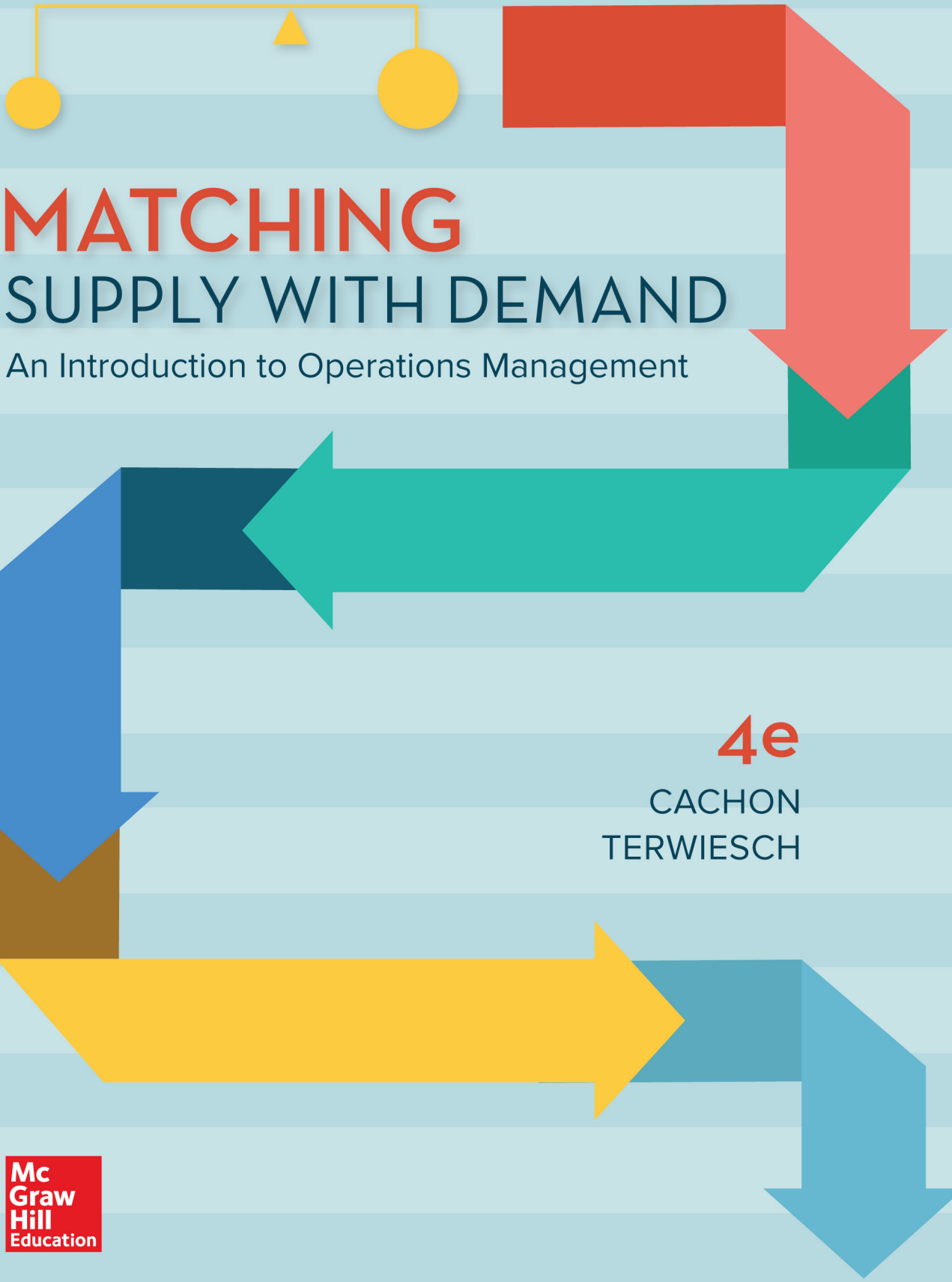

MATCHING SUPPLY WITH DEMAND

An Introduction to Operations Management

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Matching Supply with Demand

An Introduction to Operations Management

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Matching Supply with Demand

An Introduction to Operations Management

Fourth Edition

Gérard Cachon

The Wharton School, University of Pennsylvania

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To the teachers, colleagues, and professionals who shared with us their knowledge.

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Professor Cachon is the Fred R. Sullivan Professor of Operations, Information, and Decisons at The Wharton School of the University of Pennsylvania, where he teaches a variety of undergraduate, MBA, executive, and PhD courses in operations management. His research focuses on operations strategy, and in particular, on how operations are used to gain competitive advantage.

His administrative responsibilities have included Chair of the Operations, Information and Decisions Department, Vice Dean of Strategic Initiatives for the Wharton School, and President of the Manufacturing and Service Operations Society. He has been named an INFORMS Fellow and a Distinguished Fellow of the Manufacturing and Service Operations Society.

His articles have appeared in *Harvard Business Review, Management Science, Marketing Science, Manufacturing & Service Operations Management,* and *Operations Research.* He is the former editor-in-chief of *Manufacturing & Service Operations Management* and *Management Science.* He has consulted with a wide range of companies, including 4R Systems, Ahold, Americold, Campbell Soup, Gulfstream Aerospace, IBM, Medtronic, and O'Neill.

