CHAPTER 1

MANUFACTURING: ART, TECHNOLOGY, SCIENCE, AND BUSINESS

1.1 INTRODUCTION: WHAT IS "MANUFACTURING"?

The word has Latin roots: *manu,* meaning by hand, joined to *facere,* meaning to make. The dictionary definition is "*Making of articles by physical labor or machinery, especially on a large scale.*" Even this simple definition shows a significant historical trend. For hundreds of years, manufacturing was done by physical labor, in which a person with hand tools used craft skills to make objects. Since the industrial revolution 200 years ago, machinery has played an increasing role, as summarized in the second column of Figure 1.1. Also, the models for manufacturing processes have become better understood. And in more recent decades, computer aided design and manufacturing (CAD/CAM) and new concepts in quality assurance (QA) have been introduced to improve efficiency in production. It is expected that the 21st century will bring even better process models, more exacting control, and increased integration.

During the early part of the 20th century, the words *large scale*—used above in the dictionary definition—were synonymous with the mass production of Henry Ford. Most people would agree that the present trends created by the Internet have now set the stage for an even larger scale or global approach to manufacturing. We can expect to see global networks of information and distributed manufacturing enterprises. The 20th century concept of a monolithic organization clinging to one centralized corporate ethos may fade. The new culture may well be smaller, more agile corporations that can spring up for specific purposes, exist while the market sustains the new product, and then gracefully disband as the market changes. The Internet is certainly providing the infrastructure for these more flexible and informal ways of creating new enterprises that respond to people with a naturally entrepreneurial spirit. In Chapter 1, the goals are to set the stage for these broad views of manufacturing and a new era of global change.

Manufacturing: Past, Present, and Future			
Early 18th Century	19th Century	20th Century	21st Century
A person with an anvil and hammer Poorly understood process Craftspeople Cottage industry	Steam-powered machinery Improved understanding of processes Factory conditions in cities	Computer aided design, planning, and manufacturing Limited process models using closed loop control Increased factory automation	Systemwide networks and information Robust processes and intelligent control Global enterprises and virtual manufacturing corporations

Figure 1.1 Four centuries of manufacturing leading to 21st century manufacturing.

1.2 THE ART OF MANUFACTURING (FROM 20,000 B.C. TO 1770 A.D.)

In the most general sense, manufacturing is central to existence and survival. Historians connect the beginning of the last European Ice Age, approximately 20,000 years ago, to a period in which "*technology took an extra spurt*" (Pfeiffer, 1986). Cro-Magnons retreated southward from the glacial ice that, more or less, reached what are now the northern London suburbs. They manufactured rough pelts for warmth, simple tools for hunting, and crude implements for cooking. This general period of prehistory around 20,000 B.C. to 10,000 B.C. is referred to as the *Stone Age*. The availability of simple manufacturing tools and methods around the period of 10,000 B.C. also created the environment for community living, rather than an opportunistic, nomadic-tribe mentality. Such communities set the stage, at that time, for the *agrarian revolution*.

Manufacturing must have then evolved from these arts and crafts roots with occasional similar spurts prompted by climate, famine, or war. For example, the accidental discovery that natural copper ore, mixed with natural tin ore, would produce a weapon much more durable than stone replaced the Stone Age with the Bronze Age. Archaeologists believe that bronze weapons, drinking vessels, and other ornaments were made in Thailand, Korea, and other Eastern civilizations as early as 5000 B.C. At a similar time, in the Western civilizations, the evidence suggests that tin was mined in the Cornwall area of England. The two contemporaneous societies of Egypt and Mesopotamia appeared on the historical scene around 3000 B.C. While the historical roots of these cultures appear hazy, they were blessed with sophisticated artisans (Thomsen and Thomsen, 1974). Their early arts and crafts skills were then passed on to the Greeks and Romans, thereby setting the stage for European manufacturing methods. These grew very slowly indeed until the Iron Age and, finally, the industrial revolution of the 17th and 18th centuries.

One example of these early arts and crafts skills was the lost-wax casting process. It was discovered by both the Egyptians and the Koreans around the period 5000 B.C. to 3000 B.C. In the process, an artist carves and creates a wax model—say of a small statue. Sand or clay is then packed around this wax model. Next, the wax model is melted out through a small hole in the bottom to leave a hollow core. The small hole is plugged, and then liquid metal is poured into a wider hole at the top of the hollow cavity. After the metal freezes and sets, the casting is broken out of the sand. Some hand finishing, deburring, and polishing render the desired art object. Later chapters in the book will describe modern rapid-prototyping shops, connected to the Internet, producing small batches of trial-run computer casings for AT&T, Silicon Graphics, and IBM. These are high-tech operations by anyone's standards. Ironically, however, this lost-wax process remains one of the basic processes that is widely used in prototyping.

If the roots of forging and casting are with the Egyptian and Korean artisans, what about slightly more complex processes such as turning and milling? Bronze drinking vessels extracted by archaeologists from the tombs in Thebes, Egypt, show the characteristic turned rings on their bases as if made on a crude lathe. (As described later, a lathe is a turning machine tool, predominantly used today to change the diameter of a bar of steel.) The manufacturing date is estimated to be before 26 B.C., because Thebes was sacked in that year (Armarego and Brown, 1969). In the British Museum and the Natural History Museum in New York, many art objects show these characteristic turned circles from early machining operations.

Even the word *lathe* has romantic roots. It derives from the word *lath,* related to the description for a flexible stick or slender tree branch used to spin the bar as described below. Early lathes were operated by two people: one holding the tool, the other turning the bar being machined. Sooner or later someone figured out (probably one of the exhausted turning guys) that one could rig up a crude system something like an old-fashioned sewing machine treadle. A rope was wrapped and looped around the free end of the bar being machined. One end was tied to the turner's foot, rather like a stirrup; the other end was tied to the end of a springy stick or tree branch (the lath) that was nailed up into the roof rafters. As the turner raised his foot up and down, the motion rotated the bar back and forth, and the lath functioned as a return spring for the rope. Obviously this was a relatively crude process from a modern day view of achievable precision! But from the word *lath* comes today's word *lathe.* And in Britain, the word "turner" is frequently used instead of the American word "machinist" for the lathe operator.

