Operations and Supply Chain Management

Seventeenth edition

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Mc Graw Hill

OPERATIONS AND SUPPLY CHAIN MANAGEMENT, SEVENTEENTH EDITION

Published by McGraw Hill LLC, 1325 Avenue of the Americas, New York, NY 10019.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 LWI 28 27 26 25 24 23

ISBN 978-1-265-07127-1 (bound edition)
MHID 1-265-07127-6 (bound edition)
ISBN 978-1-266-46040-1 (loose-leaf edition)
MHID 1-266-46040-3 (loose-leaf edition)

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Cover Image: *greenbutterfly/Shutterstock*
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Library of Congress Cataloging-in-Publication Data

CIP data has been applied for.

mheducation.com/highered

To my wife, Rhonda, and our children Jenny, Suzy, and Jess

To my wife, Harriet, and to our children
Laurie, Andy, Glenn, Robb, and Christine

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PREFACE

Operations and supply chain management (OSCM) is a key element in the improvement in productivity in business around the world. Establishing a *competitive advantage* through operations requires an understanding of how the operations and supply chain functions contribute to productivity growth. However, our intent in this book is to do more than just show you what companies are doing to create a competitive advantage in the marketplace by conveying to you a set of skills and tools that you can actually apply.

Hot topics in business today that relate to operations and supply chain management are mitigating the risk of disruptions while reducing the cost of supply chain processes, integration and collaboration with customers and suppliers, sustainability and minimizing the long-term cost of products and processes. These topics are studied in the book with up-to-date, high-level managerial material to clarify the "big picture" of what these topics are and why they are so important to business today.

A significant feature of this book is the organization of each chapter by concise learning objectives. Each objective relates to a block of knowledge that should be studied as a unit. The objectives are carried through the end-of-chapter material that includes Concept Connections, Discussion Questions, Objective Questions, and a Practice Exam. The material is organized to ease understanding of each topic.

Success in OSCM requires a data-driven view of a firm's business. Every chapter in the book has *analytic* content that ties decisions to relevant data. Mathematical models are used to structure the data for making decisions. Given the facts that are supported by data, success in OSCM requires using a *strategy* that is consistent with the operations-related priorities of a firm. Different approaches can often be used, and usually trade-offs related to cost and other flexibility-related criteria exist. Strategies are implemented through *processes* that define exactly how things are done. Processes are executed over and over again as the firm conducts business, so they must be designed to operate efficiently to minimize cost while meeting quality-related standards. Great managers are analytic in their approach to decision making; they understand and select the appropriate strategy, and then execute the strategy through great processes. We develop this pattern throughout the topics in this book.

The reality of global customers, global suppliers, and global supply chains has made the global firm recognize the importance of being both lean and green to ensure competitiveness. Applications that range from high-tech manufacturing to high-touch service are used in the balanced treatment of the traditional topics of the field. Success for companies today requires successfully managing the entire supply flow, from the sources of the firm, through the value-added process of the firm, and on to the customers of the firm.

Each chapter includes information about how operations and supply chain–related problems are solved. There are concise treatments of the many decisions that need to be made in designing, planning, and managing the operations of a business. Many spreadsheets are available from the book website to help clarify how these problems are quickly solved.

OSCM should appeal to individuals who want to be directly involved in making products or providing services. The entry-level operations specialist is the person who determines how best to design, supply, and run the processes. Senior operations managers are responsible for setting the strategic direction of the company from an operations and supply chain standpoint, deciding what technologies should be used and where facilities should be located, purchasing the resources needed, and managing the facilities that make the products or provide the services. OSCM is an interesting mix of managing people and applying sophisticated technology. The goal is to efficiently create wealth by supplying quality goods and services.

