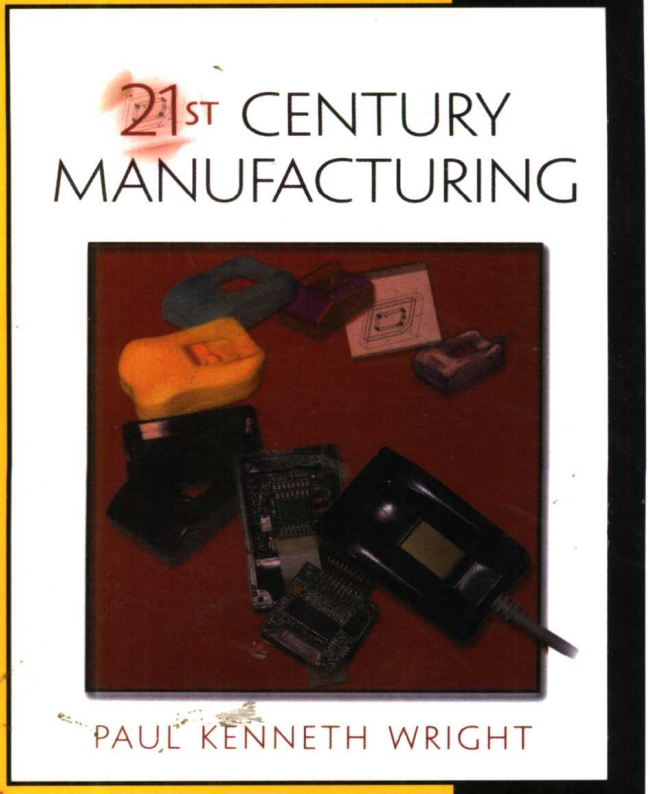
国外大学优秀教材——工业工程系列（影印版）

Paul Kenneth Wright

21世纪制造



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国外大学优秀教材——工业工程系列（影印版）

21st Century Manufacturing

21世纪制造

Paul Kenneth Wright
University of California
at Berkeley

清华大学出版社
Prentice Hall 培生教育出版集团

（京）新登字 158 号

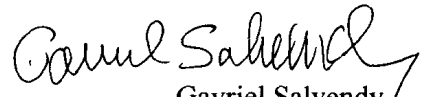
北京市版权局著作权合同登记号：图字：01-2002-2475

书　　名：21 世纪制造
作　　者：Paul Kenneth Wright
出 版 者：清华大学出版社（北京清华大学学研大厦，邮编 100084）
http:// www.tup.tsinghua.edu.cn
责任编辑：宋成斌
印 刷 者：北京牛山世兴印刷厂
发 行 者：新华书店总店北京发行所
开　　本：787×960 1/16　**印张**：30.25
版　　次：2002 年 5 月第 1 版　2002 年 5 月第 1 次印刷
书　　号：ISBN 7-302-05604-8/TB・43
印　　数：0001～5000
定　　价：49 00 元

Forward

This textbook series is published at a very opportunity time when the discipline of industrial engineering is experiencing a phenomenal growth in China academia and with its increased interests in the utilization of the concepts, methods and tools of industrial engineering in the workplace. Effective utilization of these industrial engineering approaches in the workplace should result in increased productivity, quality of work, satisfaction and profitability to the cooperation.

The books in this series should be most suitable to junior and senior undergraduate students and first year graduate students, and to those in industry who need to solve problems on the design, operation and management of industrial systems.