This introduction to manufacturing from an artistic point of view brings up the first thoughts on design for manufacturability (DFM) (see Bralla, 1998). It must be clear from the above descriptions of open-die forging, casting, and machining that there is always a trade-off between the complexity of the original design and how easily it is made. It was certainly clear to the original artisans. In any natural history museum showing European art, one can see many functional items such as cooking pots, ordinary tools, eating implements that are rather dull looking: no fancy fleurs-de-lis or insets, no beautifully rounded corners. By contrast, exotic jewelry and necklaces do contain these fanciful additions. The most decorative items are the handles and scabbards of swords. These were obviously the most important objects to even an average soldier's heart, and they were willing to pay relatively large sums of money to the artisan to create beauty as well as functionality. Asian cultures had different ways of demonstrating wealth or societal position, where simplicity was synonymous with beauty. Nevertheless, the very best materials and refined structures were employed.

An economic analysis of design for manufacturability should always keep in mind the ultimate customer. An overly fanciful, nearly impossible to fabricate sword scabbard (or the 21st century equivalent) may be exactly what the customer wants and is happy to pay for. But not all customers. Walmart, Kmart, and McDonald's show that the greatest wealth is to be obtained from the mass markets where aesthetics and highest quality materials are compromised in favor of low cost. Any new enterprise embarking on the design, planning, and fabrication of a new product should therefore begin with the market analysis. How much time and money go into each step of design, planning, and fabrication is a recurring theme of this book. Without the best case reading of the marketplace—to analyze which group of consumers is being targeted, how many items will be sold, and at what margin—no amount of fabulous technology will win.

The brief case study at the end of this chapter expresses the same opinion. The article refers to "*the next bench syndrome*" coined at Hewlett-Packard. The idea is that, in the past, engineering designers would create devices to impress their engineering colleague seated at the next bench, rather than the ultimate consumer. Today, the evidence is that HP products have improved, now that its designers have redirected their efforts to become more customer oriented. The article also mentions the early (1993–1994 era) prototypes of pen-input computers. Some readers may recall how bulky and slow these were. But today, designers and manufacturers understand what consumers genuinely want from mobile, palm-size, pen-input devices: for example, the Palm Pilot and similar products have now become well established, useful consumer products.

This section is entitled "The Art of Manufacturing," and it introduces the important link between design and manufacturing (DFM). The relationship between art, design, and manufacturing is complex. The word *art* is derived from the Latin *ars,* meaning skill. Thus, especially before the industrial revolution (1770–1820), new products were designed and manufactured by artists and craftspeople: their hand skills were predominant. By contrast, in the modern era, new products are most likely to be designed and manufactured by mathematically trained engineers. Today, some degree of intuition, and trial and error, is still needed on the factory floor to operate machinery and to set up other equipment effectively, but throughout the 21st century, the role of the craftsperson or artisan will fade away.

Does this mean that art will no longer play a role in design and manufacturing? The answer is "probably not," because art involves more than just a hand skill itself. Most scholars of art describe the concept of *aesthetic experience* that elevates a basic skill into the artistic realm. It is observed that the most successful artists—in any field such as music, dance, literature, painting, architecture, or sculpture—communicate an aesthetic experience to their audience. Communication of this aesthetic experience to the consumer will always be key for the "design artist" or "manufacturing artist" no matter how mathematically sophisticated and high-tech these fields eventually become. As this book moves on to the technology and business of manufacturing, it is suggested that new students in the field keep this concept of aesthetic experience in mind.

1.3 THE TECHNOLOGY OF MANUFACTURING: FROM THE 1770s TO THE 1970s

The first watershed that changed manufacturing from a purely artistic or at least artisan type endeavor must surely have been the industrial revolution in England, which took place in the approximate period 1770 to 1820. The most gifted historians have come up with no single reason for this revolution (Plumb, 1965; Wood, 1963). It was a combination of technological, economic, and political factors, as follows:

1. A rapid increase in the day-to-day health and living conditions of people, hence increased population for marketing purposes and the supply of a labor force for the expanding factories.
2. Access to large markets, not only in England and the rest of Europe but also in Asia and Africa, as explorers opened up new colonies and global markets. Also, historians point out that even though England had lost the American War of Independence, there nevertheless remained a huge market for goods in the rapidly expanding United States.
3. A long period of social and political stability in Britain. This provided the stage for a more entrepreneurial mood in business and commerce.
4. New techniques in banking and the handling of credit. Added to this were faster communications and reliable methods for handling mail and business documents.
5. Many successive years of successful commerce, which caused capital to accumulate and interest rates to fall. Available and cheap capital favored business. Both large-scale operations and smaller middle-class businesses were formed, which then added to a general "gold rush" type fervor around London and the industrial cities north of England.
6. For sure, the industrial revolution could not have taken off without the steam engine. (In exactly the same way, the current information age could not have taken off without the invention of the transistor and microprocessor 200 years later.) Thomas Newcomen built one of the first steam engines in 1712, but it was James Watt's improved engine designs that made steam power usable by industry: in particular, his patent for a separate condenser was granted in 1769. This steam-powered machinery that was thus set in motion during the industrial revolution paved the way for massive increases in productivity in all fields. The historians (Plumb, 1965; Wood, 1963) provide many examples, in iron, in textiles, and in machinery manufacturing. For example, a rapid series of inventions took cotton spinning out of the house and into the factory. Arkwright's water frame (1769), Hargreaves's multiplied spinning wheel (or jenny) (1770), and Crompton's mule (1779) enormously increased the amount of thread one person could spin. And it took little time to apply the steam engine to these industries such as cotton spinning. The first steam-powered machines were developed in 1785, and in the space of 15 years or so, the transition from cottage industry to factory life was complete. This naturally increased the demand for cotton, which could not have occurred without another invention

by Eli Whitney. Records show that in April 1793, he built the first cotton gin, which revolutionized and rapidly accelerated the output of cotton in Georgia and the southern states.

