MANAGEMENT SCIENCE AND BUSINESS ANALYTICS

Section 1.1 has introduced the discipline of *management science* and Section 1.2 has done the same for *business ana*lytics. They have many similarities. Both disciplines use data and quantitative factors to perform sophisticated analyses that aim to aid managerial decision making. These are overlapping disciplines that complement each other extremely well.



### An Application Vignette

The **Intel Corporation** is an American multinational technology company headquartered in Silicon Valley. It is the world's largest semiconductor chip manufacturer by revenue. It ranked No. 45 in the 2020 *Fortune* 500 list of the largest U.S. corporations with a revenue of nearly $78 billion. Its integrated circuits have been a driving force of the information revolution for over 50 years. More recently, Intel-driven computers have enabled the advent of cloud computing, big data, and the practical resurgence of artificial