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April, 2002

前　言

本教材系列的出版正值中国学术界工业工程学科经历巨大发展、实际工作中对工业工程的概念、方法和工具的使用兴趣日渐浓厚之时。在实际工作中有效地应用工业工程的手段将无疑会提高生产率、工作质量、合作的满意度和效果。

该系列中的书籍对工业工程的本科生、研究生和工业界中需要解决工程系统设计、运作和管理诸方面问题的人士最为适用。

加弗瑞尔·沙尔文迪
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2002年4月

献给《21 世纪制造》影印版

由美国 Prentice-Hall 出版社出版的《21 世纪制造》一书，具有许多新颖性和对中国工科教育与制造业发展的实用性。首先。该书采用了与其它常见教科书不同的风格。例如，它强调了从全局的观点，特别是从商业的角度来看待制造；它强调将制造放到从市场研究、设计构思与设计美学、原型制造与批量生产，以及行销策略的制订这一大环境中去进行分析和思考；它还以作者及其在加州大学伯克利分校的同事们开发的 CyberCut 网站为例子强调了互联网与万维网对制造的影响。出于以上考虑，该书每章开头讲述各项技术在总体中的地位，末尾再从技术管理的角度对本章所介绍的技术进行分析与综合。第二，它包括了生物工程（第 9 章），新开业的高科技公司要注意的问题（第 2 章），制造史（第 1 章），制造业的未来展望（第 10 章），半导体制造（第 5 章）以及计算机制造（第 6 章）这几章。特别是第 1 章和第 10 章，它们必将对中国的工科教育与制造业的发展起到重要的启发作用。因此，本人热诚地将该书推荐给中国同行并决定将它翻译成中文。中国科学院院士、华中科技大学杨叔子教授，武汉理工大学校长周祖德教授和中国国家自然科学基金委雷源忠教授还应邀给该书中文版作了序*。

该书在国外刚出版就得到了较广泛的采用。据 Prentice-Hall 出版社 2001 年 10 月提供的数据，除该书作者所在的加州大学伯克利分校用于工学院与商学院合办的技术管理硕士班及机械工程专业以外，另有宾夕法尼亚州立大学、亚利桑那州立大学、密歇根大学、波特兰州立大学以及北达科斯塔州立大学的机械工程系或工业工程系已经采用该书作为教材。由于美国以外的销售数据没有按大学统计，因此无法确切了解其实际采用情况。但是，总共约 3000 册已销往除非洲以外的世界各地，其中包括 50 册已销往香港。根据本人多年在中美两国从事教学与国际交流的经验来看，该书的特点较适合作为中国的机械工程、制造工程、工业工程及管理工程专业的制造工程或制造工艺概论的教材。使用该书作为教材的另一个好处在于，学生和教师可登录到各章习题与附录中提供的网站中去完成不同的虚拟制造或网络驱动制造实验及练习而不受本校的设备限制。预祝各位读者使用该书成功、愉快！

冯常学　博士
《21 世纪制造》中文版主译
美国 Bradley 大学工业与制造工程系副教授
2001 年 11 月于美国伊利诺伊州皮奥里

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* 该书中译本即将由清华大学出版社出版。

Preface

This is a book that deals with today's technologies and the future of *manufacturing.* It includes details of the product design process, rapid prototyping, and a survey of manufacturing techniques relevant to today's production of consumer electronics or electromechanical devices. Biotechnology has been added because of the substantial future career opportunities in this field of manufacturing. The book also aims to provide a balanced view for the *management of technology.*

WHAT WILL 21ST CENTURY MANUFACTURING LOOK LIKE?

Within our imaginations, we probably all share a similar futuristic vision of electronic commerce, product design, and automated manufacturing.

Quite certainly the Internet and the World Wide Web of the 21st century will be vastly enriched. Using virtual reality and a haptic interface, a future consumer might "reach into" a computer and feel the virtual texture of a sweater that they want to mail-order. Quite certainly, keyboards will disappear: thus, in a voice-activated conversation with a virtual salesagent, the consumer might negotiate batch size (in many cases as low as one), size, color, and price, and then arrange for overnight fabrication and immediate delivery of a fully customized product. Somewhere else, clothing designers will already have sent beautifully rendered computer graphics images to fully automated factories. These images will sit quietly—waiting to be customized to an incoming order. And when the order comes, sophisticated machine tools and robots will spring to life automatically and smoothly fabricate the product for that specific consumer of the 21st century. The words "mass customization" are being used today for such a scenario.