Before joining The Wharton School in July 2000, Professor Cachon was on the faculty at the Fuqua School of Business, Duke University. He received a PhD from The Wharton School in 1995.

He is an avid proponent of bicycle commuting (and other environmentally friendly modes of transportation). Along with his wife and four children he enjoys hiking, scuba diving, and photography.

Christian Terwiesch *The Wharton School, University of Pennsylvania*

Professor Terwiesch is the Andrew M. Heller Professor of Opertions, Information, and Decisions at the Wharton School of the University of Pennsylvania. He is also a Senior Fellow of the Leonard Davis Institute for Health Economics, a Co-Director of the Mack Institute of Innovation Management, and holds a faculty appointment in Penn's Perelman School of Medicine. His research on operations management, research and development, and innovation management appears in many of the leading academic journals, including *Management Science, Operations Research, Marketing Science,* and *Organization Science.* He has received numerous teaching awards for his courses in Wharton's MBA and executive education programs.

Professor Terwiesch has researched with and consulted for various organizations, including a project on concurrent engineering for BMW, supply chain management for Intel and Medtronic, and product customization for Dell. Most of his current work relates to health care and innovation management. In the health care arena, some of Professor Terwiesch's recent projects include the analysis of capacity allocation for cardiac surgery procedures at the University of California–San Francisco and at Penn Medicine, the impact of emergency room crowding on hospital capacity and revenues (also at Penn Medicine), and the usage of intensive care beds in the Children's Hospital of Philadelphia. In the innovation area, recent projects include the management of the clinical development portfolio at Merck, the development of open innovation systems, and the design of patient-centered care processes in the Veterans Administration hospital system.

Professor Terwiesch's latest book, *Innovation Tournaments,* outlines a novel, process-based approach to innovation management. The book was featured by *BusinessWeek,* the *Financial Times,* and the *Sloan Management Review.*

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Along with our students, we would like to thank our co-teachers in the core: Naren Agrawal, Krishnan Anand, Omar Besbes, Morris Cohen, Marshall Fisher, Richard Lai, Chris Lee, Pranab Majumder, Serguei Netessine, Kathy Pearson, Taylor Randall, Nicolas Reinecke, Daniel Snow, Stephan Spinler, Anita Tucker, Karl Ulrich, Senthil Veeraraghavan, and Yu-Sheng Zheng. In addition to useful pedagogical advice and quality testing, they shared many of their own practice problems and questions.

This book is not the first book in Operations Management, nor will it be the last. We hope we have incorporated the best practices of existing books while introducing our own innovations. The book by Anupindi et al. as well as the article by Harrison and Loch were very helpful to us, as they developed the process view of operations underlying Chapters 2 through 9. The book by Chase and Aquilano was especially useful for Chapter 7. We apply definitions and terminology from those sources whenever possible without sacrificing our guiding principles.

We also have received some indirect and direct assistance from faculty at other universities. Garrett van Ryzin's (Columbia) and Xavier de Groote's (INSEAD) inventory notes were influential in the writing of Chapters 2 and 16, and the revenue management note by Serguei Netessine (Wharton) and Rob Shumsky (Dartmouth) was the starting point for Chapter 18. The process analysis, queuing, and inventory notes and articles written by Martin Lariviere (Northwestern), Michael Harrison (Stanford), and Christoph Loch (INSEAD) were also influential in several of our chapters. Martin, being a particularly clever question designer, was kind enough to share many of his questions with us.

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The many cases and practical examples that illustrate the core concepts of this book reflect our extensive collaboration with several companies, including the University of Pennsylvania Hospital System in the Philadelphia region, the Circored plant in Trinidad, the Xootr factory in New Hampshire, the An-ser call center in Wisconsin, the operations group at O'Neill in California, and the supply chain group at Medtronic in Minnesota. We have benefited from countless visits and meetings with their management teams. We thank the people of these organizations, whose role it is to match supply and demand in the "real world," for sharing their knowledge, listening to our ideas, and challenging our models. Special thanks go to Jeff Salomon and his team (Interventional Radiology), Karl Ulrich (Xootr), Allan Fromm (An-ser), Cherry Chu and John Pope (O'Neill), and Frederic Marie and John Grossman (Medtronic). Allan Fromm deserves extra credit, as he was not only willing to share with us his extensive knowledge of service operations that he gathered as a CEO of a call center company but also proofread the entire manuscript and tackled most of the practice problems. Special thanks also to the McKinsey operations practice, in particular Stephen Doig, John Drew, and Nicolas Reinecke, for sharing their practical experience on Lean Operations and the Toyota Production System.

We especially thank our friend, colleague, and cycling partner Karl Ulrich, who has been involved in various aspects of the book, starting from its initial idea to the last details of the design process, including the cover design.

Through each edition of this text we have been supported by a fantastic team at McGraw Hill: Chuck Synovec, Noelle Bathurst, Tobi Philips, Harper Christopher, and Fran Simon.

Finally, we thank our family members, some of whom were surely unwilling reviewers who nevertheless performed their family obligation with a cheerful smile.

