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Competitive Manufacturing

1.1 MANUFACTURING MATTERS

In the earlier part of the 20th century, manufacturing became a capital-intensive activity. A rigid mode of mass production replaced mostly small-batch and make-to-order fabrication of products. A turning point was the 1920s. With increased household incomes in North America and Europe came large-scale production of household appliances and motor vehicles. These products steadily increased in complexity, thus requiring design standardization on the one hand and labor specialization on the other. Product complexity combined with manufacturing inflexibility led to long product life cycles (up to 5 to 7 years, as opposed to as low as 6 months to 1 year in today's communication and computation industries), thus slowing down the introduction of innovative products.

In the post–World War II (WWII) era we saw a second boom in the manufacturing industries in Western Europe, the U.S.A., and Japan, with many domestic companies competing for their respective market shares. In the early 1950s, most of these countries imposed heavy tariffs on imports in order to protect local companies. Some national governments went a step further by either acquiring large equities in numerous strategic companies or providing them with substantial subsidies. Today, however, we witness the fall of many of these domestic barriers and the emergence of multinational companies attempting to gain international competitive advantage via distributed design and manufacturing across a number of countries (sometimes several continents), though it is important to note that most such successful companies are normally those that encountered and survived intense domestic competition, such as Toyota, General Motors, Northern Telecom (Nortel), Sony, and Siemens. Rapid expansion of foreign investment opportunities continue to require these companies to be innovative and maintain a competitive edge via a highly productive manufacturing base. In the absence of continuous improvement, any company can experience a rapid drop in investor confidence that may lead to severe market share loss.

Another important current trend is conglomeration via mergers or acquisitions of companies who need to be financially strong and productive in order to be internationally competitive. This trend is in total contrast to the 1970s and 1980s, when large companies (sometimes having a monopoly in a domestic market) broke into smaller companies voluntarily or via government intervention in the name of increased productivity, consumer protection, etc. A similar trend in political and economic conglomeration is the creation of free-trade commercial zones such as NAFTA (the North American Free Trade Agreement), EEC (the European Economic Community), and APEC (the Asia-Pacific Economic Cooperation).

One can thus conclude that the manufacturing company of the future will be multinational, capital as well as knowledge intensive, with a high level of production automation, whose competitiveness will heavily depend on the effective utilization of information technology (IT). This company will design products in virtual space, manufacture them in a number of countries with the minimum possible (hands-on) labor force, and compete by offering customers as much flexibility as possible in choices. Furthermore, such a company will specialize in a minimal number of products with low life cycles and high variety; mass customization will be the order of the day.

In the above context, computer integrated manufacturing (CIM) must be seen as the utilization of computing and automation technologies across the enterprise (from marketing to design to production) for achieving the most effective and highest quality service of customer needs. CIM is no longer simply a business strategy; it is a required utilization of state-of-the-art technology (software and hardware) for maintaining a competitive edge.

In this chapter, our focus will be on major historical developments in the manufacturing industry in the past two centuries. In Sec. 1.2, the beginnings of machine tools and industrial robots will be briefly discussed as a prelude to a more in-depth review of the automotive manufacturing industry. Advancements made in this industry (technological, or even marketing) have benefited significantly other manufacturing industries over the past century. In Sec. 1.3, we review the historical developments in computing technologies. In Secs. 1.4 and 1.5, we review a variety of "manufacturing strategies" adopted in different countries as a prelude to a discussion on the expected future of the manufacturing industry, namely, "information-technology–based manufacturing," Sec. 1.6.

1.2 POST–INDUSTRIAL-REVOLUTION HISTORY OF MANUFACTURING TECHNOLOGIES

The industrial revolution (1770–1830) was marked by the introduction of steam power to replace waterpower (for industrial purposes) as well as animal-muscle power. The first successful uses for such power in the U.K. and U.S.A. were for river and rail transport. Subsequently, steam power began to be widely used in mechanization for manufacturing (textile, metal forming, woodworking, etc.). The use of steam power in factories peaked around the 1900s with the start of the wide adoption of electric power. Factory electrification was a primary contributor to significant productivity improvements in 1920s and 1930s.

Due to factory mechanization and social changes over the past century, yearly hours worked per person has declined from almost 3000 hours to 1500 hours across Europe and to 1600 hours in North America. However, these decreases have been accompanied by significant increases in labor productivity. Notable advances occurred in the standard of living of the population in these continents. Gross Domestic Product (GDP) per worker increased seven fold in the U.S., 10-fold in Germany, and more than 20-fold in Japan between 1870s and the 1980s.

1.2.1 Machine Tools

Material-removal machines are commonly referred to as "machine tools." Such machines are utilized extensively in the manufacturing industry for a variety of material-removal tasks, ranging from simple hole making (e.g., via drilling and boring) to producing complex contoured surfaces on rotational or prismatic parts (e.g., via turning and milling).

J. Wilkinson's (U.K.) boring machine in 1774 is considered to be the first real machine tool. D. Wilkinson's (U.S.A.) (not related to J. Wilkinson) screw-cutting machine patented in 1798 is the first lathe. There exists some disagreement as to who the credit should go to for the first milling machine. R. Johnson (U.S.A.) reported in 1818 about a milling machine, but probably this machine was invented by S. North well before then. Further developments on the milling machine were reported by E. Whitney and J. Hall (U.S.A.) around 1823 to 1826. F. W. Howe (U.K.) is credited with the design of the first universal milling machine in 1852, manufactured in the U.S.A. in large numbers by 1855. The first company to produce machine tools, 1851, Gage, Warner and Whitney, produced lathes, boring machines, and drills, though it went out of business in the 1870s.

As one would expect, metal cutting and forming has been a major manufacturing challenge since the late 1700s. Although modern machine tools and presses tend to be similar to their early versions, current machines are more powerful and effective. A primary reason for up to 100-fold improvements is the advancement in materials used in cutting tools and dies. Tougher titanium carbide tools followed by the ceramic and boron-nitride (artificial diamond) tools of today provide many orders of magnitude improvement in cutting speeds. Naturally, with the introduction of automatic-control technologies in 1950s, these machines became easier to utilize in the production of complex-geometry workpieces, while providing excellent repeatability.