At the beginning of the 21st century, *electronic commerce, product design, and manufacturing* are now global enterprises, increasingly integrated by the World Wide Web. Reliable electronic infrastructures and prompt customer delivery mechanisms mean that design services and manufacturing plants can be installed in any country. Any country? Perhaps any planet. By the 22nd century, surely someone will be exploiting

as-yet-unknown minerals on a remote planet. These will be partially processed on the spot and subsequently converted to consumer products for people living throughout our solar system and even beyond. The Website <**Mars-manufacturing.com**> might be worth reserving now.

This is a realistic vision. One that is perhaps rooted in the television documentaries over the past two decades showing welding robots on the automobile lines in Detroit. Today's exponential growth of the Internet and the World Wide Web seems to further expand our personal boundaries, with visions of access to a wide variety of services, including opportunities for online shopping and custom designing. Our natural curiosity about the future then extrapolates today's capabilities to more Hollywood-esque images of design studios and automated manufacturing systems. These might be distributed throughout our solar system and guided from the mission control deck of a "Starship Enterprise."

THE ECONOMIC CONTEXT FOR 21ST CENTURY MANUFACTURING

With this future in mind, what should be included in a college level manufacturing course? What do future students need to know? What is exciting?

Some economic issues must be mentioned before answering the above questions. New constraints have been forced upon all manufacturers in the last 10 years or so. Being knowledgeable and efficient in the basic processing methods is still very important but not sufficient. Introducing new automation and robotic systems to reduce factory-floor labor costs is also important but not sufficient.

Many of these new pressures on all manufacturers have been the result of international competition. At the same time, consumers have been made more aware of their choices. Here is a quote from *The Economist* magazine that emphasizes the power of consumer choice:

> Suppose one had walked into a video shop a decade ago looking for Betamax tapes. Sony's Betamax was the better standard, almost everyone agreed: but the VHS had the marketing muscle, and customers fell into line. They wanted three walls of films to choose from, not one.

In the final analysis, if a manufacturing company is going to be successful in the 21st century, being good at just "the technology" is not enough to survive. A company must be alert to change; it must offer its customers the most innovative product at the best price and the best all-around service.

WHY DID I WRITE THIS BOOK?

The University of Birmingham in England was like any other leading engineering school in the 1970s. We studied the "physics" of individual manufacturing processes in great depth. My thesis discovered new methods for measuring temperatures very close to a cutting tool edge and correlating them with wear patterns when machining aerospace alloys. Later as a postdoctoral student at Cambridge University, my colleagues and I made movies through transparent sapphire cutting tools and studied the friction at the interface between the tool and the flowing chip. Actually it was

great fun. So, not really knowing any better, these were the topics I lectured on in my first years as a professor. However, especially after I moved to Berkeley and Silicon Valley around 1990, these one-by-one studies of individual processes (whether for metals or semiconductors) seemed an inadequate preparation for students who were going to work for Intel, Hewlett Packard, IBM, and—more recently—dot.com start-ups. Today, although these students graduate and go off to manufacture the next generation of semiconductors, computers, disc drives, and all manner of peripherals and consumer products, their day-to-day careers involve designing, prototyping, and fabricating these electromechanical products rather than just refining one of the physical processes in great depth.

It thus seemed that a more global view of manufacturing was needed for students going into product development and probably management. This book emerged from that perception. Thus Chapters 1 and 2 begin with a review of the history of manufacturing, its present state, the need for integration, and a summary of some basic principles. These first two chapters cover ground that can also be found in the other excellent and comprehensive texts (listed in the Bibliography of Chapter 1) that focus on the general field of manufacturing.