Gérard Cachon

Christian Terwiesch

Preface

This book represents our view of the essential body of knowledge for an introductory operations management course. It has been successfully used with all types of students, from freshmen taking an introductory course in operations management, to MBAs, to executive MBAs, and even PhD students.

Our guiding principle in the development of *Matching Supply with Demand* has been "real operations, real solutions." "Real operations" means that most of the chapters in this book are written from the perspective of a specific company so that the material in this text will come to life by discussing it in a real-world context. Companies and products are simply easier to remember than numbers and equations. We have chosen a wide variety of companies, small and large, representing services, manufacturing, and retailing alike. While obviously not fully representative, we believe that—taken together—these cases provide a realistic picture of operations management problems today.

"Real solutions" means that we do not want equations and models to merely provide students with mathematical gymnastics for the sake of an intellectual exercise. We feel that professional training, even in a rigorous academic setting, requires tools and strategies that students can implement in practice. We achieve this by demonstrating how to apply our models from start to finish in a realistic operational setting. Furthermore, we openly address the implementation challenges of each model/strategy we discuss so that students know what to expect when the "rubber hits the pavement."

To fully deliver on "real operations, real solutions," we also must adhere to the principle of "real simple." Do not worry; "real simple" does not mean plenty of "blah-blah" without any analytical rigor. Quite the contrary. To us, "real simple" means hard analysis that is made easy to learn. This is crucial for an operations text. Our objective is to teach business leaders, not tacticians. Thus, we need students to be able to quickly develop a foundation of formal models so that they have the time to explore the big picture, that is, how operations can be transformed to provide an organization with sustainable competitive advantage and/or superior customer service. Students who get bogged down in details, equations, and analysis are not fully capturing the valuable insights they will need in their future career.

So how do we strive for "real simple"? First, we recognize that not every student comes to this material with an engineering/math background. As a result, we tried to use as little mathematical notation as possible, to provide many real-world examples, and to adhere to consistent terminology and phrasing. Second, we provide various levels of detail for each analysis. For example, every little step in an analysis is described in the text via an explicit example; then a summary of the process is provided in a "how to" exhibit, a brief listing of key notation and equations is provided at the end of each chapter, and, finally, solved practice problems are offered to reinforce learning. While we do humbly recognize, given the quantitative sophistication of this text, that "much simpler" might be more accurate than "real simple," we nevertheless hope that students will be pleasantly surprised to discover that their analytical capabilities are even stronger than they imagined.

The initial version of *Matching Supply with Demand* made its debut in portions of the operations management core course at Wharton in the 2002–2003 academic year. This edition incorporates the feedback we have received over the last 16 years from many students, executives, and colleagues, both at Wharton and abroad.

Gérard Cachon

Christian Terwiesch

Changes to This Edition

The fourth edition has benefited from the comments and suggestions from students, faculty, and practitioners from around the world.

The implemented changes can be divided into three categories: an update of data and case examples, the addition of two chapters related to content that was not previously covered in the book, and an overall streamlining of the exposition of the existing content.

The world has changed again between this and the previous edition. Ride sharing, apartment sharing, and electric vehicles were not yet a thing "back then." Consequently, we have updated data and examples to try to maintain the timeliness of the content.

We have added two new chapters to this book. The first new chapter is about forecasting, which is an absolutely essential input to all operations models. The growth of available data only makes forecasting more relevant. The second new chapter is on scheduling. We covered scheduling in early texts, but not to the extent the topic deserves given our continued emphasis on service operations. Now we provide a dedicated and more extensive coverage of scheduling.

We have made a number of small changes that make the material easier for students to absorb. For example, we have streamlined the exposition of labor utilization calculations and we have de-emphasized the use of the expected loss function in the newsvendor and order-up-to models. Instead of the loss function, we provide the "expected inventory function," which allows students to arrive at the necessary answer with fewer steps. Furthermore, we find that students are able to intuitively grasp what the inventory function does better than the loss function.

Resources for Instructors and Students

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As described above, SmartBook provides a powerful tool to students for personalized instruction. Connect also provides access to other course supplements of interest to students. For the convenience of students, we also are providing the website www.mhhe.com/Cachon4e that will contain Case Materials and Excel files.

Brief Contents

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Chapter 1

Introduction

A central premise in economics is that prices adjust to match supply with demand: if there is excess demand, prices rise; if there is excess supply, prices fall. But while an economist may find comfort with this theory, managers in practice often do not. To them excess demand means lost revenue and excess supply means wasted resources. They fully understand that matching supply with demand is extremely difficult and requires more tools than just price adjustments.