Historians and economists emphasize strongly, however, that the new technology alone was not enough to account for the dramatic expansion in productivity and commerce. In fact, the historians point out that even steam technology was not a brand new idea. Evidence indicates that the ancient Greeks played with steam-powered toys and that the ancient Egyptians used steam-powered temple doors. Also, in the 15th century, the evidence indicates that China had already developed a rather sophisticated set of technological ideas that included steelmaking, gunpowder, and the ability to drill for natural gas. None of these previous cultures capitalized on such technologies to launch an industrial revolution. All six factors above, added together between 1770 and 1820, were needed. It is thus interesting to review the list in the context of manufacturing growth in the 21st century. In many respects, while today's technology is more related to electronics and telecommunications, to maintain growth, the social and economic drivers must remain much the same.

Once the Industrial Revolution was well under way, beyond 1820, it gave way to a more sustained period of consolidation in both Europe and the United States. The rise and consolidation of the machine tool industry, for example, was important during the period from 1840 to 1910. Increased standardization, improved precision, and more powerful machines provided a base for many other metal-product type industries. These secondary industries could expand only because of the availability of reliable machine tools. *Indeed even today, the machine tool industry is a key building block for industrial society, since it provides the base upon which other industries perform their production.* Rosenberg (1976) has written a comprehensive and engaging review of the origins of the machine tool industry and its crucial supporting role for secondary industries such as the gun making industry. Here are some typical extracts:

> Throughout the whole of the first half of the nineteenth century and culminating perhaps with the completion of Samuel Colt's armory in Hartford in 1855, the making of firearms occupied a position of decisive importance in the development of specialized precision machinery . . . it is clear that both Eli Whitney and Simeon North employed crude milling machines in their musket producing enterprises in the second decade of the nineteenth century as did John D. Hall in the Harper's Ferry Armory . . . the design of the plain milling machine was stabilized in the 1850s and rapidly assumed a prominent place in all the metal trades.

This interaction between gun making and machinery invention created the important manufacturing idea of *interchangeable parts.* Prior to this concept, each gun was handcrafted and fitted together as a unique item. This was because the dozens of subcomponents were machined with no quality control of size or geometry. By contrast, using the interchangeable parts concept, the individual subcomponents were produced with strict uniformity. In this case, any combination of them would fit together nicely. It also meant that assembly could proceed using relatively unskilled labor. Eli Whitney is often credited with the "invention" of the interchangeable parts idea. However, many historians modulate this view. It is more likely that these new manufacturing methods were developed and refined over a *period of* many years by the craftspeople in several New England armories, all of whom were struggling with the same problems of quality control and delivery time (see Rosenberg, 1976). At the same time, in France, LeBlanc developed similar methods for interchangeable parts.

How did these new methods affect customer satisfaction? Some historical accounts point out an initial anxiety from the customers, who were government agencies involved in war (accounts indicate that Thomas Jefferson gave Whitney one of the earliest contracts to make muskets). This was because the interchangeable parts concept required careful machinery setup and exacting quality control. It meant that the initial deliveries were probably slower than usual because of this added setup time. By contrast, the accounts then indicate that the customers were subsequently astonished by how quickly Whitney and other armories could mass-produce large batches. These customers were doubly happy in the event that they needed a spare part. Previously, such a repair might require the hand polishing and adjustments skills of a "fitter and turner." However, with interchangeable parts, it was just a question of buying a replacement and being fairly confident it would be the same size as the original subcomponent.

F. W. Taylor wrote *Principles of Scientific Management* in 1911, much of which was based on his factory experiences in the period 1895–1911, first at the Midvale Steel Company and then at the Bethlehem Steel Corporation. Taylor was an extraordinarily successful man in many areas. First, he co-invented, with Maunsel White, high-speed steel cutting tools that allowed a four times increase in cutting speed in the basic production processes of turning, drilling, and milling. Second, Taylor carefully analyzed individual manufacturing processes such as metal machining and tried to bring them under closer control. The Taylor equation that relates cutting speed to tool life is still used today. This work sprang naturally from the interchangeable parts concept, but for Taylor, even more systematic measurement was the main goal. Third, when he turned his attention to factory organization, he created order out of chaos. He quantified manual labor tasks by breaking them down into substeps. These smaller steps were then more efficiently organized. The goals were to shorten each subtask and get the overall task done more quickly. Such *time-and-motion* studies were so effective for industrial organization at that time that they were soon to be used by all the larger, emerging industrial corporations.

Consequently, *mass production*—usually attributed to Henry Ford—was the natural culmination of the interchangeable parts idea and Taylor's careful methods for dissecting and optimizing industrial tasks. By 1912, the first automobiles were beginning to roll off well-organized production lines (Rosenberg, 1976). The First and Second World Wars further increased the need for speed and efficiency. Weapons produced with great efficiency in the United States were crucial to the success of the Allied forces in Europe.

The knowledge gained from these efficient production methods meant that after the end of the Second World War in 1945–1946, the United States had a world monopoly, especially in comparison with the rest of the world, which was devastated from the war and would need many years to rebuild. Not only did the United States have detailed knowledge of basic manufacturing processes, but it was also very skilled in operations research (OR)—meaning the logistics of how to organize large agricultural and manufacturing enterprises. This was further fueled by the expanding electronics industry. The first *numerically controlled* (NC) machine tools were invented and refined over the period from 1951 to 1955. This period also saw the beginnings of *computer aided manufacturing* (CAM).