Moving into Chapter 3, a different approach from these other texts has been adopted. Speaking generally, other manufacturing-oriented textbooks begin with a review of material properties and then mechanics (if they are targeted at mechanical engineers) or basic electronics (if they are targeted at electrical engineers). They continue with a comprehensive description of many manufacturing processes and then conclude with some manufacturing system issues that tie the whole landscape together. However, this previous approach has some limitations for today's students. The evidence indicates that they will probably start off their careers in the technology of manufacturing, but after only a few years they will become "managers of technology."

For these future managers, the word "manufacturing" will mean much more than the basic fabrication technology. It will involve market analysis, design, production planning, fabrication (including outsourcing), distribution and sales, customer service, and, finally, being agile enough to reconfigure the factory for the next product "six months down the road." Of course one could argue that this has always been the case: but now, the pace of change is so dramatic and being first to market is so critical that there is a much greater obligation for faculty to train students for this environment.

Therefore, the new approach beginning with Chapter 3 guides students through a *product development cycle.* The goal is to embed each fabrication process in its appropriate place in the whole activity of *manufacturing in the large.*

WHO MIGHT BENEFIT FROM THIS BOOK?

The audience that has been kept in mind is a class consisting of both engineering and business students, who are interested in a survey of manufacturing processes and their strategic consequences for business and the international economy. The course has been taught for a number of years at Berkeley, but the emphasis changes somewhat according to whether it is a junior/senior course or a first-year graduate course. The level also influences the topic chosen for the semester-long CAD/CAM project

outlined in the Appendix. In the last few years the course has also been part of a management of technology program.

The analytical material is easy to digest without an extensive background in stress analysis, electronics, or biochemistry. The rationalizations for this level of treatment are that:

1. The ideas try to move beyond the basic science in each field to the strategic issues such as time-to-market.
2. On most campuses there are several subsequent graduate courses that do go into the detailed engineering issues in each domain.
3. There is a bibliography of research articles and books for the future specialist.
4. There is always the hope that other audiences, outside the academic community, might get something out of this book if it is written in a more conversational style rather than jam-packed with equations.

The first few chapters thus serve as a readable survey of the current economic factors before moving into Chapters 3 through 9, which have more technical content. The analysis of each basic process in chapters 3 through 9 is then presented in the context of business. While the central sections of these chapters focus on analysis, the market issues and the management context issues are discussed at the beginning and end of each chapter.

An especially valuable way of dealing with the new approach in a semester-long class has been to place emphasis on two activities:

1. Group projects in CAD/CAM, where students design, prototype, and fabricate a new product, including its marketing plan
2. Factory tours that support the understanding of integrated manufacturing, after which students, again in groups, write up a case study on the company, its business model, and future growth

Chapter 10 considers future management issues in more detail. It contains more open-ended topics that often come up in class discussions. For example, we may wonder about the more frightening side of automation and technology: will these future factories create inhumane relationships between machines and society, as depicted in Carel Kapek's famous play of the 1920s, *Rossum's Universal Robots?* Many people in the world today may feel the same as the Luddites—an informal protest group in the late 18th century that opposed the loss of craft skills during the first industrial revolution (1770–1820). Whether locked to a word processing terminal or an assembly line, many of today's jobs are still soulless. Or perhaps worse, unemployment in several European countries is widespread. With such pressing social issues, can we really justify fully automated factories? A further concern revolves around ecological issues. Not only are these advanced manufacturing processes energy-hungry, but they can often result in dangerous chemical by-products. How does one country create manufacturing systems that are ecologically friendly and yet efficient enough to compete against those of other countries that may have less strict environmental laws?