Due to the worldwide extensive utilization of machine tools by small, medium, and large manufacturing enterprises and the longevity of these machines, it is impossible to tell with certainty their current numbers (which may be as high as 3 to 4 million worldwide). Some recent statistics, however, quote sales of machine tools in the U.S.A. to be in the range of 3 to 5 billion dollars annually during the period of 1995 to 2000 (in contrast to $300–500 million annually for metal-forming machines). It has also been stated that up to 30% of existing machine tools in Europe, Japan, and the U.S. are of the numerical control (NC) type. This percentage of NC machines has been steadily growing since the mid-1980s, when the percentage was below 10%, due to rapid advancements in computing technologies. In Sec. 1.3 we will further address the history of automation in machine-tool control during the 1950s and 1960s.

1.2.2 Industrial Robots

A manipulating industrial robot is defined by the International Organization for Standardization (ISO) as "An automatically controlled, re-programmable, multi-purpose, manipulative machine with several degrees of freedom, which may be either fixed in place or mobile for use in industrial application" (ISO/TR 8373). This definition excludes automated guided vehicles, AGVs, and dedicated automatic assembly machines.

The 1960s were marked by the introduction of industrial robots (in addition to automatic machine tools). Their initial utilization on factory floors were for simple repetitive tasks in either handling bulky and heavy workpieces or heavy welding guns in point-to-point motion. With significant improvements in computing technologies, their application spectrum was later widened to include arc welding and spray painting in continuous-path motion. Although the commercial use of robots in the manufacturing industry can be traced back to the early 1960s, their widespread use only started in the 1970s and peaked in the 1980s. The 1990s saw a marked decline in the use of industrial robots due to the lack of technological support these robots needed in terms of coping with uncertainties in their environments. The high expectations of industries to replace the human labor force with a robotic one did not materialize. The robots lacked artificial perception ability and could not operate in autonomous environments without external decision-making support to deal with diagnosis and error recovery issues. In many instances, robots replaced human operators for manipulative tasks only to be monitored by the same operators in order to cope with uncertainties.

In late 1980s, Japan clearly led in the number of industrial robots. However, most of these were manipulators with reduced degrees of freedom (2 to 4); they were pneumatic and utilized in a playback mode. Actually, only about 10% of the (over 200,000) robot population could be classified as "intelligent" robots complying with the ISO/TR 8373 definition. The percentage would be as high as 80%, though, if one were to count the playback manipulators mostly used in the automotive industry. Table 1 shows that the primary user of industrial robots has been indeed the automotive industry worldwide (approximately 25–30%) with the electronics industry being a distant second (approximately 10–15%).

Today, industrial robots can be found in many high-precision and high-speed applications. They come in various geometries: serial (anthropomorphic, cylindrical, and gantry) as well as parallel (Stewart platform and hexapod). However, still, due to the lack of effective sensors, industrial robots cannot be utilized to their full capacity in an integrated sense with other production machines. They are mostly restricted to repetitive tasks, whose pick and place locations or trajectories are a priori known; they are not robust to positional deviations of workpiece locations (Figure 1).

TABLE 1 Industrial Robot Population in 1989

	France	Germany	Italy	Japan	U.K.	U.S.A.	World
Total population (1000s)	7	22	10	220	6	37	387
Automotive industry (%)	33	N/A	30[a]	26	33	N/A	N/A

[a] Calculated based on installations during the past 5 years.

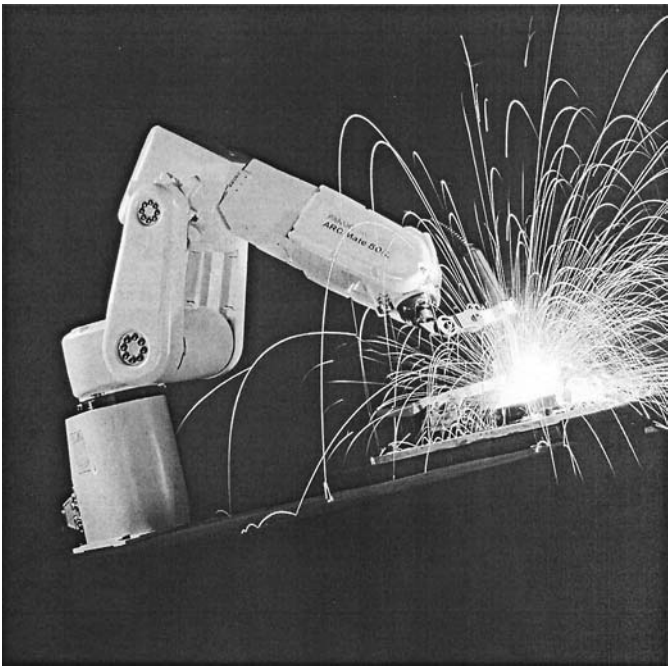

FIGURE 1 A FANUC Mate 50:L welding robot welding a part.

1.2.3 Automotive Manufacturing Industry

The automotive industry still plays a major economic role in many countries where it directly and indirectly employs 5 to 15% of the workforce (Tables 2 to 4). Based on its history of successful mass production that spans a century, many valuable lessons learned in this industry can be extrapolated to other manufacturing industries. The Ford Motor Co., in this respect, has been the most studied and documented car manufacturing enterprise.

Prior to the introduction of its world-famous 1909 Model T car, Ford produced and marketed eight earlier models (A, C, B, F, K, N, R, and S). However, the price of this easy-to-operate and easy-to-maintain car (sold for under $600) was indeed what revolutionized the industry, leading to great demand and thus the introduction of the moving assembly line in 1913. By 1920, Ford was building half the cars in the world (more than 500,000 per year) at a cost of less than $300 each. A total of 15 million Model T cars were made before the end of the product line in 1927 (Figure 2).