Features to aid in your understanding of the material include the following:

- Chapter supplements provide additional material for students that relate to the chapter. In some cases analytical tools are discussed, such as financial present value analysis and linear programming. In other cases, specialized applications such as health care and consulting are discussed.
- OSCM at Work boxes provide short overviews of how leading-edge companies are applying OSCM concepts today.
- Solved problems at the end of chapters serve as models that can be reviewed prior to attempting problems.
- The Concept Connections section in each chapter summarizes the concepts in each learning objective, has definitions of the key terms, and lists the equations where appropriate.
- Discussion questions are designed to review concepts and show their applicability in real-world settings. These are included in each chapter and organized by learning objectives.
- Objective questions at the end of chapters cover each concept and problem. These are organized by the chapter learning objectives.
- Practice exam questions at the end of each chapter are special questions designed to require a deeper understanding of the material in the chapter. They are similar to the type of short-answer questions that might be given on a test.
- Answers to selected problems are in Appendix E.
- The seventeenth edition is supported by a wealth of content in McGraw-Hill's Connect homework management system, including the adaptive SmartBook eBook, assignable and autogradable problems and exercises from the text, autogradable Interactive Excel exercises, Test Bank questions, and concept videos. Instructors can access additional resources through the Connect library, including PowerPoint slide outlines of each chapter, Excel spreadsheets for the solved problems and other examples, practice quizzes, Excel tutorials and Step-by-Step Example videos, Internet links, and video segments that illustrate the application of operations concepts in companies such as Apple, Amazon, Tesla, Honda, Disney, Ford, and many others. Additional student resources are also available in Connect.

Our aim is to cover the latest and the most important issues facing OSCM managers, as well as basic tools and techniques. We supply many examples of leading-edge companies and practices and have done our best to make the book an interesting read and give you a competitive advantage in your career.

We hope you enjoy it.

Plan of the Book

This book is about methods to effectively produce and distribute the goods and services sold by a company. To develop a better understanding of the field, this book is organized into four major sections: Strategy, Products, and Capacity; Manufacturing and Service Processes; Supply Chain Processes; and Supply and Demand Planning and Control. In the following paragraphs, we quickly describe the major topics in the book.

Strategy and sustainability are important and recurring topics in the book. Any company must have a comprehensive business plan that is supported by a marketing strategy, operations strategy, and financial strategy. It is essential for a company to ensure that the three strategies support each other. Strategy is covered from a high-level view in Chapter 2 (Strategy), and more details that relate to economies of scale and learning are covered in Strategic Capacity Management (Chapter 5), and Learning Curves (Chapter 6). Because the company strategy must be supported financially, financial tools that are commonly used are reviewed in the supplement to Chapter 5 (Investment Analysis).

The lifeline of the company is a steady stream of innovative products that are offered to the marketplace at the lowest cost possible. Design of Products and Services (Chapter 3) includes a view of how products are designed in the context of having to actually produce and distribute the product over its life cycle. The chapter includes material on how to manage and analyze the economic impact of a stream of products that are developed over time. Projects (Chapter 4) are used to implement change in a firm, be it a change in strategy, a new product introduction, or a new process.

The second section of the book, titled Manufacturing and Service Processes, focuses on the design of internal processes. Chapters 7 and 9 cover the unique characteristics of production and service processes. The supplement to Chapter 9 discusses health care services, an industry of interest to many students taking the course. Important technical material that relates to design activities is covered in Chapters 8 (Facility Layout) and 10 (Waiting Line Analysis and Simulation).

Chapter 11, Process Design and Analysis, is a nuts-and-bolts chapter on process flow charting and static process analysis using some easily understood real-life examples. The supplement to Chapter 11 discusses how these techniques are used in consulting businesses, another industry of interest to many students taking the course.

An essential element of process design is quality. Quality Management is the topic of Chapter 12. Here we cover total quality management concepts, quality analysis tools, and ISO 9000 and 14000. Technical details covering all the statistical aspects of quality are in Chapter 13 (Statistical Quality Control).

The third section of the book, titled Supply Chain Processes, expands our focus to the entire distribution system from the sourcing of material and other resources to the distribution of products and services. We discuss the concepts behind lean manufacturing and just-in-time processes in Chapter 14. These are ideas used by companies throughout the world and are key drivers for efficient and quick-responding supply systems. Many different transformation processes are needed to put together a supply chain. There are critical decisions such as: Where should we locate our facility? What equipment should we buy or lease? Should we outsource work or do it in-house? These are the topics of Chapters 15 and 16 that relate to logistics, distribution, location of facilities, sourcing, and procurement. All of these decisions have a direct financial impact on the firm.