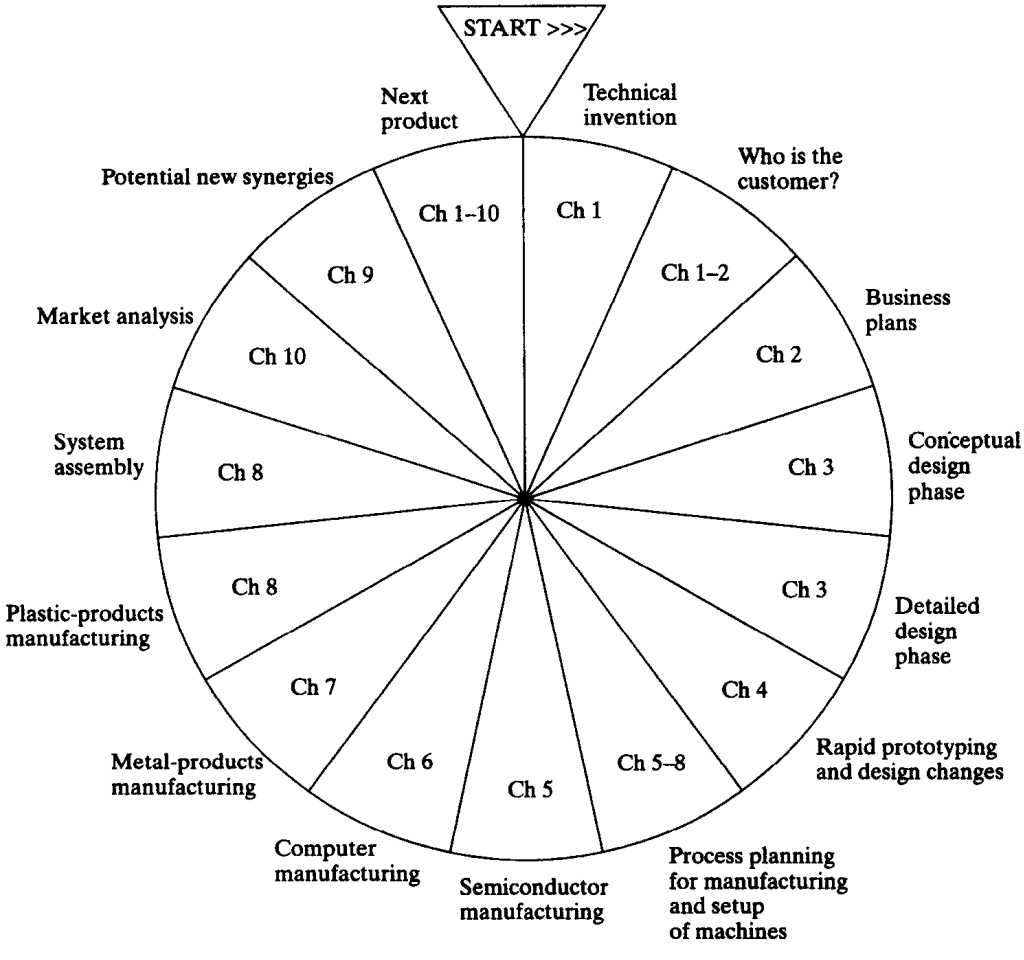
In summary, the "old manufacturing mentality" (certainly pre-1980) was mostly focused on getting products through machines and out the door to the loading dock. This had several weaknesses. In particular, it relied on a distant marketing organization to make the link to the customer. This is not so today, and this book focuses on "manufacturing in the large" and associated "business issues." Throughout the next century, manufacturing will be much more than machining metals, etching wafers, assembling computers, or controlling bioreactors. Manufacturing will be an integral part of an extended social enterprise. Today, it drives the "global economy"; probably in the future, it will drive a "solar system economy."

OUTLINE: A JOURNEY ALONG THE PRODUCT DEVELOPMENT PATH

The following subjects and chapters are organized as a journey along the product development path with emphasis on the fabrication techniques.

The following figure is a summary of this approach, using one of today's cell phones or handheld computers as a metaphor for the fabrication techniques needed.