TABLE 2 Motor Vehicle[a] Production Numbers per Year per Country (1000s)

	1899	1905	1910	1925	1950	1968	1993	1999
U.S.A.	3	25	187	4,265	8,005	10,206	10,864	13,024
Canada				161	388	1,353	2,237	3,056
France	2	20	38	177	357	2,459	3,155	3,032
Germany[b]	1	4	13	55	304	3,739	3,990	5,687
Italy	N/A	1	5	40	127	1,592	1,267	1,701
Japan				N/A	32	4,674	11,227	9,905
S. Korea[c]						45	2,050	2,832
U.K.	1.6	3	14	176	785	2,183	1,569	1,972
World	N/A	55	256	4,800	10,577	29,745	46,856	54,947

[a] "Motor vehicle" includes passenger cars, trucks, and buses.
[b] Federal Republic of Germany only prior to 1980.
[c] South Korean motor vehicle industry started in 1962 (3000 vehicles).

The first automobile, however, is attributed to N. J. Cugnot, a French artillery officer, who made a steam-powered three-wheeled vehicle in 1769. The first internal-combustion–based vehicle is credited to two inventors: the Belgian E. Lenoir (1860) and the Austrian S. Marcus (1864). The first ancestors of modern cars, however, were the separate designs of C. Benz (1885) and G. Daimler (1886). The first American car was built by J. W. Lambert in 1890–1891.

Since the beginnings of the industry, productivity has been primarily achieved via product standardization and mass production at the expense of competitiveness via innovation. Competitors have mostly provided customers with a price advantage over an innovative advantage. Almost 70

TABLE 3 Motor Vehicle Registration by Country by Year (1000s)

	1925	1950	1953	1992	1998
U.S.A.	19,954	49,177	101,039	190,362	210,901
Canada	718	2,537	7,539	17,010	17,581
France	735	2,422	13,220	29,060	32,300
Germany	323	998[a]	14,289	42,009	46,030
Italy	114	758	8,976	32,260	30,000
Japan	33	337	12,482	61,658	71,209
S. Korea	—	15	58	5,231	10,739
U.K.	902	3,306	12,786	26,651	25,283
World	24,564	70,400	216,608	613,530	663,038

[a] Federal Republic of Germany.

TABLE 4 Employment in U.S. Automobile Industry Plants (1000s)

1925	1950	1976	1999
474	839	881	1,000

automotive companies early on provided customers with substantial innovative differences in their products, but today there remain only three major U.S. car companies that provide technologically very similar products.

From 1909 to 1926, Ford's policy of making a single, but best-priced, car allowed its competitors slowly to gain market share, as mentioned above, via technologically similar but broader product lines. By 1925, General Motors (GM) held approximately 40% of the market versus 25% of Ford and 22% of Chrysler. In 1927, although Ford discontinued its production of the Model T, its strategy remained unchanged. It introduced a second generation of its Model A with an even a lower price. (Ford discontinued production for 9 months in order to switch from Model T to Model A). However, once again, the competitiveness-via-price strategy of Ford did not survive long. It was completely abandoned in the early 1930s (primarily owing to the introduction of the V-8 engine), finally leading to some variability in Ford's product line.

In 1923–1924, industrial design became a mainstream issue in the automobile industry. The focus was on internal design as well as external

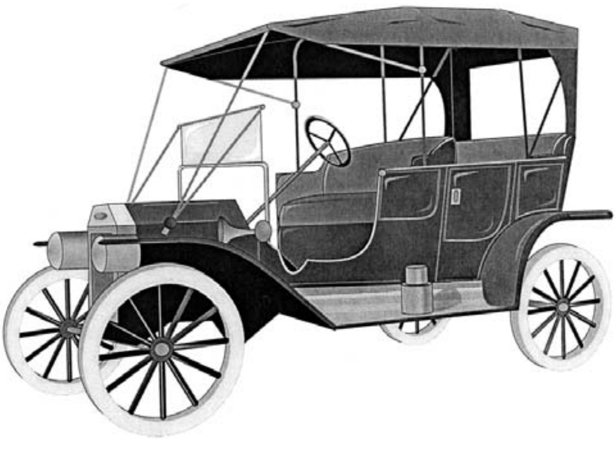

FIGURE 2 The Ford Model T car.

styling and color choices. In contrast to Ford's strategy, GM, under the general management of A. P. Sloan (an MIT graduate), decided to develop a line of cars in multiple pricing categories, from the lowest to the highest. Sloan insisted on making GM cars different from the competition's, different from each other, and different from year to year, naturally at the expense of technological innovation. The objective was not a radical innovation but an offer of variety in frequent intervals, namely incremental changes in design as well as in production processes. Sloan rationalized product variety by introducing several platforms as well as frequent model changes within each platform. His approach to increased productivity was however very similar to Ford's in that each platform was manufactured in a different plant and yearly model changes were only minor owing to prohibitive costs in radically changing tooling and fixturing more than once every 4 to 6 years. The approach of manufacturing multiple platforms in the same plant in a mixed manufacturing environment was only introduced in the late 1970s by Toyota (Table 5). The question at hand is, naturally, How many platforms does a company need today to be competitive in the decades to come?

Chrysler followed GM's lead and offered four basic car lines in 1929; Chrysler, DeSoto, Dodge, and Plymouth. Unlike GM and Ford, however, Chrysler was less vertically integrated and thus more open to innovation introduced by its past suppliers. (This policy allowed Chrysler to gain market share through design flexibility in the pre-WWII era).

The automobile's widespread introduction in the 1920s as a non luxury consumer good benefited other industries, first through the spin-off of manufacturing technologies (e.g., sheet-metal rolling used in home appliances) and second through stimulation of purchases by credit. Annual production of washing machines doubled between 1919 and 1929, while annual refrigerator production rose from 5000 to 890,000 during the same period. Concurrently, the spillover effect of utilization of styling and color as a marketing tool became very apparent. The market was flooded with purple bathroom fixtures, red cookware, and enamelled furniture. One can draw parallels to the period of 1997–2000, when numerous companies, including Apple and Epson, adopted marketing strategies that led to the production of colorful personal computers, printers, disk drives, and so forth.