Consider the following examples:

- In 2017, Tesla began shipping its very popular electric car, the Model 3. While they hoped to quickly achieve a production rate of 5,000 vehicles per week, they were far behind that goal. Meanwhile, well over 500,000 customers were waiting for their preordered car.
- In New York, taxi cab medallions, a regulatory requirement in most cities, once were traded for upwards of $1 million. With the emergence of new mobility services such as Uber and Lyft, these prices have plummeted. A reason for the success of these platforms is their flexibility to provide more driver capacity when and where needed.
- The city of Hamburg, Germany, completed the Elbphilharmonie, a world-class concert house with a spectacular design. Project management for this new musical venue was also spectacular, but for very different reasons. In 2005, the local government predicted construction costs to be 186 million euros and an opening of 2009. The final bill, however, was 789 million euros and it took until 2016 to complete the work.
- 30-year-old John Verrier entered an emergency department in the Bronx at 10 p.m. at night complaining about a rash. He was found dead over eight hours later, still stuck in the waiting room. Throughout the country, emergency room waiting times exceed two hours.
- GoPro launched a consumer drone, the Karma, with much fanfare. Unfortunately, only one month after launch, GoPro was forced to recall the drone because a dangerous malfunction could cause the drone to lose power and fall to the ground. GoPro was able to relaunch the Karma three months later, but missed the crucial holiday season due to the quality defect.

All of these cases have in common that they suffer from a mismatch between demand and supply, with respect either to their timing or to their quantities.

This book is about how firms can design their operations to better match supply with demand. Our motivation is simply stated: by better matching supply with demand, a firm gains a significant competitive advantage over its rivals. A firm can achieve this better match through the implementation of the rigorous models and the operational strategies we outline in this book.

To somewhat soften our challenge to economic theory, we do acknowledge it is possible to mitigate demand–supply mismatches by adjusting prices. For example, the effective market price for the Tesla Model 3 did rise, as became visible in the product's preowned price exceeding the list price. But, this price adjustment was not under Tesla's control, nor did Tesla collect the extra surplus from it. In other words, we view that price adjustment as a symptom of a problem, rather than evidence of a healthy system. Moreover, in many other cases, price adjustments are impossible. The time period between the initiation of demand and the fulfillment through supply is too short or there are too few buyers and sellers in the market. There simply is no market for emergency care in operating rooms or waiting times in call centers.

Why is matching supply with demand difficult? The short answer is that demand can vary, in either predictable or unpredictable ways, and supply is inflexible. On average, an organization might have the correct amount of resources (people, product, and/or equipment), but most organizations find themselves frequently in situations with resources in the wrong place, at the wrong time, and/or in the wrong quantity. Furthermore, shifting resources across locations or time is costly, hence the inflexibility in supply. For example, physicians are not willing to rush back and forth to the hospital as they are needed and retailers cannot afford to immediately move product from one location to another. While it is essentially impossible to always achieve a perfect match between supply and demand, successful firms continually strive for that goal.

Table 1.1 provides a sample of industries that we will discuss in this book and describes their challenge to match supply with demand. Take the airline industry (last column in Table 1.1.). Over the last two decades, most large airlines operating in the United States were able to increase their aircraft load factor (the percentage of seats on a plane that are utilized by a paying customer) from about 70–75 percent to over 80 percent. What might be annoying to us as consumers because of more congested boarding processes, a packed cabin, and an increased likelihood of being bumped on a flight, is critical to the financial success of the airlines. Transporting one more passenger on a flight increases the costs of operating the flight only by a very small number. Revenue, in contrast, grows significantly, and, given this combination, profits can double or triple by increasing the load factor by a few percentage points.

TABLE 1.1 Examples of Supply–Demand Mismatches

	Retailing	Iron Ore Plant	Emergency Room	Pacemakers	Air Travel
Supply	Consumer electronics	Iron ore	Medical service	Medical equipment	Seats on specific flight
Demand	Consumers buying a new video system	Steel mills	Urgent need for medical service	Heart surgeon requiring pacemaker at exact time and location	Travel for specific time and destination
Supply exceeds demand	High inventory costs; few inventory turns	Prices fall	Doctors, nurses, and infrastructure are underutilized	Pacemaker sits in inventory	Empty seat
Demand exceeds supply	Forgone profit opportunity; consumer dissatisfaction	Prices rise	Crowding and delays in the ER; potential diversion of ambulances	Forgone profit (typically not associated with medical risk)	Overbooking; customer has to take different flight (profit loss)
Actions to match supply and demand	Forecasting; quick response	If prices fall too low, production facility is shut down	Staffing to predicted demand; priorities	Distribution system holding pacemakers at various locations	Dynamic pricing; booking policies

(*continued*)

TABLE 1.1 Concluded

	Retailing	Iron Ore Plant	Emergency Room	Pacemakers	Air Travel
Managerial importance	Per-unit inventory costs for consumer electronics retailing all too often exceed net profits	Prices are so competitive that the primary emphasis is on reducing the cost of supply	Delays in treatment or transfer have been linked to death	Most products (valued $20k) spend 4–5 months waiting in a trunk of a salesperson before being used	About 30% of all seats fly empty; a 1–2% increase in seat utilization makes the difference between profits and losses
Reference	Chapter 2, The Process View of the Organization; Chapter 14, Betting on Uncertain Demand: The Newsvendor Model; Chapter 15, Assemble-to-Order, Make-to-Order, and Quick Response with Reactive Capacity	Chapter 3, Understanding the Supply Process: Evaluating Process Capacity; Chapter 4, Estimating and Reducing Labor Costs	Chapter 9, Variability and Its Impact on Process Performance: Waiting Time Problems; Chapter 10, The Impact of Variability on Process Performance: Throughput Losses	Chapter 16, Service Levels and Lead Times in Supply Chains: The Order-up-to Inventory Model	Chapter 18, Revenue Management with Capacity Controls

This illustrates a critical lesson: even a seemingly small improvement in operations can have a significant effect on a firm's profitability precisely because, for most firms, their profit (if they have a profit) is a relatively small percentage of their revenue. Hence, improving the match between supply and demand is a critically important responsibility for a firm's management.