In summary, from the end of the Second World War, throughout the 1960s, and into the early 1970s, the United States enjoyed more than 25 years of unparalleled wealth. Excellence in manufacturing was one of the key components to this wealth.

1.4 A SCIENCE OF MANUFACTURING: THE 1980s TO THE PRESENT

1.4.1 Overview: Engineering Science and Organizational Science

It is perhaps human nature to "fall asleep at the wheel" when we are successful. Despite the commercial prowess of the United States in 1970, and despite the early promise of the new ideas in computer aided manufacturing (CAM), many manufacturing operations in the United States were left vulnerable to the new Japanese efficiency and quality assurance (QA) methods. These began to make a very noticeable impact by the mid-1970s.

Consumer items such as VCRs, microwave ovens, televisions, and cameras were the first to be taken over by Japanese manufacturers (such as Matsushita and Sony) and, subsequently, by other Pacific Rim countries. Furthermore, given the reluctance of the "Big Three" U.S. automobile manufacturers to change their designs to reflect increased gas prices in the 1970s, and a general demand from consumers for more reliable vehicles, it was not long before Toyota, Honda, and Nissan were stealing away a worrisome chunk of the U.S. car markets.

Beginning around 1980, how did the United States respond to these challenges? At first, the responses were emotional and a little derogatory. Magazine articles of the early 1980s alleged that our ever-cunning competitors in Europe and Japan were at worst "dumping" steel, autos, and memory chips at below real market costs, merely to penetrate the U.S. market. Or perhaps, more mildly, these new competitors were successful only because of cheaper labor costs. Not surprisingly then, the first rational U.S. response was to heavily invest in *robotics* and unattended *flexible manufacturing systems* (FMS) in order to reduce factory floor labor costs. Taken together, robotics and unattended flexible manufacturing systems can be defined as *computer integrated manufacturing* (CIM).

By the mid-1980s, this investment in CIM did begin to show considerable promise. Nevertheless, as emphasized in the preface, to compete in manufacturing, no amount of fabulous technology alone can win the day. To make a true turnaround in manufacturing excellence, these investments in robotics and FMS needed to be executed in the context of *total quality management* (TQM).

The next two subsections review more details of these issues under two headings:

- *Engineering Science,* defined for this book as the hardware and software of CIM
- *Organizational Science,* defined for this book as the management and TQM issues

It is thus likely that we are now in a historical period, beginning around 1980, in which certain ideas are solidifying that will become the cornerstones of manufacturing analysis. To call them a science may be an exaggeration, but it is useful to nonetheless set the stage for a handful of irrefutable concepts that will stay with manufacturing analysis in the future. These ideas build upon each other, as shown in Figure 1.2.

1.4.2 Engineering Science

The initial visionary work on the application of computers to manufacturing was done by a handful of people including Harrington (1973), Merchant (1980), and Bjorke (1979). They created the idea of computer integrated manufacturing (CIM) as the way to automate, optimize, and integrate the operations of the total system of manufacturing. During the 1980s, CIM naturally expanded to include the use of robotics and artificial intelligence (AI) techniques (see Wright and Bourne, 1988).

The three circles in Figure 1.3 show the early emphasis from the CIM era of Harrington, Merchant, and Bjorke. It includes the basic physics of each process (such

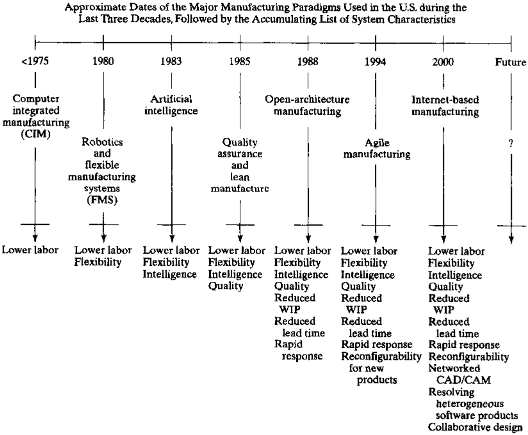

Figure 1.2 Major paradigms in manufacturing.

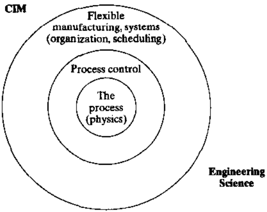

Figure 1.3 Engineering science aspects of Computer Integrated Manufacturing (CIM).

as machining, welding, or semiconductor manufacturing), control issues (such as servo-control of robots and processing machinery), and flexible manufacturing system (FMS) scheduling (e.g., for the production of machined components or IC wafers).

Does Figure 1.3 constitute an engineering science, where the word *science* may be defined in a dictionary as "systematically formulated knowledge"? The key issue is whether mathematical formalism and rigorous proofs can be developed. The pro-science data include the following observations.

First, in the inner circle, there is the physics of the basic processes in materials processing and semiconductors. These processes have, at their deepest roots, topics such as dislocation theory for the basic understanding of plasticity and lattice physics for the basic understanding of the way in which transistors work. At the same time, as metals are deformed in plastic deformation processes such as machining and forging, there are now some very standardized methods (such as the finite element analysis method) that can be universally applied to predict forces across a wide range of individual processes. Similarly, whether ICs are made by NMOS, CMOS, or BiPolar (see Chapter 5), the fundamentals of lithography and doping and the like stay the same. Such observations are a genuine basis for scientific methods and principles that can be widely applied across several manufacturing steps.

Second, in the next circle, there is now a well-established body of knowledge in control theory that prescribes stability, settling time, and accuracy in machines used for manufacturing. Combined with the standard kinematic analyses for linkages, cams and drive mechanisms, and friction, another body of scientific knowledge has been established for this part of manufacturing, primarily concerned with machinery control. Especially as integrated circuits get smaller and smaller, precise machine motions of the lithography patterns are crucial to the success of the whole industry. And here again a body of scientific knowledge exists for optics, materials science, and related issues in solid mechanics.