1.3 RECENT HISTORY OF COMPUTING TECHNOLOGIES

The first electronic computer was built by a team led by P. Eckert and J. Mauchley, University of Pennsylvania, from 1944 to 1947 under the auspices of the U.S. Defense Department. The result was the Electronic

TABLE 5 Platforms/Models for Some Automotive Manufacturers During the Period 1964–1993

	Ford		GM		Chrysler		Fiat		Renault		Volkswagen		Nissan		Toyota	
	1960/64	1990/93	60/64	90/93	60/64	90/93	60/64	90/93	60/64	90/93	60/64	90/94	60/64	90/93	60/64	90/93
Platforms	5.8	7.5	10.0	15.8	5.6	7.8	4.8	7.0	2.2	6.8	1.4	5.0	2.4	17.5	2.0	13.8
Models	7.2	12.5	20.8	31.8	10.0	13.3	8.4	13.5	3.8	8.0	2.6	9.0	2	22.3	2.0	24.3

Numerical Integrator and Computer (ENIAC); the subsequent commercial version, UNIVAC I, became available in 1950.

The first breakthrough toward the development of modern computers came, however, with the fabrication of semiconductor switching elements (transistors) in 1948. What followed was the rapid miniaturization of the transistors and their combination with capacitors, resistors, etc. in multilayered silicon-based integrated circuits (ICs). Today, millions of such elements are configured within extremely small areas to produce processor, memory, and other types of ICs commonly found in our personal computers and other devices (such as calculators, portable phones, and personal organizers).

Until the late 1970s, a typical computer network included a centralized processing unit ("main-frame"), most probably an IBM make (such as IBM-360), which was accessed by users first by punched cards (1950–1965) and then by "dumb" terminals (1965–1980). The 1970s can be considered as the decade when the computing industry went through a revolution, first with the introduction of "smart" graphic terminals and then with the development of smaller main-frame computers, such as the DEC-PDP minicomputer. Finally came the personal (micro) computers that allowed distributed computing and sophisticated graphical user interfaces (GUIs).

In the late 1980s, the impact of revolutionary advances in computer development on manufacturing was twofold. First, with the introduction of computer-aided design (CAD) software (and "smart" graphic terminals), engineers could now easily develop the geometric models of products, which they wanted to analyze via existing engineering analysis software (such as ANSYS). One must, however, not forget that computers (hardware and software) were long being utilized for computer-aided engineering (CAE) before the introduction of CAD software. The second major impact of computing technology was naturally in automatic and intelligent control of production machines. But we must yet again remember that numerical control (NC) was conceived of long before the first computer, at the beginning of the 20th century, though the widespread implementation of automatic-control technology did not start before the 1950s. An MIT team is recognized with the development of the NC machine-tool concept in 1951 and its first commercial application in 1955.

The evolution of computer hardware and software has been mirrored by corresponding advances in manufacturing control strategies on factory floors. In late 1960s, the strategy of direct numerical control (DNC) resulted in large numbers of NC machines being brought under the control of a central main-frame computer. A major drawback with such a centralized control architecture was the total stoppage of manufacturing activities when the main-frame computer failed. As one would expect, even short periods of downtime on factory floors are not acceptable. Thus the DNC strategy was quickly abandoned until the introduction of computer numerical control (CNC) machines.

In the early 1970s, with the development of microprocessors and their widespread use in the automatic control of machine tools, the era of CNC started. These were stand-alone machines with (software-based) local processing computing units that could be networked to other computers. However, owing to negative experience that manufacturers had with earlier DNC strategies and the lack of enterprise-wide CIM-implementation strategies, companies refrained from networking the CNC machines until the 1990s. That decade witnessed the introduction of a new strategy, distributed computer numerical control (DCNC), in which CNC machines were networked and connected to a central computer. Unlike in a DNC environment, the role of a main-frame computer here is one of distributing tasks and collecting vital operational information, as opposed to direct control.

1.3.1 CAD Software and Hardware

Research and development activities during the 1960s to 1980s resulted in proprietary CAD software running on proprietary computer platforms. In 1963, a 2-D CAD software SKETCHPAD was developed at M.I.T. CADAM by Lockheed in 1969, CADD by Unigraphics, and FASTDRAW by McDonell-Douglas followed this initial development. The 1970s were dominated by two major players, Computer Vision and Intergraph. IBM significantly penetrated the CAD market during the late 1970s and early 1980s with its CATIA software, which was originally developed by Dessault Industries in France, which naturally ran on IBM's main-frame (4300) computer, providing a time-sharing environment to multiple concurrent users.

With the introduction of minicomputers (SUN, DEC, HP) in the late 1970s and early 1980s, the linkage of CAD software and proprietary hardware was finally broken, allowing software developers to market their products on multiple platforms. Today, the market leaders in CAD software (ProEngineer and I-DEAS) even sell scaled-down versions of their packages for engineering students (for $300 to 400) that run on personal computers.

1.4 MANUFACTURING MANAGEMENT STRATEGIES

It has been said many times, especially during the early 1980s, that a nation can prosper without a manufacturing base and survive solely on its service industry. Fortunately, this opinion was soundly rejected during the 1990s, and manufacturing once again enjoys the close attention of engineers, managers, and academics. It is now agreed that an enterprise must have a competitive manufacturing strategy, setting a clear vision for the company and a set of achievable objectives.

A manufacturing strategy must deal with a variety of issues from operational to tactical to strategic levels. These include decisions on the level of vertical integration, facilities and capacity, technology and workforce, and of course organizational structure.

The successful (multinational) manufacturing enterprise of today is normally divided into a number of business units for effective and streamlined decision making for the successful launch of products and their production management as they reach maturity and eventually the end of life. A business unit is expected continually and semi-independently to make decisions on marketing and sales, research and development, procurement, manufacturing and support, and financial matters. Naturally, a manufacturing strategy must be robust and evolve concurrently with the product.

As the history of manufacturing shows us, companies will have to make difficult decisions during their lives (which can be as short as a few years if managed unsuccessfully) in regard to remaining competitive via marketing efforts or innovative designs. As one would expect, innovation requires investment (time and capital): it is risky, and return on investment can span several years. Thus the majority of products introduced into the market are only marginally different from their competitors and rarely survive beyond an initial period.