Section Four, titled Supply and Demand Planning and Control, covers the techniques required to actually run the system. This is at the heart of OSCM. The Internet of Things (Chapter 17) is a term used to describe the connection of intelligent devices through the Internet. This technology combined with the use of enterprise resource planning systems has rapidly changed the way business is done today. The basic building blocks are Forecasting (Chapter 18), Sales and Operations Planning (Chapter 19), Inventory Management (Chapter 20), Material Requirements Planning (Chapter 21), and Workcenter Scheduling (Chapter 22). These daily processes are often partially automated with computer information systems.

Making fact-based decisions is what OSCM is all about, so this book features extensive coverage of decision-making approaches and tools. One useful way to categorize decisions is by the length of the planning horizon, or the period of time that the decision maker must consider. For example, building a new plant would be a long-term decision that a firm would need to be happy with for 10 to 15 years into the future. At the other extreme, a decision about how much inventory for a particular item should be ordered for tomorrow typically has a much shorter planning horizon of a few months or, in many cases, only a few days. Such short-term decisions are usually automated using computer programs. In the intermediate term are decisions that a company needs to live with for only 3 to 12 months. Often these decisions correspond to yearly model changes and seasonal business cycles.

As you can see from this discussion, this material is all interrelated. A company's strategy dictates how operations are designed. The design of the operation dictates how it needs to be managed. Finally, because businesses are constantly being presented with new opportunities through new markets, products, and technologies, a business needs to be very good at managing change.

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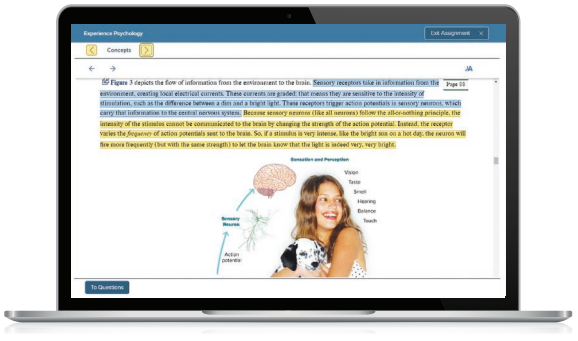

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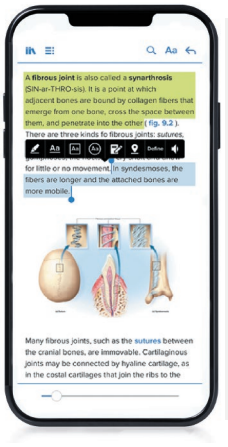

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"I really liked this app—it made it easy to study when you don't have your textbook in front of you."

- Jordan Cunningham,
  Eastern Washington University

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ACKNOWLEDGMENTS

Many very talented scholars have made major contributions to specific chapters in this edition of the book. We are pleased to thank the following individuals:

Ronny Richardson of Kennesaw State University and Emily Bello of University of Louisville, who spent countless hours checking problems and improving Connect.

Supplements are a great deal of work to write, and we appreciate the efforts that make teaching the course easier for everyone who uses the text. Emily Bello of University of Louisville updated the test bank and created the Connect guided examples. Ronny Richardson of Kennesaw State University updated the PowerPoint decks.

We also want to thank the following individuals for their thoughtful reviews of the previous edition and their suggestions for this text: Dr. Richard Dawe, Golden Gate University; Robert G. Stoll, Ashland University; Janaina Siegler, Butler University; Jennifer Flanagan, Texas Woman's University; Drew Stapleton, University of Wisconsin La Crosse; Henry Aigbedo, Oakland University; Olga Pak, Penn State University; Iddrisu Awudu, Quinnipiac University; Art Hudson, Villanova University; Vinay Gonela, Texas A&M University; Stanislaus Solomon, Southern Illinois University Edwardsville; Kaan Kuzu, University of Wisconsin Milwaukee; Ana L. Rosado Feger, Ohio University; Jeffrey D. Vondy, University of Mary; Jan Zantinga, University of Georgia; Dr. Cristiane Biazzin, Northern Kentucky University; Dr. Balaji Janamanchi, Texas A&M International University; Robert Myers, Georgia Tech University; Steve Lundregan, Ohio State University; Mark Hanna, Georgia Southern University.