Third, in the outer circle, the scheduling of a flexible manufacturing system is shown. This involves the analytical areas of discrete event simulation, statistical modeling, optimization, and queuing theory. These are the cornerstones of many Industrial Engineering and Operations Research Departments. In recent years, the AI community has added some additional science to this area, referred to as constraint based reasoning. In summary, the mathematics behind these scheduling issues is now well established in its own right as a science and has very important applications to the scheduling of semiconductor plants where wafers must be economically moved in and out of lithography machines and ovens (Leachman and Hodges, 1996). Despite the more engineering-science approaches to manufacturing already described, they also needed the more organizational methods reviewed next to really make a full impact.

1.4.3 Organizational Science

Ironically, many of the new philosophies involving total quality management were invented by U.S. industrial engineers such as W. E. Deming. Also, historians point out that although the first industrial robot was patented in the United States in 1961, its most enthusiastic users were first in Japan (Engelberger, 1980). Quite simply, the new competitors from Japan and other Pacific Rim countries merely took the "best ideas that were out there" and then applied them with absolute dedication and perfection.

For example, Taiichi Ono championed the Toyota Production System, which reduced work in progress by *pulling* products through a flexible manufacturing system (FMS) rather than *pushing* unnecessary amounts of subcomponents into an already log-jammed system. *Just in time* (JIT) manufacturing is often used to describe this method of operation. *Lean manufacturing* is another associated phrase emphasizing a focus on reduced work-in-progress (WIP) and inventory.

At the same time a new approach to quality control was pioneered by Toyota. In the "old" definition of quality control (QC), a component was measured, *after* it had been made, to see if the processing operation(s) had created the dimensions specified by the designer. Then, if the component did not meet the specified dimensions, it was rejected.

By contrast, today, the "new" Toyota methods focus on measurements *during* the production line activities. Therefore the focus changes: rather than measuring at the end of the line and rejecting parts, measurements are done along the way. Also, machines are adjusted to prevent faulty parts from occurring in the first place. In summary, this has come to be called in-process quality control—or total quality management (TQM). And it puts responsibility on the individual worker and/or machine rather than "punting" problems downstream to be eventually uncovered by inspectors (Cole, 1999). TQM is thus added as a new circle in Figure 1.4, which enlarges the previous Figure 1.3 with organizational and business issues.

As implied in Figure 1.4, *concurrent engineering* (CE)—also known as concurrent design—is a topic that is closely related to TQM. Concurrent engineering also became important during the late 1980s, because too many U.S. companies indulged in *over-the-wall manufacturing*. This catchphrase can be explained as follows: The evidence was widespread in many companies that designers did their work in a social vacuum. Beautiful CAD images were rendered on high-end, graphics-oriented work

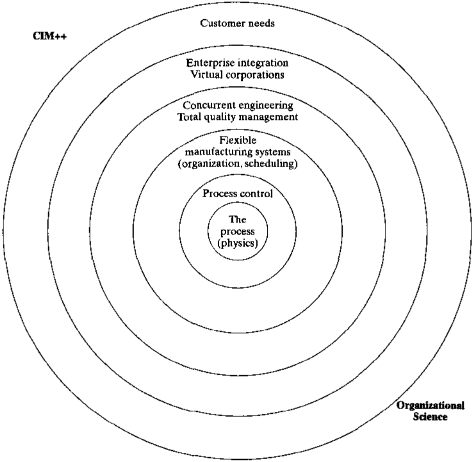

Figure 1.4 Organizational science aspects of computer integrated manufacturing, with more focus on the customer rather than the technology itself (shown earlier in Figure 1.3).

stations, but these images had to be reinterpreted for the specific operation of robots and machine tools on the factory floor. And during this translation, many ambiguities and errors arose, causing long delays between design and manufacturing.

Some of the reasons for the over-the-wall manufacturing of previous decades actually go back to the autocratic F. W. Taylor. He believed that only the design engineers were intelligent enough to make the decisions for production. He asserted that the manufacturing engineers should stay out of the decision loop and just do what they were told. This also seems to have had an influence on the way in which university courses were organized for many decades and the way in which pay scales and responsibilities were divided up in most factories. In general, the designers were university trained; the manufacturers, trade-school trained. By the 1980s, this compartmentalization was not as helpful. *Taylorism* is used today with an unpleasant tone. It creates gulfs between designers and manufacturing engineers, breaks down communication, and creates time delays in a manufacturing system.

Sadly, it took U.S. manufacturers several years to honestly acknowledge that an increased focus on concurrent engineering and total quality management was the only way out of the mess. Here is a quote from "The Quality Wars" by Jeremy Main:

> All of the Big Three started off on more or less the same footing, took different paths to get out of the crisis, but then all ended up doing essentially the same thing. They have found no substitute for TQM.

Luckily for the general economy of the United States, it was not all bad news in the 1980s. The rise of the computer industry led to enormous growth in both hardware and software. And despite a somewhat roller-coaster behavior, the manufacturing of semiconductors in the United States continued with increasing health (Macher et al., 1998). Hardware, operating systems, and software continued to be the forte of U.S. companies, thanks to the creative venture capitalists and the computer culture of Silicon Valley in particular. At the same time, the biotechnology and pharmaceutical industry boomed during the 1980s.

By the late 1980s the organizational sciences of TQM, JIT, CE, and lean manufacturing, combined with the engineering sciences of CIM, all began to create an important improvement in U.S. manufacturing (Schonberger, 1998; Macher et al., 1998). And this set the stage for the economic growth of the 1990s, as described in the next section.