No manufacturing enterprise can afford the ultraflexibility continually to introduce new and innovative products into the market place. Most, instead, only devote limited resources to risky endeavors. A successful manufacturing company must strike a balance between design innovation and process innovation. The enterprise must maintain a niche and a dominant product line, in which incremental improvements must be compatible with existing manufacturing capability, i.e., fit within the operational flexibility of the plant. It is expected that a portion of profits and cost reductions achieved via process innovations on mature product lines today will be invested in the R&D of the innovative product of tomorrow. One must remember that these innovative products of the future can achieve up to 50 to 70% market-share penetration within a short period from their introduction.

1.4.1 Manufacturing Flexibility

Manufacturing flexibility has been described as the ability of an enterprise to cope with environmental uncertainties: “upstream” uncertainties, such as production problems (e.g., machine failures and process-quality problems) and supplier-delivery problems, as well as “downstream” uncertainties due to customer-demand volatility and competitors’ behavior. Rapid technological shifts, declining product life cycles, greater customization, and increased globalization have all put increased pressure on manufacturing companies significantly to increase their flexibility. Thus a competitive company must today have the ability to respond to customer and market demands in a timely and profitable manner. Sony is such a company, that has introduced hundreds of variations of its original Walkman in the past decade.

Manufacturing flexibility is a continuous medium spanning from operational to strategic flexibilities on each end of the spectrum: *operational flexibility* (equipment versatility in terms of reconfigurability and reprogrammability), *tactical flexibility* (mix, volume, and product-modification robustness), and *strategic flexibility* (new product introduction ability). One can rarely achieve strategic flexibility without having already achieved the previous two. However, as widely discussed in the literature, tactical flexibility can be facilitated through in-house (advanced-technology-based) flexible manufacturing systems or by outsourcing, namely, through the development of an effective supply chain.

It has been argued that as an alternative to a vertically integrated manufacturing company, strategic outsourcing can be utilized to reduce uncertainties and thus to build competitive advantage without capital investment. As has been the case for several decades in Germany and Japan, early supplier involvement in product engineering allows sharing of ideas and technology, for product as well as process improvements. Naturally, with the ever-increasing effectiveness of current communication technologies and transportation means, supply chains do not have to be local or domestic. Globalization in outsourcing is here to stay.

1.4.2 Vertical Integration Versus Outsourcing

Every company at some time faces the simple question of “make or buy.” As discussed above, there exists a school of thought in which one maintains tactical or even strategic flexibility through outsourcing. But it is also common manufacturing wisdom that production adds value to a product, whereas assembly and distribution simply add cost. Thus outsourcing must be viewed in the light of establishing strategic alliances while companies join together with a common objective and admit that two hands sometimes can do better than one. Naturally, one can argue that such alliances are in fact a form of vertical integration.

The American auto industry, in its early stages, comprised companies that were totally vertically integrated. They started their production with the raw material (for most of the vehicle components) and concluded their organizational structure with controlling distribution and retail sales. Chrysler was one of the first American companies to break this organizational structure and adopt the utilization of (closely allied) supply chains. IBM was one of the latecomers in reducing its vertical integration and forming alliances with chip makers and software developers for its PC product line.

Managers argue in favor of vertical integration by pointing to potential lower costs through savings on overall product design and process optimization, better coordination and concurrency among the activities of different manufacturing functions (financial, marketing, logistics), and finally by maintaining directly their hand on the pulse of their customers. Another strong argument is the reduction of uncertainties via better control over the environment (product quality, lead times, pricing strategies, and of course intellectual property).

A common argument against vertical integration has been that once a company crosses an optimal size, it becomes difficult to manage, and it loses its innovative edge over its competitors. Many such companies quickly (and sometimes not so quickly) realize that expected cost reductions do not materialize and they may even increase. Vertical integration may also lead a company to have less control over its own departments. While it is easier to let an under-performing supplier go, the same simple strategy cannot be easily pursued in-house.

1.4.3 Taylor/Ford Versus Multitalented Labor

Prior to discussing the role of labor in manufacturing, it would be appropriate briefly to review production scales. Goods produced for the population at large are manufactured on a larger scale than the machines used to produce them. Cars, bicycles, personal computers, phones, and household appliances are manufactured on the largest scale possible. Normally, these are manufactured in dedicated plants where production flexibility refers to a family of minor variations. Machine tools, presses, aircraft engines, buses, and military vehicles on the other hand are manufactured in small batches and over long periods of time. Naturally, one cannot expect a uniform labor force suitable for both scales of manufacturing.

While operators in a job-shop environment are expected to be multitalented ("flexible"), the labor force in the mass production environment is a collection of specialists. The latter is a direct product of the labor profile advocated by F. Taylor (an engineer by training) at the turn of the 20th century and perfected on the assembly lines of Ford Motor Company.

In the pre-mass-production era of the late 1880s, manufacturing companies emphasized "piece rates" in order to increase productivity, while floor management was left to the foremen. However, labor was not cooperative in driving up productivity, fearing possible reductions in piece rates. In response to this gridlock, Taylor introduced the "scientific management" concept and claimed that both productivity and salaries (based on piece rates) could be significantly improved. The basis of the claim was optimization of work methods through a detailed study of the process as well as of the ergonomic capability of the workers. (Some trace the beginning of the discipline of industrial engineering to these studies.)

Taylor advocated the breaking down of processes into their smallest possible units to determine the optimal way (i.e., the minimum of time) of accomplishing the individual tasks. Naturally at first implementation depended on the workers' willingness to specialize on doing a repetitive task daily, which did not require much skill, in order to receive increased financial compensation. (Some claim that these well-paying blue-collar jobs significantly reduced motivation to gain knowledge and skills in the subsequent generations of labor.)

In order to reduce wasted time, Taylor required companies to shorten material-handling routes and accurately to time the deliveries of the subassemblies to their next destination, which led to in-depth studies of routing and scheduling, and furthermore of plant layouts. Despite significant productivity increases, however, Taylor's ideas could not be implemented in job shops, where the work involved the utilization of complex processes that required skilled machinists to make decisions about process planning. Lack of mathematical modeling of such processes, even today, is a major factor in this failure, restricting Taylor's scientific management ideas to simple assembly tasks that could be timed with a stopwatch.