Thanks to the McGraw-Hill Education team who make this possible—Rebecca Olson, Director; Eric Weber, Portfolio Manager; Harper Christopher, Executive Marketing Manager; Eva Lopez, Product Developer; Sherry Kane, Content Project Manager; George Theofanopoulos, Assessment Project Manager; and Egzon Shaqiri, Senior Designer. Also, thanks to Gary Black for keeping Connect current.

Finally, I want to thank my past coauthors Dick Chase and Nick Aquilano for giving me the opportunity to work with them on their book for the past 25 years. I had the opportunity to work with Nick Aquilano on two editions of the book and with Dick Chase on six editions. They have been an inspiration to me and wonderful colleagues.

F. Robert Jacobs

NOTE TO INSTRUCTORS

Discussion of Seventeenth Edition Revisions

The revisions to the seventeenth edition are a reflection of how the field is changing and an intent to make the material relevant to students. Each chapter is organized around a short set of learning objectives. These learning objectives define the major sections of each chapter. A complete set of Discussion Questions together with Objective Questions, which include concepts and problems, are included.

The many questions now included in each chapter are all available for use in Connect, the automated assignment grading system available to adopters of the book. In addition, Interactive Excel exercises are now available in Connect.

Much work has been put into Connect to make it an easy to use and reliable tool. The Objective Question problems are available and many have both static versions (these are identical to the problem in the book) and scenario versions. In the scenario versions of the problem, the parameters have been changed, but the problem is essentially the same, thus allowing students to see different examples of the same problem. The instructor can select predefined or set up custom problem sets that students can complete. These are automatically graded with the results available in a spreadsheet that can be easily downloaded by the instructor. There are many options for how these problem sets can be used, such as allowing the students multiple tries, giving the students help, and timed exams.

In this edition, we have continued to focus on supply chain analytics, while featuring material on more specialized applications such as health care, consulting, investment analysis, and optimization. Supply chain analytics involve the analysis of data to better solve business problems. We recognize that this is not really a new concept because data have always been used to solve business problems. But what is new is the reality that there are so much more data now available for decision making.

In the past, most analysis involved the generation of standard and ad hoc reports that summarized the current state of the firm. Software allowed query and "drill down" analysis to the level of the individual transaction, useful features for understanding what happened in the past. Decision making was typically left to the decision makers, based on their judgment or simply because they were aware of the rules. The new "analytics" movement takes this to a new level using statistical analysis, forecasting to extrapolate what to expect in the future, and even optimization, possibly in real time, to support decisions.

In this edition, our goal is to capture this spirit of using integrated analytic and strategic criteria in making operations and supply chain decisions. We have done this in two major ways. First, we have organized the material in the book by integrating the strategic and analytic material. Next, we have added 4 new Analytics Exercises (we now have 15 in total) spread throughout the chapters. In this edition, many small changes designed to increase clarity, simplify assumptions, and make the exercises better learning tools have been made.

These Analytics Exercises use settings that are modern and familiar to students taking the course. They include Starbucks, cell phones, notebook computers, a wholesale tree farm company, Taco Bell Restaurant, Toyota, a retail website-based company, and industrial products that are sourced from China/Taiwan and sold globally. The book has been reorganized into four major sections: Strategy, Products, and Capacity; Manufacturing and Service Processes; Supply Chain Processes; and Supply and Demand Planning and Control. Our strategy is to weave analytics into the managerial material so students see the important role of data analysis in making operations and supply chain management decisions.