1.5 THE BUSINESS OF MANUFACTURING

Ayres and Miller (1983) provide the succinct definition of manufacturing as the "confluence of the supply elements (such as the new computer technologies) and the demand elements (the consumer requirements of delivery, quality, and variety)." This definition perhaps needs some minor clarification. It relates to the natural "push" of new technologies onto the general marketplace on the one hand. Today, for example, new chips, faster computers, and faster modems are in constant development and being announced almost on a daily basis. On the other hand, there is a hungry "pull" from the marketplace. For example, users want to download programs faster from the Internet and run more lifelike graphics with their video games.

In summary, Ayres and Miller observe that at any time in technological progress, there is a confluence of these "push-pull factors" that stimulates more efficient methods of design and manufacturing on the one hand, and more demanding consumers on the other.

What do these demanding consumers of the 21st century want? Ayres and Miller's definition states that they want delivery, quality, and variety. In more colloquial language, they want pizza, eyeglasses, and their vacation photographs in "one hour or less or their money back." Even in more industrial settings, large computer design companies such as Sun and IBM make similar demands on their manufacturing oriented subsuppliers such as Solectron—a fast growing company in the assembly of printed circuit boards (PCBs).

Thus, in the 1990s, the best companies extended concurrent engineering and TQM to a higher level. This meant a "seamless" connection, all the way from factory floor manufacturing to the desires of the consumer. While this may seem obvious and sensible today, the "old" (certainly pre-1980) factory mentality was mostly focused on getting products out the door and leaving things to a distant marketing organization to make the link to the customer. This is not so today, and this section of Chapter 1 focuses on business issues and manufacturing-in-the-large.

These broader views are shown on the right of Figure 1.2. *Open-architecture manufacturing* and *agile manufacturing* were thus new paradigms that permeated the 1990s. These emphasized quickly reconfigurable enterprises that could respond to the new customer demands of "delivery, quality, and variety" (Greenfeld et al., 1989; Goldman et al., 1995; Anderson, 1997).

By the mid-1990s, Internet-based manufacturing was the natural extension of these paradigms, emphasizing the sharing of design and manufacturing services on the Internet (Smith and Wright, 1996).

The availability of the Internet, videoconferencing, and relatively convenient air travel seem to pave the way for increased global commerce. Large business organizations can be split up but then orchestrated over several continents—perhaps to take advantage of excellent design teams in one country and low-cost, efficient manufacturing teams in another. But in fact, for a variety of cultural and economic reasons, industrial growth has always been dependent on situations where "large businesses are distributed." This was just as true in the year 1770 when cotton from Georgia in the United States was shipped to Bradford in England for manufacturing into garments and then exported to an expanding population throughout the increasingly global British Empire. It was still true in the year 1970, just before the creation of the Internet: product design in the United States and the use of cheaper "offshore manufacturing" was a standard practice. In the 21st century, with the World Wide Web and videoconferencing, there is the *potential* for much faster exploitation of advanced design studios in one location and cheap labor in another. Nevertheless, clear communications—first, between the customer and the designer, and second, between the designer and the manufacturer—remain vital for realizing this potential and obtaining fast time to market. In later chapters of the book, examples will show that those companies that beat their competitors in launching the next chip, cell phone, or any consumer product will usually gain the most profit (see Ulrich and Eppinger, 1995).

Enterprise integration thus appears in the fifth circle of Figure 1.4. This term is actually the idea of concurrent engineering carried to a much larger scale and covering the whole corporation. The key requirement is the integration of all the divisions of a manufacturing-in-the-large enterprise. To reiterate, before 1980, Taylorism created competitiveness rather than cooperation between these various divisions (Cole, 1999). The more 21st century approach must involve the breaking down of barriers between people and subdivisions of an organization so that the whole of the enterprise can share problems openly, work toward shared goals, define shared productivity measures, and then share the dividends equally. Time to market will then benefit from this integrated design and manufacturing approach. This is one central message of this book.

Beyond such intercorporation trust comes the possibility of agreements with outside corporations. These agreements might spring up for a temporary period to suit the commercial opportunity at hand. This more ephemeral version of the old style monolithic business is called the *virtual corporation*. Nishimura (1999) argues that a successful 21st century virtual corporation must continue to rely on the core competency skills of each player, but at the same time, each participant must become more experienced in partnering skills.

Thurow (1999) goes further and argues that "cannibalization is the challenge for old business firms." It means that older well-recognized companies must now fragment into smaller business divisions. These will interact tightly for certain business ventures but then disband when their usefulness is over.

Open-architecture manufacturing, agile manufacturing, Internet-based manufacturing, and the virtual corporation all sound exciting. However, it does not take much imagination to look at Figure 1.2 and realize that a new buzzword or phrase will arrive soon. The reader is left to fill in the question mark. Perhaps the most important thing, emphasized in Figure 1.2, is that each era builds upon the previous one, and that under no circumstances should the organizational sciences built around total quality management be forgotten. New engineering science technologies, such as the Web, offer new ways of creating products and services, but efficiency and in-process quality control in basic manufacturing will always be mandatory.

1.6 SUMMARY

By reviewing the art, technology, science, and business aspects of manufacturing, it can be concluded that the activity of manufacturing is much more than machining metals or etching wafers: manufacturing is an extended social enterprise. In the last 250 years, people have been dramatically changed by the advances in manufacturing. Society has moved from an agrarian society, to handcrafts in cottage industries, to the operation of machinery in factories, to computer automation/robotics (and all its associated software writing and maintenance), and finally to telemanufacturing by modem and the Web.

Gifted philosophers such as Marx and Maslow have noted that people actually prefer to work rather than do nothing. But they want to get recognition for their labors beyond a paycheck. In the early transitions described in Section 1.3, up until the 1950s, craftsmanship often lost out to mass production and the dehumanization of work. Today, by and large, people are not inclined to work in dangerous factory situations or sit in a sea of cubicles carrying out monotonous word processing tasks just for the paycheck.