The other examples in Table 1.1 are drawn from a wide range of settings: health care delivery and devices, retailing, and heavy industry. Each suffers significant consequences due to demand–supply mismatches, and each requires specialized tools to improve and manage its operations.

To conclude our introduction, we strongly believe that effective operations management is about effectively matching supply with demand. Organizations that take the design of their operations seriously and aggressively implement the tools of operations management will enjoy a significant performance advantage over their competitors. This lesson is especially relevant for senior management given the razor-thin profit margins firms must deal with in modern competitive industries.

1.1 Learning Objectives and Framework

In this book, we look at organizations as entities that must match the supply of what they produce with the demand for their product. In this process, we will introduce a number of quantitative models and qualitative strategies, which we collectively refer to as the "tools of operations management." By "quantitative model" we mean some mathematical procedure or equation that takes inputs (such as a demand forecast, a processing rate, etc.) and outputs a number that either instructs a manager on what to do (how much inventory to buy, how many nurses to have on call, etc.) or informs a manager about a relevant performance measure (e.g., the average time a customer waits for service, the average number of patients in the emergency room, etc.). By "qualitative strategy" we mean a guiding principle: for example, increase the flexibility of your production facilities, decrease the variety of products offered, serve customers in priority order, and so forth. The next section gives

a brief description of the key models and strategies we cover. Our learning objective for this book, put as succinctly as we can, is to teach students how and when to implement the tools of operations management.

Just as the tools of operations management come in different forms, they can be applied in different ways:

1. Operations management tools can be applied to ensure that resources are used as efficiently as possible; that is, the most is achieved with what we have.
2. Operations management tools can be used to make desirable trade-offs between competing objectives.
3. Operations management tools can be used to redesign or restructure our operations so that we can improve performance along multiple dimensions simultaneously.

We view our diverse set of tools as complementary to each other. In other words, our focus is neither exclusively on the quantitative models nor exclusively on the qualitative strategies. Without analytical models, it is difficult to move beyond the "blah-blah" of strategies and without strategies, it is easy to get lost in the minutia of tactical models. Put another way, we have designed this book to provide a rigorous operations management education for a strategic, high-level manager or consultant.

We will apply operations tools to firms that produce services and goods in a variety of environments—from apparel to health care, from call centers to pacemakers, and from kick scooters to iron ore fines. We present many diverse settings precisely because there does not exist a "standard" operational environment. Hence, there does not exist a single tool that applies to all firms. By presenting a variety of tools and explaining their pros and cons, students will gain the capability to apply this knowledge no matter what operational setting they encounter.

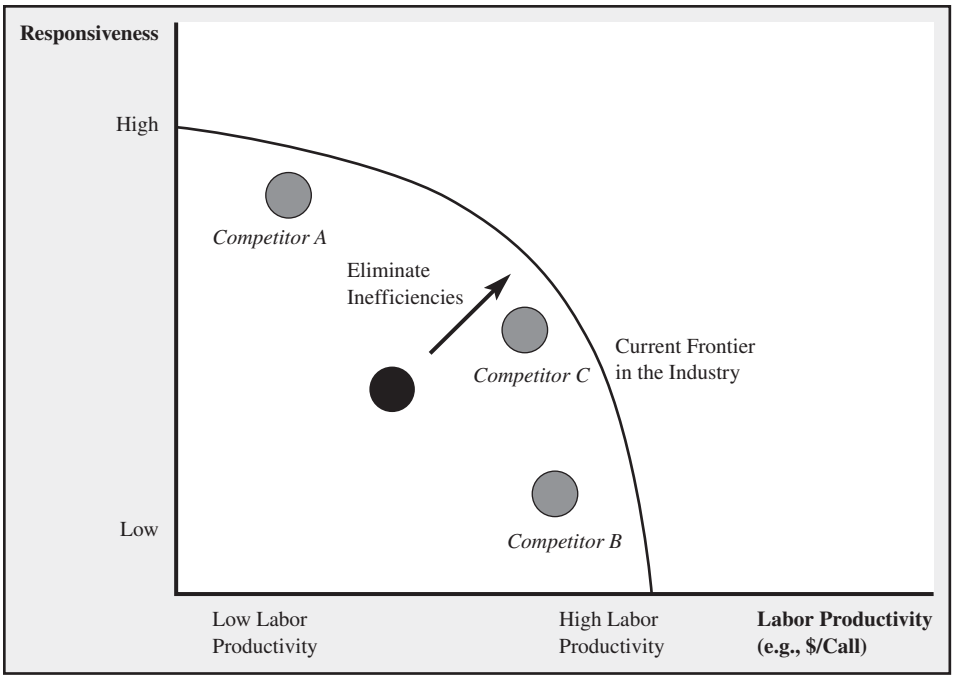
Consider how operations tools can be applied to a call center. A common problem in this industry is to find an appropriate number of customer service representatives to answer incoming calls. The more representatives we hire, the less likely incoming calls will have to wait; thus, the higher will be the level of service we provide. However, labor is the single largest driver of costs in a call center, so, obviously, having more representatives on duty also will increase the costs we incur per call.