In the first section, Strategy, Products, and Capacity, our chapters cover Strategy, Design of Products and Services, Projects, Strategic Capacity Management, Investment Analysis, and Learning Curves. The key themes of operations strategy, product design to support the strategy, and strategic capacity are a good foundation for learning about operations and supply chain management. Because most strategic plans are implemented using projects, we include this topic in the first section as well. In the projects chapter, we introduce a good amount of

material on product design through examples and exercises, emphasizing the strategic importance of these projects to the success of the firm.

The second section, Manufacturing and Service Processes, gets into the nuts and bolts of operations management. The section introduces the ways manufacturing and service systems are organized. The Quality Management and Statistical Quality Control chapters cover topics that would be appropriate for a green-belt program and include good coverage of the popular value-stream mapping technique.

The third section, Supply Chain Processes, discusses processes that source material for internal operations and then distribute products to the customers. The analytic models involved with location/transportation are included here. The topics are tied together in the Lean Supply Chain chapter, which now stresses the cost versus disruption risk trade-offs that are involved in such tactics as single sourcing and just-in-time inventory.

The fourth section, Supply and Demand Planning and Control, covers the techniques typically implemented in Enterprise Resource Planning Systems. These include Forecasting, Sales and Operations Planning, Inventory Management, Material Requirements Planning, and Workcenter Scheduling. We also include supplements on Linear Programming Using the Excel Solver and the Theory of Constraints, a set of thought-provoking concepts.

The following is a list of the major revisions in selected chapters:

- *Chapter 1 Introduction*—The initial example was changed and now relates to making three types of jeans using a combination of domestic and global suppliers. Insight from the impact of supply chain disruptions has been added to current OSCM issues. The Analytics Exercise using efficiency measures was updated, and it is now easier to obtain the comparison data.
- *Chapter 2 Strategy*—The opening vignette now features Moderna, the innovative COVID-19 vaccine provider. The Activity-System-Map was updated. The section on risk was rewritten to reflect current thought. The new Analytics Exercise "Carbon Footprint Quiz," was added. This is an exercise requiring CO_2 emissions calculations.
- *Chapter 3 Design of Products and Services*—A new opening vignette that features the All-Electric Chevy Silverado RST pickup truck was written for this chapter. There are also many updates to examples in the chapter.
- *Chapter 4 Projects*—The new opening vignette features Starlink, the innovative Elon Musk project that provides broadband Internet using a constellation of satellites in low-Earth orbit. Many other edits were made to the chapter to clarify notation.
- *Chapter 5 Strategic Capacity Management*—The opening vignette featuring the Tesla Model 3 was updated. Objective Question 9 was updated to make it easier to understand. The Shouldice Hospital case was updated.
- *Chapter 5S Investment Analysis*—Only minor changes were made.
- *Chapter 6 Learning Curves*—A new Tesla's Model 3 Learning Curve Analytics Exercise was added. New material was added to the chapter showing how to fit a power function to historical production data to obtain learning curve parameters using Excel. The new Analytics Exercise uses the technique.
- *Chapter 7 Manufacturing Processes*—A new AI Manufacturing Technology opening vignette was written. The vignette discusses the use of vision technology for monitoring manufacturing processes.
- *Chapter 7S Manufacturing Technology*—Only minor changes were made.
- *Chapter 8 Facility Layout*—The pictures were changed to better correspond to the different types of layouts described in the chapter. Objective Question 8 was updated to clarify what is meant by *rectilinearly*.
- *Chapter 9 Service Processes*—A new opening vignette featuring Orlando Universal Studios was added. Material on platform services was updated, and many other changes were made to better reflect the impact the Internet has had on services.
- *Chapter 9S Health Care*—Changes were made to the capacity metrics to reflect what is currently used by health care providers.