As the futurist Naisbitt says, people want "high-tech high-touch," meaning all the modern conveniences of life with a softer approach. Thus, once people have enough money, they strive to re-create their jobs, to make them more interesting, or to reeducate themselves for a more intellectually rewarding job. In today's corporations, this generally means moving off the factory floor. Initially, a person's reeducation might lead to a position in machinery diagnostics and repair or in the organization of production. In time, such a position might grow into general management, personnel, and business oriented decision making. It is likely that for several more decades, a *combination of people and partial automation* solutions will be seen on the factory floor. Today, the cost-effective solution is to use mechanized equipment for, say, moving pallets of printed circuit boards through a reflow solder bath but to concurrently use human labor for inspection, monitoring, rework, and the occasional corrective action.

Despite this partial-automation/partial-human situation, the long-term trend is to invest in sophisticated capital equipment that can work completely unattended by humans. This has always been the stated goal of computer integrated manufacturing (Harrington, 1973; Merchant, 1980).

This leaves the people to work with knowledge issues. The trends in both Figures 1.1 and 1.2 from left to right emphasize this change from Taylor's "hired hands" to "*knowledge workers*"—a term first coined by Peter Drucker in the 1940s. For many industries, there is also a shift in balance from *capital-intensive machinery* to *software and corporate knowledge.* Many top managers are being forced to rethink the way their organization functions. Indeed the role of "management" in and of itself is being reevaluated. This is especially true in newer start-up companies where the culture is informal and youth oriented.

Drucker (1999) reexamines the foundations of management within this new context. He argues that management policy within a firm should focus on "customer values and customer decisions on the distribution of their disposable income." This is consistent with the themes at the beginning of Chapter 2 and throughout this book. Without a clear answer to the question "Who is the customer?" product development, design, prototyping, and fabrication may be misguided.

In the 21st century, providing an environment that promotes creativity and flexibility will continue to be the social trend—a rather different emphasis than that of the early "time-and-motion studies" at the beginning of the 20th century! Furthermore, in contrast to working for one company for a lifetime, new graduates see themselves as *free agents,* namely, gaining more skills by moving from one company to another every one to three years (see Jacoby, 1999; Cappelli, 1999).

Given these trends, this introductory Chapter 1 ends with the question, "Will there be manufacturing, and will people work in the year 2100?"

The answer is probably "No" to anything that looks like manual labor, but "Yes" to collective enterprises where people design, plan, and install automation equipment and make things for consumers. And probably, those consumers (in the outer circle of Figure 1.4) will need or want pretty much the same things they have always needed or wanted since before the Greeks and the Romans: good health, nice food, happy relationships, attractive clothes, safe and comfortable housing, as-fast-as-possible transportation, and gizmos for entertainment.

We might telecommute and telemanufacture: one day we might, as admired on "Star Trek," even teletransport—but the human soul will probably stay pretty earthy and basic.

1.7 REFERENCES

Anderson, D. M. 1997. *Agile product development for mass customization.* Chicago: Irwin Publishing.

Armarego, E. J. A., and R. H. Brown. 1969. *The machining of metals.* Englewood Cliffs, N.J.: Prentice-Hall.

Ayres, R. U., and S. M. Miller. 1983. *Robotics: applications and social implications.* Cambridge, MA: Ballinger Press.

Bjorke, O. 1979. Computer aided part manufacturing. *Computers in Industry* 1, no. 1: 3–9.

Bralla, J. G., Ed. 1998. *Design for manufacturability handbook,* 2nd ed.New York: McGraw-Hill.

Cappelli, P. 1999. Career jobs are dead. *California Management Review* 42, no. 1: 146–167.

Cole, R. E. 1999. *Managing quality fads: How american business learned to play the quality game.* New York and Oxford: Oxford University Press.

Drucker, P. F. 1999. *Management challenges for the 21st century.* New York: HarperCollins Publishers.

Engelberger, J. F. 1980. *Robotics in practice.* New York: Amacom Press.

Goldman, S., R. Nagel, and K. Preiss. 1995. *Agile competitors and virtual organizations.* New York: Van Nostrand Reinhold.

Greenfeld, I., F. B. Hansen, and P. K. Wright. 1989. Self-sustaining open system machine tools. In *Transactions of the 17th North American Manufacturing Research Institution,* 304–310.

Harrington, J. 1973. *Computer integrated manufacturing.* New York: Industrial Press.

Jacoby, S. M. 1999. Are career jobs headed for extinction? *California Management Review* 42, no. 1: 123–145.

Leachman, R. C., and D. A. Hodges. 1996. Benchmarking semiconductor manufacturing. *IEEE Transactions on Semiconductor Manufacturing* 9, no. 2: 158–169.

Macher, J. T., D. C. Mowery, and D. H. Hodges. 1998. Reversal of fortune? The recovery of the U.S. semiconductor industry. *California Management Review* 41, no. 1: 107–136. Berkeley: University of California, Haas School of Business.

Merchant, M. E. 1980. The factory of the future—technological aspects. *Towards the Factory of the Future,* PED-Vol. 1, 71–82. New York: American Society of Mechanical Engineers.

Nishimura, K. 1999. Opening address. In *Proceedings of the 27th North American Manufacturing Research Conference.* Berkeley, CA.

Pfeiffer, J. E. 1986. Cro-magnon hunters were really us: working out strategies for survival. *Smithsonian Magazine,* 75–84.

Plumb, J. H. 1965. *England in the eighteenth century.* Middlesex, England: Penguin Books.

Rosenberg, N. 1976. *Perspectives on technology.* Cambridge, England: Cambridge University Press.

Schonberger, R. 1998. *World class manufacturing: The next decade.* New York: Free Press.

Smith. C. S., and P. K. Wright. 1996. CyberCut: A World Wide Web based design to fabrication tool. *Journal of Manufacturing Systems* 15, no. 6: 432–442.

Taylor, F. W. 1911. *Principles of scientific management.* New York: Harper and Bros.