Chapter 1: Manufacturing: art, technology, science, and business
Chapter 2: Manufacturing analysis: some basic questions for a start-up company
Chapter 3: Product design, computer aided design (CAD), and solid modeling
Chapter 4: Solid freeform fabrication (SFF) and rapid prototyping
Chapter 5: Semiconductor manufacturing
Chapter 6: Computer manufacturing
Chapter 7: Metal-products manufacturing
Chapter 8: Plastics-products manufacturing and system assembly
Chapter 9: Biotechnology
Chapter 10: Conclusions


START >>>
Technical invention
Who is the customer?
Business plans
Conceptual design phase
Detailed design phase
Rapid prototyping and design changes
Process planning for manufacturing and setup of machines
Semiconductor manufacturing
Computer manufacturing
Metal-products manufacturing
Plastic-products manufacturing
System assembly
Market analysis
Potential new synergies
Next product
Ch 1
Ch 1–2
Ch 2
Ch 3
Ch 3
Ch 4
Ch 5–8
Ch 5
Ch 6
Ch 7
Ch 8
Ch 8
Ch 10
Ch 9
Ch 1–10

Acknowledgments

I have been fortunate in having many talented and congenial colleagues during the 30 years in which I have been actively interested in "manufacturing." Many ideas in this book have evolved from these close friendships, coauthorships, joint projects, informal discussions at various conferences, and many interactions with students. Warm thanks are extended to all these colleagues and students. If any of you feel that I have misrepresented you, or forgotten a citation to your work, please let me know at <**pwright@robocop.me.berkeley.edu**>. There is certain to be a revision of this book, and corrections can easily be made.

Looking back on my career in manufacturing, I recall my thesis work at the University of Birmingham, England, carried out with Dr. Edward Moor Trent. Sadly, he passed away in the spring of 1999 after a long decline, but it was possible to honor his great influence on my life by joining him as a coauthor in the Fourth Edition of his original book, *Metal Cutting.* Thanks are also due to Professor G. Rowe, Dr. D. Milner, Dr. T. Childs, Dr. R. Lorenz, Dr. P. Dearnley, and Mr. E. Smart, who were colleagues in the "machining research group" at Birmingham.

At the Cavendish Laboratory, Cambridge University, England, I would also like to thank my colleagues in the "transparent sapphire tool group": Professor D. Tabor, Dr. N. Gane, Dr. J. Williams, Dr. D. Doyle, and Dr. J. G. Horne.

At the University of Auckland in New Zealand, thanks are due to Mr. P. D. Smith, Professor R. F. Meyer, the late Professor J. H. Percy, Dr. J. L. Robinson, Dr. P. S. Jackson, Dr. A. W. Wolfenden, Professor G. Arndt, and Mr. George Moltzchianiwisky. I also thank Mr. L. S. Aiken, Mr. W. Beasley, Dr. John Meikle, and Mr. Peter Connor at the "old" Department of Scientific and Industrial Research in New Zealand. The late Professor P. L. B Oxley, Professor E. J. A. Armarego, Professor R. H. Brown, and Dr. M. G. Stevenson in Australia are thanked for their interactions.

At Carnegie Mellon University in Pittsburgh, Pennsylvania, I warmly acknowledge Professors Raj Reddy, Angel Jordan, and William Sirignano—who together inspired the growth of the Robotics Institute and manufacturing research—and the following colleagues: the late Dr. J. L. Swedlow, Dr. D. A. Bourne, Dr. C. C. Hayes,

Dr. R. S. Rao, Dr. M. Fox, Dr. A. Bagchi, Dr. A. J. Holzer, Dr. J. G. Chow, Dr. S. C. Y. Lu, Dr. D. W. Yen, Dr. C. King, Mr. H. Kulluk, Dr. M. R. Cutkosky, Dr. F. B. Prinz, Dr. S. Finger, Dr. M. Nagurka, Dr. P. Khosla, Dr. L. Weiss, Dr. R. Sturges. Many of these colleagues are now successful professors and researchers around the United States.