- *Chapter 10 Waiting Line Analysis and Simulation*—Objective Question 18 was updated to make it clearer.
- *Chapter 11 Process Design and Analysis*—When Little's Law is appropriate for use was clarified. The Runner Edge case was rewritten to remove reference to queuing models.
- *Chapter 11S Operations Consulting*—This was updated to focus on Operating Consulting. Terminology was updated to remove *reengineering.* Other updates reflect current companies.
- *Chapter 12 Quality Management*—The title of the chapter to better reflect current thought. The Baldrige Award criteria were revised, and Tesla's Quality Challenge case was updated to reflect new global activity of the company.
- *Chapter 13 Statistical Quality Control*—Terminology in the opening vignette was revised to reduce confusion. The standard deviation formula was fixed, the solution to Solved Problem 3 was rewritten, and previous edition Objective Questions 11 and 12 were deleted.
- *Chapter 14 Lean Supply Chains*—The opening vignette on the hazards of lean manufacturing practices learned during the COVID-19 Pandemic is new. The term *muda* as often used to refer to elimination of waste in supply chains was added, and the Value Stream Mapping presentation was updated.
- *Chapter 15 Logistics and Distribution Management*—The name of chapter was changed to better reflect the topics in it, and the section on Distribution Facilities was rewritten to reflect refinements in the use of the terms *warehouse, distribution center,* and *fulfillment center.* Two OSCM at Work boxes were added; one describes Amazon's supply chain, and the other features self-driving truck technology.
- *Chapter 16 Global Sourcing and Procurement*—The new opening vignette How the COVID-19 Pandemic Led to Empty Shelves introduces the bullwhip effect in the context of shortages in toilet paper. The new OSCM at Work box titled SpaceX—Orbit Freight Carrier was included. The impact of reusable rockets on the ability to place satellites in Earth orbit is described. Examples in the chapter were also updated.
- *Chapter 17 The Internet of Things and ERP*—A new opening vignette titled The World of Connected Assets was added.
- *Chapter 18 Forecasting*—The Starbucks opening vignette was updated. A new OSCM at Work that describes the use of Artificial Intelligence (AI) in Demand Forecasting was added. Finally, the new Analytics Exercise Forecasting Demand at Sebastian River Farms uses regression to find a trend line. It then moves to the calculation of multiplicative season indexes to forecast future demand.
- *Chapter 19 Sales and Operations Planning*—The costs in the examples were updated to better reflect current values. The name of Bradford Manufacturing in the Analytics Exercise was changed, and the data in it were updated.
- *Chapter 19S Linear Programming Using the Excel Solver*—Only minor edits were made.
- *Chapter 20 Inventory Management*—The new Analytics Exercise Inventory Control at Sebastian River Farms was added. The exercise involves setting reorder points and tree-planting decisions at a tree farm.
- *Chapter 21 Material Requirements Planning*—The description of MRP and the Least Unit Cost section were updated.
- *Chapter 22 Workcenter Scheduling*—The new opening vignette that describes the scheduling of Major League Baseball teams was added.
- *Chapter 22S Theory of Constraints*—The five-step focusing process for bank loans was updated.

F. Robert Jacobs
June 2022

Walkthrough

The following section highlights the key features developed to provide you with the best overall text available. We hope these features give you maximum support to learn, understand, and apply operations concepts.

Chapter Opener

Facility Layout 8

Learning Objectives

LO8-1 Analyze the common types of manufacturing layouts.
LO8-2 Illustrate layouts used in nonmanufacturing settings.

Amazon Go—The Cashierless Grocery Store

The Amazon Go stores are built around a new technology so you can walk in the store, take what ever you want from the shelves, and then just walk out. You are automatically charged for whatever you took.

Amazon envisions all types of Go stores: grocery stores where you get some food items, lunchtime spots that sell prepared foods like sandwiches and salads, or stores that sell refrigerated food kits with different ingredients for cooking a full meal.

The new stores are loaded with technology, with hundreds of sensors and cameras monitoring everything the customer does. The normal retail store pay areas with checkout stands and cashiers are not needed in a Go store. The stores rely on image recognition software and artificial intelligence to make the magic happen. Amazon has developed a proprietary code that uses circles and diamonds to identify things in the stores. They use weight sensors to know when something has been removed or placed back on a shelf.

On leaving the store, the customer is given a precise list of what was bought. Think of the data that Amazon collects about each customer. They know precisely the path you took through the store, what products you picked up and considered, and exactly how much time you spent in the store. This data can be used to improve the selection offered in the store and optimize the layout of shopping areas.

