21ST CENTURY MANUFACTURING

PAUL KENNETH WRIGHT

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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?

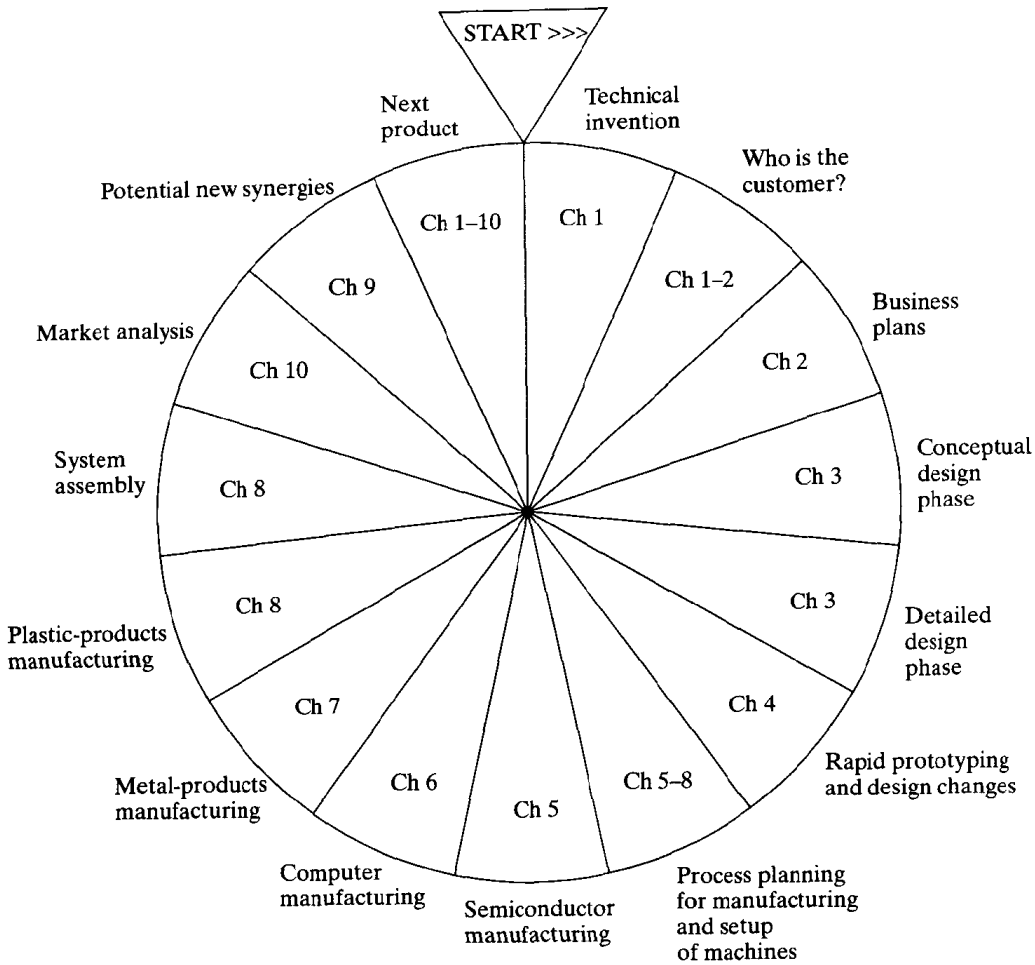
In summary, the "old manufacturing mentality" (certainly pre-1980) was mostly focused on getting products through machines and out the door to the loading dock. This had several weaknesses. In particular, it relied on a distant marketing organization to make the link to the customer. This is not so today, 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 1–10
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 9
Ch 10

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Contents