At the Courant Institute of Mathematical Sciences at New York University, acknowledgments are due to Professor J. T. Schwartz, Professor K. Perlin, Mr. I. Greenfeld, Mr. F. B. Hansen, Mr. L. Pavlakos, Dr. J. Hong, and Dr. X. Tan. These colleagues launched the open-architecture manufacturing research, and I thank them for their inspiration and teamwork.

At the University of California, Berkeley, Professor David Dornfeld, Professor Carlo Sequin, Dr. Frank Wang, Dr. Sung Ahn, Dr. Chuck Smith, Professor Paul Sheng, Professor Robert Brodersen, Professor Jan Rabaey, Professor David Hodges, Professor Robert Cole, and Professor Ken Goldberg are my day-to-day research colleagues. At the same time, Professors Erich Thomsen, Joseph Frisch, and the late Shiro Kobayashi were the founders of manufacturing-related research at Berkeley, and I thank them for their interest in this newer approach to manufacturing. Also, for their friendship and support, I thank Professor David Bogy, Professor Hami Kazerooni, Professor Paul Gray, Professor Masayoshi Tomizuka, Professor Kyriakos Komvopoulos, Professor Dan Mote, Professor Karl Hedrick, Professor Shankar Sastry, and Professor John Canny. Dr. Sara Okamura was a patient guide for the chapter on Biotechnology (Chapter 9).

For their detailed assistance in the preparation of the manuscript I thank Bonita Korpi, William Chui, Lisa Madigan, Andrew Lipman, and Zachary Katz. Dan Chapman has played an invaluable role in preparing art work and taking care of many details.

Thanks are also due to my graduate students from the Integrated Manufacturing Laboratory and Design Studio at Berkeley. They include Dr. Sanjay Sarma, now a Professor at M.I.T.; Dr. Steven Schofield, now at Siemens; Dr. James Stori, now a Professor at the University of Illinois, Urbana-Champaign; V. Sundararajan; Ganping Sun; Shad Roundy; Jaeho Kim; John Michael Brock; Juan Plancarte; Ryan Inouye; Matt Mueller; Louis Marchetti; Dan Odell; Kiyoshi Urabe; Kevin Chan; Fadel Hamed; Damien Crochet; Naomi Molly An; Mark McKenzie; Louis Marchetti; Roshan DeSouza; Balaji Kannan; Michael Montero; Ashish Mohole; and Socrates Gomez. Also the students that work with Professor Carlo Sequin are thanked: Jordan Smith, Jane Yen, Jainling Wang, and Sara McMains.

In addition, Berkeley has been the temporary home for many visitors who have also been contributors to the ideas in this book. I warmly thank Dr. Bruce Kramer from the National Science Foundation, Professor Jami Shah from Arizona State University, and Professor Jay Gunasekera from Ohio University.

From around the world I acknowledge the following inspiring friends in manufacturing: Professor Richard DeVor and Professor Shiv Kapoor at the University of Illinois, Urbana-Champaign; Professor B. F. von Turkovich at the University of Vermont; Professors R. Komanduri and J. Mize, now at Oklahoma State University; Professor J. T. Black at Auburn University; Professor S. Kalpakjian at the Illinois Institute of Technology; Professor H. Voelcker at Cornell University; Professor F. Ling at the