The Amazon Go storefront
Rocky Grimes/Shutterstock

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Opening Vignettes

Each chapter opens with a short vignette to set the stage and help pique students' interest in the material about to be studied. A few examples include

- Tesla, Chapter 5
- Disney, Chapter 12
- Amazon, Chapter 20

From Bean to Cup: Starbucks Global Supply Chain Challenge

Starbucks Corporation is the largest coffeehouse company in the world, with over 34,000 stores in more than 84 countries. The company serves over 140 million customers each week.

Forecasting demand for a Starbucks is an amazing challenge. The product line goes well beyond drip-brewed coffee sold on demand in the stores. It includes espresso-based hot drinks, other hot and cold drinks, coffee beans, salads, hot and cold sandwiches and paninis, pastries, snacks, and items such as mugs and tumblers. Many of the company's products are seasonal or specific to the locality of the store. Starbucks-branded ice cream and coffee are also offered at grocery stores around the world.

The creation of a single, global logistics system was important for Starbucks because of its far-flung supply chain. The company generally brings coffee beans from Latin America, Africa, and Asia to the United States and Europe in ocean containers. From the port of entry, the "green" (unroasted) beans are trucked to storage sites, either at a roasting plant or nearby. After the beans are roasted and packaged, the finished product is trucked to regional distribution centers, which range from 200,000 to 300,000 square feet in size. Coffee, however, is only one of the many products held at these distribution centers. They also handle other items required by Starbucks retail outlets, everything from furniture to cappuccino mix.

In the first Analytics Exercise at the end of the chapter, we consider the challenging demand forecasting problem that Starbucks must solve to successfully run this complex supply chain.

Starbucks Coffee in Bur Juman Center Shopping Mall, Dubai, United Arab Emirates.
Atlantide Phototravel/Getty Images

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OSCM at Work—SpaceX—Orbit Freight Carrier

Elon Musk, the innovative billionaire who popularized the idea of the electric vehicle with Tesla Motors, recently announced the prices SpaceX charges to move satellites into orbit. Companies that operate communications satellites in orbit need to figure out some way to get these gadgets into space. In the early days, these companies hitched rides on NASA rockets, the Space Shuttle, and other government vehicles. Today there are more options including rockets launched by countries and private companies.

SpaceX has made the idea of putting a satellite into orbit much like sending a load of merchandise across the country in a truck. The company has two reusable vehicles, the Falcon 9 and the Falcon Heavy, each of which can carry many satellites into space on a single launch. There is now a price tag on carrying items into space, much as there is a price to ship goods on a truck across the country. Of course, it is a little more expensive. A slot on a Falcon 9 was listed as starting at $1.1 million. A whole Falcon 9 can be reserved for $67 million, and the larger Falcon Heavy goes for $97 million—an amazing bargain compared to options available in the past.

Joseph Marino/Alamy Stock Photo

It will be interesting to track what SpaceX, led by Elon Musk, does in the future with the new Starship that is being developed. To give some perspective, the Falcon 9 carries 22,800 kgs in space, the Falcon Heavy carries 63,800 kgs, and the Starship will carry over 100,000 kgs. It is estimated that the Starship also can carry 100 people into space at a time.

OSCM at Work Boxes

The boxes provide examples or expansions of the topics presented by highlighting leading companies practicing new, breakthrough ways to run their operations. Examples include:

- "Inspire the World, Create the Future," Chapter 3
- Animation and Simulation Software, Chapter 10
- Malcom Baldrige National Quality Award, Chapter 12
- Open Information Warehouse, Chapter 17

Key Ideas

Important points in the text are called out and summarized in the margins.

KEY IDEA

Companies are positioned in different places in the supply chain. Within the context of their position, they all require planning, sourcing, making, delivering, and returning processes.

Solved Problems

Representative problems are placed at the end of appropriate chapters. Each includes a worked-out solution, giving students a review before solving problems on their own.