Thomsen, E. G., and H. H. Thomsen. 1974. Early wire drawing through dies. *Transactions of the ASME, Journal of Engineering for Industry* 96, Series B, no. 4: 1216–1224. Also see Thomsen, E. G. Tracing the roots of manufacturing technology: A monogram of early manufacturing techniques. *Journal of Manufacturing Processes.* Dearborn, Mich.: SME.

Thurow, L. 1999. Building wealth. *The Atlantic Monthly* 283, no. 6: 57–69.

Ulrich, K. T., and S. D. Eppinger. 1995. *Product design and development.* New York: McGraw-Hill.

Wood, A. 1963. *Nineteenth century Britain.* London: Logmans.

Wright, P. K., and D. A. Bourne. 1988. *Manufacturing intelligence.* Reading, MA: Addison Wesley.

1.8 BIBLIOGRAPHY

1.8.1 Technical

Compton, W. D. 1997. *Engineering management.* Upper Saddle River, N.J.: Prentice-Hall.

Cook, N. H. 1966. *Manufacturing analysis.* Reading, MA: Addison Wesley.

DeGarmo, E. P., J. T. Black, and R. A. Kohser, 1997. *Materials and processes in manufacturing,* 8th ed. New York: Prentice Hall.

Groover, M. P. 1996. *Fundamentals of modern manufacturing.* Upper Saddle River, NJ: Prentice-Hall.

Jaeger, R. C. 1988. *Introduction to microelectronic fabrication.* Reading, MA: Addison Wesley Modular Series on Solid State Devices.

Kalpakjian, S. 1997, *Manufacturing processes for engineering materials.* 3rd ed. Menlow Park, CA: Addison Wesley Longman.

Koenig, D. T. 1987. *Manufacturing engineering: Principles for optimization.* Washington, New York, and London: Hemisphere Publishing Corporation.

Pressman, R. S., and J. E. Williams. 1977. *Numerical control and computer-aided manufacturing.* New York: Wiley and Sons.

Schey, J. A. 1999. *Introduction to manufacturing processes.* New York: McGraw-Hill.

Womak, J. P., D. T. Jones, and D. Roos. 1991. *The machine that changed the world.* New York: Harper Perennial.

1.8.2 Social

Sale, K. 1996. *Rebels against the future: the Luddites and their war on the industrial revolution.* Reading, MA: Addison Wesley.

1.8.3 Recommended Subscriptions

The Economist, **<www.economist.com>,** 25 St. James St., London SW1A 1HG. This often includes special "pull-out sections" on "high technology": for example, see the June 20, 1998, copy that contains "Manufacturing" and the June 26, 1999, copy that contains "Business and the Internet."

Fast Company, **<www.fastcompany.com>,** 77 North Washington St., Boston, MA, 02114-1927.

The Red Herring, **<www.redherring.com>,** Redwood City, CA, Flipside Communications.

Scientific American, **<http://www.sciam.com>,** 415 Madison Ave., New York, NY, 10017-1111.

Wired **<www.wired.com>,** 520 3rd St., 3rd Floor, San Francisco, CA, 94107-1815.

1.9 CASE STUDY: "THE NEXT BENCH SYNDROME"

Many of the chapters in the book contain a case study that attempts to combine an engineering view of a situation or a product with the management context. Ideally, this combination gives a balanced approach for the management of technology. Some key points that may be learned in this first introductory case study include:

- Product design and prototype manufacturing should involve as much engineering creativity as possible. But!—along the way, always ask some tough, consumer-oriented questions. A sample list follows:
  - Which group of consumers is going to buy this product?
  - Is it at the right price point for this group?
  - Does it have "shelf appeal" among equally priced products?
  - Will consumers enjoy using the product and spread the word to friends?
  - Will customers return to buy the next revision of the product because they have come to appreciate its aesthetic qualities as well as its functional ones?
  - In the 21st century, these *customer needs* will remain as an all-embracing topic—shown in the outer circle of Figure 1.4.

The text below is abstracted from "Tech-Driven Products Drive Buyers Away," written by Glenn Gow in the *San Francisco Chronicle,* March 1995.

> Technology companies are usually great innovators. Most of their new ideas come from engineers. But when engineers (alone) use their ideas to drive new product planning, companies risk failure. The Lisa computer from Apple was an engineering-driven failure, as were most (early) pen-based computers and many computer-aided software engineering packages.
>
> Hewlett-Packard (HP) used to suffer from engineer-driven production so often they developed a name for it: "next-bench syndrome." An engineer working on a new product idea would turn to the engineer on the next bench and ask him what he thought. The first engineer, then, was building a product for the engineer on the next bench.
>
> HP has since developed some very ingenious ways to truly understand the needs of their customers. While the next-bench syndrome may not be completely eliminated, HP has grown significantly in several areas (printers, Unix systems, systems management software, etc.) . . . by demonstrating the value of customer input to the engineering team. To help marketing gain a better understanding of customer needs, HP created customer focus groups, with the engineering team attending the focus groups.

1.10 REVIEW MATERIAL

1. In a spreadsheet with four columns, list the main attributes of manufacturing through four centuries, 18th to 21st, under the headings of equipment, process, and people.

2. Beginning with James Watt's invention of a separate condenser for the steam engine in 1769, list the six factors that historians usually identify that then led to the first industrial revolution between 1770 and 1820. In addition, for each factor, write a sentence or two about the same needs in today's information age revolution, beginning with the transistor in 1947, the first IC in 1958, and the first microprocessor in 1971.
3. Define in short bullets of 25 to 50 words (a) the next bench syndrome, (b) interchangeable parts, and (c) design for manufacturability/assembly (DFM/A).
4. List in a table format five or six reasons why the United States was "asleep at the wheel during the early 1970s," soon leading to losses in competitiveness against Honda/Toyota/Sony. In a second column, list next to each entry some of the organizational science approaches to manufacturing promoted especially by Toyota.
5. List in a table format the six or seven "major manufacturing paradigms" in the last three decades.