The first use of operations management tools is to ensure that resources are used as effectively as possible. Assume we engage in a benchmarking initiative with three other call centers and find that the performance of our competitors behaves according to Figure 1.1: Competitor A is providing faster response times but also has higher costs. Competitor B has longer response times but has lower costs. Surprisingly, we find that competitor C outperforms us on both cost and service level. How can this be?

It must be that there is something that competitor C does in the operation of the call center that is smarter than what we do. Or, in other words, there is something that we do in our operations that is inefficient or wasteful. In this setting, we need to use our tools to move the firm toward the frontier illustrated in Figure 1.1. The frontier is the line that includes all benchmarks to the lower left; that is, no firm is outside the current frontier. For example, a premium service might be an important element of our business strategy, so we may choose not to compromise on service. And we could have a target that at least 90 percent of the incoming calls will be served within 10 seconds or less. But given that target, we should use our quantitative tools to ensure that our labor costs are as low as possible, that is, that we are at least on the efficiency frontier.

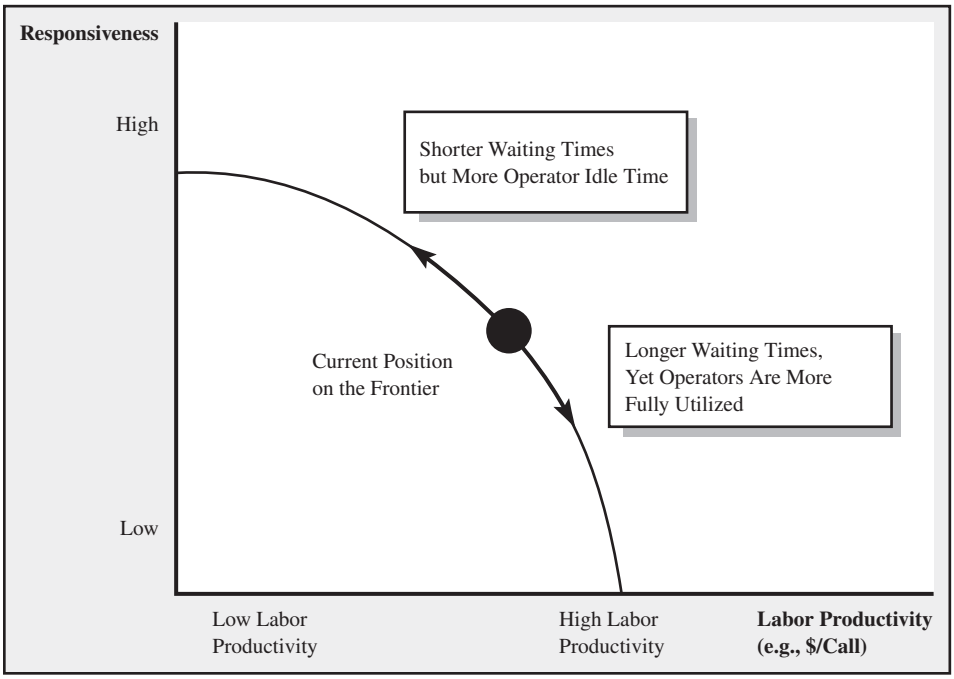
The second use of operations management tools is to find the right balance between our competing objectives, high service and low cost. This is similar to what is shown in Figure 1.2. In such a situation, we need to quantify the costs of waiting as well as the costs of labor and then recommend the most profitable compromise between these two objectives.

FIGURE 1.1
Local Improvement of Operations by Eliminating Inefficiencies



Moving to the frontier of efficiency and finding the right spot on the frontier are surely important. But outstanding companies do not stop there. The third use for our operations management tools is to fundamentally question the design of the current system itself. For example, a call center might consider merging with or acquiring another call center to gain scale economies. Alternatively, a call center might consider an investment in the development of a new technology leading to shorter call durations.