Solved Problems

LO10–2 **SOLVED PROBLEM 1**

Quick Lube Inc. operates a fast lube and oil change garage. On a typical day, customers arrive at the rate of three per hour and lube jobs are performed at an average rate of one every 15 minutes. The mechanics operate as a team on one car at a time.

Assuming Poisson arrivals and exponential service, find

a. Utilization of the lube team.
b. The average number of cars in line.
c. The average time a car waits before it is lubed.
d. The total time it takes to go through the system (that is, waiting in line plus lube time).

Solution

$\lambda = 3, \mu = 4$

a. Utilization $\rho = \frac{\lambda}{\mu} = \frac{3}{4} = 75\%$.

b. $L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{3^2}{4(4-3)} = \frac{9}{4} = 2.25$ cars in line.

c. $W_q = \frac{L_q}{\lambda} = \frac{2.25}{3} = 0.75$ hour, or 45 minutes.

d. $W_s = \frac{L_s}{\lambda} = \frac{\lambda}{\mu - \lambda} \Big/ \lambda = \frac{3}{4-3} \Big/ 3 = 1$ hour (waiting + lube).

Concept Connections

The Concept Connections grid appears at the end of every chapter. This tool draws students' attention to the main points, key terms, and formulas for each learning objective. The organization of the Concept Connections gives students a quick and effective reference when applying the chapter content.

Concept Connections

LO10-1 Understand what a waiting line problem is.

Summary

- The study of waiting in line is the essence of this problem. Queuing theory is the mathematical analysis of the waiting line.
- A queuing (or waiting line) system is composed of three major parts: (1) the customers arriving to the system, (2) the servicing of the customers, and (3) how customers exit the system.
- Queuing theory assumes that customers arrive according to a Poisson arrival distribution and are served according to an exponential service time distribution. These are specific probability distributions that often match well with actual situations.

Key Terms

Queuing system A process where customers wait in line for service.

Arrival rate The expected number of customers that arrive each period.

Exponential distribution A probability distribution associated with the time between arrivals.

Poisson distribution Probability distribution for the number of arrivals during each time period.

Service rate The number of customers a server can handle during a given time period.

Practice Exams

The Practice Exams are designed to allow students to see how well they understand the material using a format that is similar to what they might see in an exam. This feature includes many straightforward review questions, but also has a selection that tests for mastery and integration/application level understanding, that is, the kind of questions that make an exam challenging. The practice exams include short answers at the bottom so students can see how well they have answered the questions.

Practice Exam

Answer the following questions. Answers are listed at the end of this section.

1. The queuing models assume that customers are served in what order?
2. Consider two identical queuing systems except for the service time distribution. In the first system, the service time is random and Poisson distributed. The service time is constant in the second system. How would the waiting time differ in the two systems?
3. What is the average utilization of the servers in a system that has three servers? On average, 15 customers arrive every 15 minutes. It takes a server exactly three minutes to wait on each customer.
4. What is the expected waiting time for the system described in question 3?
5. Firms that desire high service levels where customers have short wait times should target server utilization levels at no more than this percentage.
6. In most cases, if a firm increases its service capacity by 10 percent, it would expect waiting times to be reduced by what percentage? Assume customer arrivals and service times are random.
7. An ice cream stand has a single window and one employee to serve customers. During their busy season, 30 customers arrive each hour, on average. It takes 1.5 minutes, on average, to serve a customer. What is the utilization of the employee?
8. How long would customers have to wait in line, on average, at the ice cream shop discussed in question 7?
9. Random service times can be modeled by this.
10. A bank teller takes 2.4 minutes, on average, to serve a customer. What would be the hourly service rate used in the queuing formulas?
11. There are three teller windows in the bank described in the prior question. On average, 60 customers per hour arrive at the bank. What will be the average number of customers in line at the bank?

Answers to Practice Exam 1. First come, first served 2. Waiting time in the first system is two times the second. 3. 100% 4. Infinite 5. 70–80% 6. Greater than 10% 7. 75% 8. .075 hours, or 4.5 minutes 9. Exponential distribution 10. 25 customers per hour 11. 2.5888 (from Exhibit 10.9)