Taylor's work, though developed during 1880 to 1900, was only implemented on a larger scale by H. Ford on his assembly lines during 1900 to 1920 (and much later in Europe). The result was synchronous production lines, where operators (treated like machines) performed specialized tasks during their shifts for months. They were often subjected to time analyses in order to save, sometimes, just a few seconds. On a larger scale, companies extrapolated this specialization to the level of factories, where plants were designed to produce a single car model, whose discontinued production often resulted in the economic collapse of small towns.

The standarization of products combined with specialized labor increased efficiency and labor productivity at the expense of flexibility. Ford Motor Company's response to growing demands for product variety was "They can have any color Model T car, so long as it is black." This attitude almost caused its collapse in the face of competition from GM under the management of A. Sloan, which started to market four different models by 1926. GM managed to remain competitive by maintaining standarization at the fundamental component and subassembly level, while permitting customers to have some choice in other areas.

Following the era of the Taylor/Ford paradigm of inflexibility, flexible manufacturing was developed as a strategy, among others, in response to increased demand for customization of products, significantly reduced lead-times, and a need for cost savings through in-process and post-process inventory reductions. The strategy has become a viable alternative for large-batch manufacturing because of (1) increases in in-process quality control (product and process), (2) technological advancements spearheaded via innovations in computing hardware and software, and (3) changes in production strategies (cellular manufacturing, just-in-time production, quick setup changes, etc.).

One can note a marked increased in customer inflexibility over the past two decades and their lack of willingness to compromise on quality and lead-time. Furthermore, today companies find it increasingly hard to maintain a steady base of loyal customers as global competitiveness provides customers with a large selection of goods. In response, manufacturing enterprises must now have the ability to cope with the production of a variety of designs within a family of products, to change or to increase existing product families and be innovative.

Due to almost revolutionary changes in computing and industrial-automation technologies, shop-floor workers must be continually educated and trained on the state of the art. The above described "factory of the future" requires labor skilled not only in specific manufacturing processes but as well in general computing and control technologies. Naturally, operators will be helped with monitoring and decision-making hardware and software integrated across the factory. A paramount task for labor in manufacturing will be maintenance of highly complex mechatronic systems. Thus these people will be continuously facing intellectual challenges, in contrast to the boredom that faced the specialists of the Taylor Ford factories.

1.4.4 MRP Versus JIT

A follow-up to Taylor's paradigm of minimizing waste due to poor scheduling was the development of the material requirements planning (MRP) technique in the 1960s. MRP is time-phased scheduling of a product's components based on the required delivery deadline of the product itself. An accurate bill of materials (BOM) is a necessity for the successful implementation of MRP. The objective is to minimize in-process inventory via precise scheduling carried out on computers.

Just-in-time (JIT) manufacturing, as pioneered in Japan by the Toyota Motor Company in early 1970s and known as the *kanban* or card system, requires operators to place orders to an earlier operation, normally by passing cards. As with MRP, the objective is inventory minimization by delaying production of components until the very last moment.

Although often contrasted, MRP and JIT strategies can be seen as complementary inventory management strategies. JIT emphasizes that production of any component should not be initiated until a firm order has been placed—a pull system. MRP complements this strategy by back-scheduling the start of the production of this part in order to avoid potential delays for lengthy production activities. MRP anticipates a pull command in advance of its occurrence and triggers the start of production for timely completion and meeting a future demand for the product in a timely manner.

U.S. manufacturers, prior to their encounter with JIT manufacturing, expected MRP magically to solve their complex scheduling problems in the early 1970s, they quickly abandoned it while failing to understand its potential. Although the modest gains of MRP were to be strengthened by the development of manufacturing resource planning (also known as MRP II) in the 1980s, with the introduction of JIT at the same time period, many manufacturing managers opted out from implementing MRP II in favor of JIT, only to recognize later that the two were not competitive but actually complementary techniques for inventory management. A key factor in this was the common but false belief that MRP requires large-batch production owing to the long periods of time needed to retool the machines.

Naturally, JIT was quickly noted to be not as a simple technique as it appeared to be but very challenging to implement. JIT had arrived to the U.S.A. from Japan, where the concept of single-minute die exchange (SMDE) allowed manufacturers to have small batches and product mix on the same line. SMDE, when combined with in-process quality control, was a winning strategy. It took almost a decade for the U.S. manufacturers to meet the triple-headed challenge of JIT, SMDE, and quality control.

Today one can easily see the natural place of JIT in manufacturing enterprises, where orders are received via the internet and passed on to the factory floor as they arrive. JIT eliminates large in-process (or even post production) inventories and allows companies to pass on the significant cost savings to the customers. However, with reduced in-process inventories, a plant is required to have eliminated all potential problems in production in regard to machine failures and product quality. For example, it is not unusual for an automotive parts manufacturing company to work with half-a-day inventory. Industrial customers expect multiple daily deliveries from their suppliers, with potentially severe penalties imposed on delivery delays.

1.5 INTERNATIONAL MANUFACTURING MANAGEMENT STRATEGIES

The 20th century witnessed the development of manufacturing strategies typical to certain continents, countries, and even some specific regions within federalist countries. Current multinational companies, however, must develop manufacturing strategies tailored to local markets as well as have an overall business strategy to compete globally. Prior to a brief review of several key economic engines in the world, it would be appropriate to define manufacturing strategy as a plan to design, produce, and market a well-engineered product with a long-range vision. Competitive priorities in this context can be identified as quality (highest ranked), service, cost, delivery, and product variety. Thus a comprehensive strategy would require design and manufacture of a superior product (backed by an excellent service team) produced at lower costs than the competitor's and delivered in a timely manner.

1.5.1 The U.S. Approach

The U.S.A. has always been the leader in product innovation but not very adept at converting basic R&D into viable commercial products. An exception is software design and marketing, where the U.S.A. maintains three quarters of the world's software market with an excellent information network.