FIGURE 1.2
Trade-Off between Labor Productivity and Responsiveness



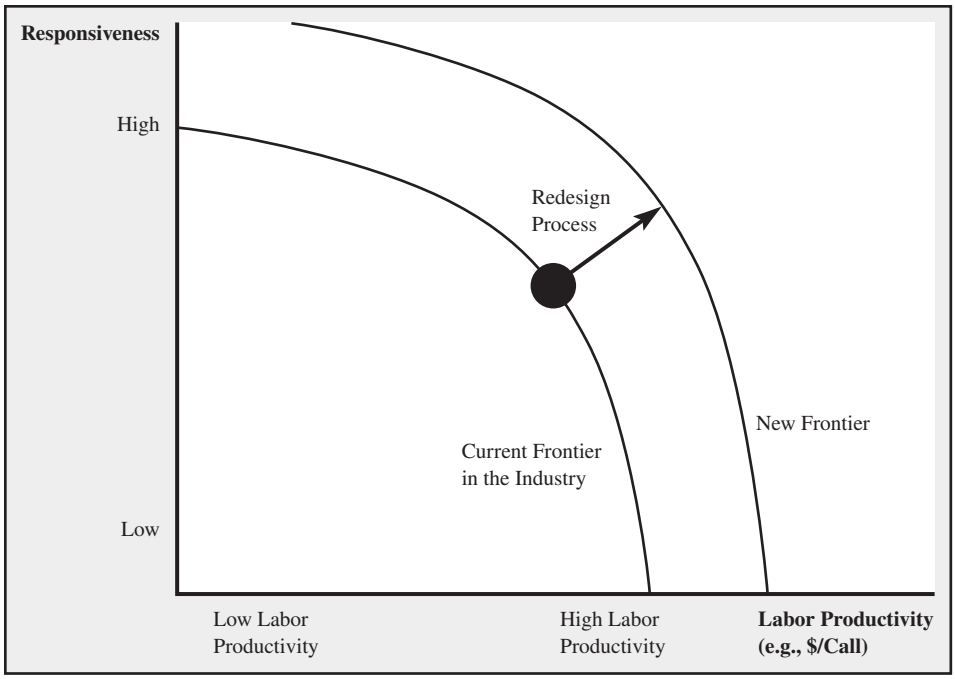


FIGURE 1.3
Redesigning the Process to Operate at an Improved Frontier

In such cases, a firm pushes the envelope, that is, moves the frontier of what previously was infeasible (see Figure 1.3). Hence, a firm is able to achieve faster responsiveness and higher labor productivity. But, unfortunately, there are few free lunches: while we have improved both customer service and labor productivity, pushing out the frontier generally requires some investments in time and effort. Hence, we need to use our tools to quantify the improvements we can achieve so that we can decide whether the effort is justifiable. It is easy to tell a firm that investing in technology can lead to shorter call durations, faster service, and higher labor productivity, but is that investment worthwhile? Our objective is to educate managers so that they can provide "big ideas" and can back them up with rigorous analysis.

1.2 Road Map of the Book

This book can be roughly divided into six clusters of closely related chapters.

The first cluster, Chapters 2–6, analyzes business processes (the methods and procedures by which a service is completed or a good is produced). For the most part, the view taken in those chapters is one of process without variability in service times, production times, demand arrival, quality, and so forth. Hence, the objective is to organize the business process to maximize supply given the resources available to the firm.

Chapters 7–8 focus on quality, either through specific quantitative methods for managing quality (Chapter 7) or through general principles for maximizing quality (Chapter 8).

Chapters 9–10 introduce variability into business process analysis. Chapter 9 discusses how variability can lead to waiting and Chapter 10 demonstrates how variability can lead to lost demand.

Chapters 11–12 discuss scheduling. Chapter 11 covers different methods for sequencing work and Chapter 12 focuses on the complexities of scheduling the activities for a single large project.

Chapters 13–16 discuss inventory control, information management, and process flexibility. Issues include demand forecasting, stocking quantities, performance measures, and response times.

Chapters 17–19 conclude the book with several strategic topics, including ways to mitigate risks, trying to influence demand through pricing, and coordinating the supply chain.

The following provides a more detailed summary of the contents of each chapter:

- Chapter 2 defines a process, introduces the basic process performance metrics, and provides a framework for characterizing processes (the product–process matrix). Little's Law is introduced, an essential formula for understanding business processes and the link between operations management and financial accounting.
- Chapter 3 introduces process analysis tools from the perspective of a manager (as opposed to an engineer): how to determine the capacity of a process and how to compute process utilization.
- Chapter 4 looks at assembly operations with a specific focus on labor costs, an extremely important performance metric. It frequently drives location decisions (consider the current debate related to offshoring) and has—especially in service operations—a major impact on the bottom line. We define measures such as labor content, labor utilization, and idle time. We also introduce the concept of line balancing.
- Chapter 5 studies production in the presence of setup times and setup costs (the EOQ model). A key issue is the impact of product variety on production performance.
- Chapter 6 connects the operational details of process analysis with key financial performance measures for a firm, such as return on invested capital. Through this chapter we discover how to make process improvement translate into enhanced financial performance for the organization.
- Chapter 7 details the tools of quality management, including statistical process control, six-sigma, and robust design.
- Chapter 8 describes how Toyota, via its world-famous collection of production strategies called the Toyota Production System, achieves high quality and low cost.
- Chapter 9 explores the consequences of variability on a process. As we will discuss in the context of a call center, variability can lead to long customer waiting times and thereby is a key enemy in all service organizations. We discuss how an organization should handle the trade-off between a desire for minimizing the investment into capacity (e.g., customer service representatives) while achieving a good service experience for the customer.
- Chapter 10 continues the discussion of variability and its impact on service quality. As we will discuss in the context of emergency medicine, variability frequently can lead to situations in which demand has to be turned away because of insufficient capacity. This has substantial implications, especially in the health care environment.
- Chapter 11 continues the theme of waiting times by discussing decisions related to sequencing (In which order should waiting units of demand be served?) and scheduling (Should we promise units of supply to our customers ahead of time?).
- Chapter 12 investigates project management, a process that is designed for a single, somewhat unique, project such as a ship, a new building, or a satellite.
- Chapter 13 introduces ways to plan for future demand based on forecasting techniques. While we cannot predict the future, we should try to learn as much as possible from demand realizations of the past.
- Chapter 14 focuses on the management of seasonal goods with only one supply opportunity. The newsvendor model allows a manager to strike the correct balance between too much supply and too little supply.

