Matching Supply with Demand

An Introduction to Operations Management

Fifth Edition

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MATCHING SUPPLY WITH DEMAND: AN INTRODUCTION TO OPERATIONS MANAGEMENT, FIFTH EDITION

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

About the Authors

Gérard Cachon *The Wharton School, University of Pennsylvania*

Professor Cachon is the Fred R. Sullivan Professor of Operations, Information, and Decisions and a Professor of Marketing. 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 4 children he enjoys hiking, scuba diving, and photography.

Christian Terwiesch *The Wharton School, University of Pennsylvania*

Christian Terwiesch is the Andrew M. Heller Professor at the Wharton School of the University of Pennsylvania. He is a Professor in and the chair of Wharton's Operations, Information, and Decisions department, co-director of Penn's Mack Institute for Innovation Management, and also holds a faculty appointment in Penn's Perelman School of Medicine. His research on Operations Management and on Innovation Management appears in many of the leading academic journals ranging from Management Science to The New England Journal of Medicine.

Professor Terwiesch has been teaching MBA and executive courses for 24 years and has received a number of teaching awards for his Operations Management course. Based on his MBA course and this book, Professor Terwiesch has launched the first Massive Open Online Course (MOOC) in business on Coursera. By now, well over half a million students enrolled in the course.

His first management book, Innovation Tournaments, was published by Harvard Business School Press. The novel, process-based approach to innovation outlined in the book was featured by BusinessWeek, the Financial Times, and the Sloan Management Review and has led to innovation tournaments in organizations around the world. His latest book, Connected Strategies, combines his expertise in the fields of operations, innovation, and strategy to help companies take advantage of digital technology leading to new business models. The book has been featured as the cover story of the Harvard Business Review and has been featured by Bloomberg/BusinessWeek as one of the best books in 2020.

Professor Terwiesch has researched with and consulted for various organizations. From small start-ups to Fortune 500 companies, he has helped companies become more innovative, often by implementing innovation tournament events and by helping to restructure their innovation portfolio. He holds a doctoral degree from INSEAD and a Diploma from the University of Mannheim.

Just like his co-author, he is a passionate cyclists and commutes to Penn's campus by bike. Since both authors have a good chunk of their commute in common, large parts of this book have been discussed on bike rides.

Acknowledgments

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We begin with the 2004 Wharton MBA class that weathered through our initial version of the text. It is not practical for us to name every student that shared comments with us, but we do wish to name the students who took the time to participate in our focus groups: Gregory Ames, Maria Herrada-Flores, Justin Knowles, Karissa Kruse, Sandeep Naik, Jeremy Stackowitz, Charlotte Walsh, and Thomas (TJ) Zerr. The 2005 MBA class enjoyed a much more polished manuscript, but nevertheless contributed numerous suggestions and identified remaining typos and errors (much to our chagrin). Since then, we have continued to receive feedback from our undergraduate, MBA, and executive MBA students at Wharton. In addition to Wharton students, we received helpful feedback from students at Texas A&M, the University of Toronto, and INSEAD.

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.

Matthew Drake (Duquesne University) provided us with invaluable feedback during his meticulous accuracy check of both the text and the solutions, and we thank him for his contribution.

Several brave souls actually read the entire manuscript and responded with detailed comments. These reviewers included Leslie M. Bobb (Bernard M. Baruch College), Sime Curkovic (Western Michigan University–Kalamazoo), Scott Dobos (Indiana University–Bloomington), Ricki Ann Kaplan (East Tennessee State University), and Kathy Stecke (University of Texas at Dallas).

Our Ph.D. student "volunteers," Karan Girotra, Diwas KC, Marcelo Olivares, and Fuqiang Zhang, as well as Ruchika Lal and Bernd Terwiesch, took on the tedious job of quality testing. Robert Batt, Santiago Gallino, Antonio Moreno, Greg Neubecker, Michael Van Pelt, and Bethany Schwartz helped to collect and analyze data and could frequently solve practice problems faster than we could. The text is much cleaner due to their efforts.

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: Harper Christopher, Anne Ehrenworth, Melissa Leick, and Eric Weber.

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 lessons we have learned over the last 2 decades of teaching the content of this book to thousands of students at Wharton and beyond. Much has happened during this time, including the global financial crisis and the Covid-19 pandemic.

The challenges and the opportunities associated with better matching supply with demand, however, have only grown. We hope that through this book and through our teaching we can help reduce some of the costs that arise when supply and demand do not match, be it in the form of insufficient care capacity in ICUs or global supply shortages of goods and services.

Gérard Cachon

Christian Terwiesch

New to This Edition

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

The world has changed again between this and the previous edition. Consequently, we have updated data and examples to try to maintain the timeliness of the content.

We have made a number of changes that make the material easier for students to absorb, including:

Chapter 1: A new introduction with current examples throughout
Chapter 2: New data for retailers; new information on inventory turns
Chapter 3: Refined explanation of process capacity
Chapter 5: New discussion on setup times and product variety; refined explanation of the SMED method
Chapter 8: New information on the limitations of lean systems, in light of Covid-19
Chapter 11: New examples of scheduling
Chapter 13: New data on the pandemic outbreak; new discussion on the importance of other forecasting methods beyond time series analysis, especially in the context of Covid-19
Chapter 17: New data on Hon Hai sales revenue
Chapter 19: New data on inflows and outflows through the U.S. retail trade sector

In addition, we have moved all of the Selected Solutions to the end of each respective chapter.

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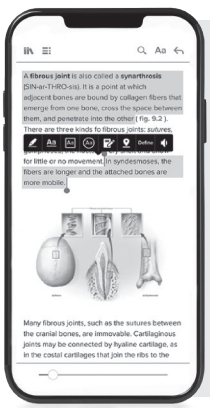

"I really liked this app—it made it easy to study when you don't have your text-book in front of you."

- Jordan Cunningham, Eastern Washington University

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