The 1980s and early 1990s were typified in U.S.A. by significant downsizing, where companies tried to achieve lean manufacturing machines capable of producing products of superior quality (as good as Japanese). Reengineering became a key word for change in the way managers thought about their manufacturing processes, though the results were far from revolutionary. Often external consultants were brought in to propose management strategies that were not followed up after their departure.

The late 1990s, however, saw a dramatic shift in U.S. productivity, building on innovation in the philosophy of product design. This combined with the economic (mostly financial) problems that came about in Japan resulted in an unprecedented manufacturing boom in the U.S.A. Hewlett-Packard (HP) was a typical U.S. company capturing a large share of the world's color ink-jet printers and scanners. HP went from no printer manufacturing in 1984 to nearly $8 billion in sales in the mid-1990s. A primary factor in this success was HP's strategic flexibility.

It is important, however, to note that although the U.S.A. currently has a quarter of the world gross domestic product (GDP), the European Economic Community (EEC) is now the world's largest market, with the U.S.A. in second place. U.S. manufacturing companies are partially responsible for this drop, primarily because of their short-term vision and concentration on domestic markets. Despite the economic good times, most still continue to emphasize the objective of quarterly profits by maximizing the utilization of their current capacity (technological and workforce).

The following selective objectives are representative of the current (not-so-competitive) state of the U.S. manufacturing industry:

Customer responsiveness: Deliver what is ordered, in contrast to working with customers to provide solutions that fit their current product's life-cycle requirements and furthermore anticipate their future requirements.

Manufacturing process responsiveness: Dependence on hard tooling, fixed capacity and processes that lag product needs, in contrast to having a reconfigurable and scalable manufacturing plant that implements cost-effective processes that lead product needs and can react to rapidly changing customer requirements. One must not confuse automated machines with truly autonomous systems that have closed-loop processing capability for self-diagnosis and error recovery. Variable capacity must be seen as a strategic weapon to be used for competitiveness and not something to be simply solved by outsourcing or leasing equipment based on the latest received orders.

Human resource responsiveness: Encouragement of company loyalty in exchange for lifetime employment promise, in contrast to hiring of "knowledge individuals" who plan their own careers and expect to be supported in their continuing education efforts. The current U.S. workforce is in a high state of flux, where a company's equity is constantly evaluated by the knowledge and skills of its employees as opposed to only by the value of their capital. In the future, companies will be forced invest not only in capacity and technology but also in training that will increase the value of their employees, without a fear of possible greater turnover.

Global market responsiveness: Dependence on local companies run by locals but that are led by business strategies developed in the U.S.A., in contrast to operating globally (including distributed R&D efforts) and aiming to achieve high world market share. Globalization requires understanding of local markets and cultures for rapid responsiveness with no particular loyalty to any domestic politics.

1.5.2 Germany's Approach

Germany's industrial strength has been in the manufacturing of high-performance products of excellent quality. A common virtue to all German companies is to get things right the first time in well-ordered plants. The workforce is highly skilled, drawn from a population of young people who have passed through a traditional apprenticeship system. Their in-depth knowledge of manufacturing processes lets them more easily adapt to new technologies. At the upper echelon of management, one finds managers with Ph.D. degrees in engineering who are well-versed in economics. Engineering is a degree held in the highest esteem among all professional degrees.

Most German companies have long had reliable supply chains that they utilize for the joint design of well-engineered products. Long-term business objectives mandate strategic management decisions with lower intervention levels from stockholders. However, with rapid globalization of companies and their markets, the German approach to manufacturing management may have to evolve as well.

One must note that, as is the case with their Japanese counterparts, German companies tend to improve on their products and manufacturing processes, as opposed to emphasizing innovation as the U.S. companies attempt to do. Their long history of very high labor costs forced German manufacturers to invest heavily in plant renewals through advanced production machines and in the process achieve at least tactical flexibility levels in many of their companies.

1.5.3 Japan's Approach

Japanese engineering has long concentrated on incremental innovation and commercialization of economically viable inventions. Television, the VCR, and the CD player are a few products developed offshore (by RCA, Ampex, and Phillips, respectively) but successfully commercialized by Sony.

In the 1960s, the Made-in-Japan stamp on products was seen as a symbol of unsuccessful imitations of their American and European counterparts, attempting to penetrate foreign markets based solely on a price advantage. The following two decades caught the world by surprise when (once again) low-price but (this time) superior quality (strategically selected) Japanese household products flooded the world markets. First came televisions, then audio equipment, and finally cars. Although the Japanese companies easily penetrated the U.S. and British markets (and in some instances completely eliminated local competitors), the European continent mostly shut these products out by protectionist actions. In the U.S.A., the local and federal governments joined forces in the 1980s to help the American auto industry survive and not suffer the fate of the television industry for example.

In the 1980s, numerous Japanese automobile makers opened assembly plants in the U.S.A., the U.K., and Canada in order to deal with the increasing local criticism that imports took jobs away from local people. Though they were strictly assembly plants at the start, most of their valuable components being imported from Japan (for maintaining a high level of quality), these plants now have their own local supply chains as a true step toward globalization.

Like Germany, Japan must also heavily rely on exports of manufactured goods to owing the lack of local raw materials as and energy sources. Most such export companies have developed their competitive edge through intense local competitions in attempting to satisfy the domestic population's demand for high quality and timely delivery of goods. The just-in-time production strategy developed in Japan could not be implemented unless manufacturing processes were totally predictable. Another factor adding to the low uncertainty environment was the concept of *keiretsu* (family) based supply chains, which in most cases included large financial institutions. These institutions provided local manufacturing companies with large sums for investment, for capital improvements that did not come with any strings attached, thus, letting companies develop long-term strategies. With the globalization of the world's financial markets, it is now difficult for Japanese companies to secure such low-risk investments.

Like their German counterparts, most Japanese companies have developed operational and tactical flexibility which they rely on for stable, repetitive mass production of goods. However, unlike their European competitors, the Japanese companies have developed a fundamental advantage, significantly shorter product development cycles. This advantage is now being challenged on several fronts by European and American competitors in markets such as telecommunications, automotive, computing, and lately even household electronics.