• Chapter 15 expands upon the setting of the previous chapter by allowing additional supply to occur in the middle of the selling season. This "reactive capacity" allows a firm to better respond to early season sales information.

• Chapter 16 continues the discussion of inventory management with the introduction of lead times. The order-up-to model is used to choose replenishment quantities that achieve target availability levels (such as an in-stock probability).

• Chapter 17 highlights numerous risk-pooling strategies to improve inventory management within the supply chain: for example, location pooling, product pooling, universal design, delayed differentiation (also known as postponement), and capacity pooling.

• Chapter 18 covers revenue management. In particular, the focus is on the use of booking limits and overbooking to better match demand to supply when supply is fixed.

• Chapter 19 identifies the bullwhip effect as a key issue in the effective operation of a supply chain and offers coordination strategies for firms to improve the performance of their supply chain.

Some of the chapters are designed to be "entry level" chapters, that is, chapters that can be read independently from the rest of the text. Other chapters are more advanced, so they at least require some working knowledge of the material in another chapter. Table 1.2 summarizes the contents of the chapters and indicates prerequisite chapters.

TABLE 1.2 Chapter Summaries and Prerequisites

Chapter	Managerial Issue	Key Qualitative Framework	Key Quantitative Tool	Prerequisite Chapters
2: The Process View of the Organization	Understanding business processes at a high level; process performance measures, inventory, flow time, and flow rate	Product–process matrix; focus on process flows	Little's Law Inventory turns and inventory costs	None
3: Understanding the Supply Process: Evaluating Process Capacity	Understanding the details of a process	Process flow diagram; finding and removing a bottleneck	Computing process capacity and utilization	Chapter 2
4: Estimating and Reducing Labor Costs	Labor costs	Line balancing; division of labor	Computing labor costs, labor utilization Minimizing idle time	Chapters 2, 3
5: Batching and Other Flow Interruptions: Setup Times and the Economic Order Quantity Model	Setup time and setup costs; managing product variety	Achieving a smooth process flow; deciding about setups and ordering frequency	EOQ model Determining batch sizes	Chapters 2, 3
6: The Link between Operations and Finance	Process improvement to enhance corporate performance	Return on Invested Capital (ROIC) tree	Computing ROIC	Chapters 2, 3
7: Quality and Statistical Process Control	Defining and improving quality	Statistical process control; six-sigma	Computing process capability; creating a control chart	None
8: Lean Operations and the Toyota Production System	Process improvement for competitive advantage	Lean operations; Toyota Production System	—	None

(*continued*)

TABLE 1.2 Concluded

Chapter	Managerial Issue	Key Qualitative Framework	Key Quantitative Tool	Prerequisite Chapters
9: Variability and Its Impact on Process Performance: Waiting Time Problems	Waiting times in service processes	Understanding congestion; pooling service capacity	Waiting time formula	None
10: The Impact of Variability on Process Performance: Throughput Losses	Lost demand in service processes	Role of service buffers; pooling	Erlang loss formula Probability of diverting demand	Chapter 9
11: Scheduling to Prioritize Demand	How to set priorities and how to reserve capacity	Priority rules and appointment systems	First-come-first-served; SPT rule	Chapter 9
12: Project Management	Time to project completion	Critical path	Critical path analysis	Chapters 2, 3
13: Forecasting	How to use past data about demand to predict future demand realizations	Time series–based forecasting	Exponential smoothing / demand patterns	None
14: Betting on Uncertain Demand: The Newsvendor Model	Choosing stocking levels for seasonal-style goods	Improving the forecasting process	Forecasting demand The newsvendor model for choosing stocking quantities and evaluating performance measures	None
15: Assemble-to-Order, Make-to-Order, and Quick Response with Reactive Capacity	How to use reactive capacity to reduce demand–supply mismatch costs	Value of better demand information; assemble-to-order and make-to-order strategies	Reactive capacity models	Chapter 14
16: Service Levels and Lead Times in Supply Chains: The Order-up-to Inventory Model	Inventory management with numerous replenishments	Impact of lead times on performance; how to choose an appropriate objective function	The order-up-to model for inventory management and performance-measure evaluation	Chapter 14 is highly recommended
17: Risk Pooling Strategies to Reduce and Hedge Uncertainty	How to better design the supply chain or a product or a service to better match supply with demand	Quantifying, reducing, avoiding, and hedging uncertainty	Newsvendor and order-up-to models	Chapters 14 and 16
18: Revenue Management with Capacity Controls	How to manage demand when supply is fixed	Reserving capacity for high-paying customers; accepting more reservations than available capacity	Booking limit/protection level model; overbooking model	Chapter 14
19: Supply Chain Coordination	How to manage demand variability and inventory across the supply chain	Bullwhip effect; supply chain contracts	Supply chain contract model	Chapter 14