University of Texas, Austin; Dr. O. Richmond, Dr. M. Devenpeck, and Dr. E. Appleby from Alcoa Research Laboratories; Professors N. P. Suh and D. Hardt at M.I.T.; Professors T. Kurfess, S. Liang, S. Melkote, and J. Colton at Georgia Tech.; Professors S. K. Gupta and D. Nau at the University of Maryland; Professor W. Regli at Drexel; Professors S. Ramalingam and Kim Stelson at Minnesota; Dr. R. Woods at Kaiser Aluminum; Professors Y. Koren, G. Ulsoy, D. Dutta, and J. Stein at the University of Michigan; Professors K. Weinmann and J. Sutherland at Michigan Technological University; Professor K. P. Rajurkar at the University of Nebraska; Professor J. Tlusty at the University of Florida; Professors A. Lavine and D. Yang at UCLA; Professors I. Jawahir, A. T. Male, and O. Dillon at the University of Kentucky; Professor Tony Woo at the University of Washington; Professor S. Settles, now at the University of Southern California; Professor W. DeVries at Iowa State University; Professors M. DeVries, J. Bollinger, and R. Gadh at the University of Wisconsin; Professor D. Williams at Loughborough University, England; Professor M. Gregory and colleagues at Cambridge University, England; Professor Nabil Gindy, Dr. T. Ratchev, and colleagues at Nottingham University, England; Professor M. Elbestawi and his group at McMaster University, Canada; Professor Y. Altintas at the University of British Columbia, Canada; and the many colleagues at NSF, Boeing, and Ford/Visteon mentioned below.

Several years ago, Cincinnati Milacron was a great source of support for my work, and I acknowledge Mr. R. Messinger, Dr. R. Kegg, and Mr. L. Burnett. Similarly, for the support and interactions from Westinghouse I thank Tom Murrin (now at Duquesne University), Jose Isasi, Gary Schatz, and Jerry Colyer.

Collaboration with Sandia National Laboratories has been invaluable, and I thank Mr. L. Tallerico, Dr. R. Stoltz, Mr. A. Hazleton, and Dr. R. Hillaire for their support.

I am also grateful to colleagues at The Boeing Company, Dr. Donald Sandstrom in particular, for their funding and for new insights on high-speed machining.

Funding from the Ford Motor (and particularly the Visteon organization) is gratefully acknowledged, and I particularly thank Mr. Charles Szuluk and Dr. Shuh Liou for their long-term interest in integrated manufacturing. I also thank Mr. Craig Muhlhauser, Mr. Ashok Goyal, Mr. Glenn Warren, and Dr. Eugene Greenstein.

Support from the National Science Foundation has been invaluable in developing some of the fundamental ideas. Many colleagues have served at NSF during the course of the research: Dr. B. Kramer, Dr. C. Astill, Dr. B von Turkovich, Dr. W. Spurgeon, Dr. J. Meyer, Dr. T. Woo, Dr. S. Settles, Dr. J. Lee, Dr. M. DeVries, Dr. W. DeVries, Dr. L. Martin-Vega, Dr. C. Srinivasan, Dr. B. Chern, Dr. C. Wardle, Dr. M. Foster, and Dr. G. Hazelrigg have all played a role in this work. Support from DARPA, AFOSR, and ONR is also gratefully acknowledged as is the personal interest of Dr. W. Isler, Dr. E. Mettala, and Dr. J. Sheridan.

Thanks are due to the staff at Prentice Hall, Carlisle Communications, and the several colleagues who deserve a double mention for reviewing the early drafts of the book: Professor Costas Spanos, Professor Richard Devor, Professor Angel Jordan, Professor Serope Kalpakjian, Professor J. Black, Professor Klaus Weinmann, Professor Robert Cole, Professor Kenneth Goldberg, Professor M. Elbestawi, Professor Caroline Hayes, Professor Mark Cutkosky, Professor Mikell

Groover, Professor Kim Stelson, Dr. C alvin Kin, Mr. Randy Erickson, and Professor David Hodges, who first encouraged t his combination of manufacturing and management of technology.

My wife Terry has contributed ir ı innumerable ways to the writing, especially by spending many hours discussing the content and scope. My brother Derek and my late parents are implicitly part of the book. The loving company of my three sons Samuel, Joseph, and Thomas and my t wo stepdaughters Jessi and Jen has made the writing a lighthearted task. Neverthele:ss, I want to thank you all—my family, my students, and my colleagues—for "puttiıg up with me" during the recent months in which I know I have been hyper-preoc cupied.

Paul Wright,
Berkeley, CA
Spring 2000

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