Japanese companies are currently being forced to shift to innovative product development and marketing as see witness several phenomena occurring worldwide: (1) competition catching up with their productivity (including quality) and tactical flexibility levels, (2) financial globalization eroding their long-enjoyed unconditional investment support, and (3) penetration of information technology into all areas of manufacturing. It did not take long before for companies such as Sony rapidly shifted paradigms and stopped the economic slide.

Keiretsu

The Japanese term *keiretsu*, as used outside Japan, has normally referred to a horizontal group of companies that revolve around a large financial core (a bank plus a trading company—*shosha*). Most horizontal keiretsus also include a large manufacturing company in the center of the group. On the periphery, there is a large number of smaller companies (local banks, insurance companies, manufacturers, etc.) that add up to hundreds of firms associated with an individual keiretsu. Occasionally, there is also a large manufacturing company (for example, Toyota) on the periphery with a loose connection to the horizontal keiretsu, but having a vertical keiretsu itself.

Many vertical keiretsus (supply chains), such as Toyota, Toshiba, and Nissan, belong to one or another horizontal keiretsu. However, some may belong to several horizontal keiretsus (for example, Hitachi), while others maintain a (relative) independence (for example, Sony and Bridgestone). It has been estimated that several thousands of smaller companies form a pyramid to supply the flagship company that bears the name of a vertical keiretsu.

Most horizontal keiretsus have started as businesses owned by individual families at the turn of the 20th century (some even earlier). The four largest families were Mitsui (one of the largest conglomerates in the world), Mitsubishi, Sumitomo, and Yasuda. All these groups prospered throughout the century, but they lost their family control after WWII owing to political pressures and antimonopoly laws. The 1950s were a decade of intense efforts by the Japanese government for the formation of strong and competitive keiretsus. The result was the birth of many clusters, including the big six: Mitsui, Mitsubishi, Sumitomo, Fuyo, Sanwa, and Dai-Ichi Kangyo (DKB).

The Mitsui keiretsu (founded in 1961) has at its core the Sakura Bank, the Mitsui Bussan trading company, and the Mitsui Fudosan real-estate company. Toyota and Toshiba are peripheral vertical keiretsus aligned with the Mitsui Group. The Fuyo keiretsu (founded in 1966) has at its core the Fuji Bank supported by the Marubeni trading company and Canon. Other large manufacturing companies on the periphery of this group include Nissan Motors and Hitachi, the latter belonging to the Sanwa keiretsu as well.

The vertical keiretsus in Japan can be classified into either of manufacturing or trading/distribution. From the start, companies within a vertical keiretsu supplied exclusively those above them in the pyramid, thus developing and maintaining a total social loyalty to the parent company—unlike in the U.S.A., where subcontractors could provide competitors with similar or the same components. Since the 1980s, these keiretsu ties are slowly loosening, especially owing to the establishment of many satellite Japanese plants across the world that supply other local competitors.

The leading vertical keiretsus include the Toyota Group and the Sony Group. The parent flagship company of the former group is Toyota Motors (an automobile manufacturer), which totally dominates the local vehicle market in Japan (as high as 40 to 50%) and whose sales were near $70 billion in the mid 1990s. There are ten core companies at the top level of the Toyota group, and there are several thousands of companies at the lowest level, which generate sales also at a comparable to level that of Toyota Motors ($50 billion in the mid-1990s).

Although the Matsushita Group is the largest vertical keiretsu in the Japanese electronics industry (comprising companies such as, Panasonic, Technics, and JVC), the Sony Group has the most widely recognized name in the world. While Matsushita made almost $60 billion in yearly sales in the mid-1990s, Sony's sales were less than half of these and primarily targeted for export. Lately, the Sony group has made several acquisitions around the world (outside the audio-visual industry), primarily in the entertainment industry (music and movies).

1.5.4 Italy's Approach

Italy is one of the world's most industrialized (top seven) countries, and the northern part of the country enjoys a historical manufacturing base. Owing to cultural attitudes, there are only a very few large companies, most of which were government-owned or government-dominated for many decades. The many thousands of small companies have been owned by individuals and compete in niche markets. Unlike in Germany, most manufacturing managers in Italy have a sales or finance background, and there are few engineers. Being primarily an export-oriented country, domestic competition is underdeveloped. As a company that was forced to deal with this issue, Fiat had to adopt a completely new manufacturing strategy in the late 1980s to maintain its share of the European car market (12–15%). Computer integrated manufacturing (CIM) was adopted in Fiat at a huge financial burden and coupled with a merger of automation and a highly skilled labor force.

1.5.5 Sweden's Approach

The Scandinavian countries of Sweden, Finland, and Norway are culturally similar in putting an emphasis on their populations' welfare. The 1990s in Sweden were a period of increased productivity and of the revitalization of private companies having a strong interest in exports, which led to a reevaluation of the countrys' social infrastructure. Companies such as Volvo and Ericsson have decentralized structures and emphasize teamwork and the utilization of multiskilled operators frequently working in manufacturing workcells (in contrast to flow lines). Lead-time is an important issue in their supply chains that include a very large number of (non-Swedish) European companies.

1.5.6 The U.K. Approach

In the 1890s, the U.K. was the largest manufacturing economy, and its output dominated 25% of the world's market. A century later, in the 1990s, this number shrank to less than 5%, and the U.K. has been overtaken by Germany, France, Japan, and the U.S.A. The U.K. experienced a deindustrialization since the 1960s, and major manufacturing industries (including the automotive) were significantly weakened. As expected, dominance in the world's financial services did not contribute to the U.K.'s development to compensate for the major deindustrialization. Since the 1990s, there has been a reversal in government policies that emphasize once again the importance of manufacturing to the U.K.'s well being. However, most companies investing in manufacturing are foreign multinationals (German, Japanese, and American). It is expected that these companies will lead the U.K. out of deindustrialization and teach the local people the importance of global competitiveness.

1.6 INFORMATION-TECHNOLOGY-BASED MANUFACTURING

The transition from the agrarian society of the 1700s to the industrial society of the 1900s resulted in the industrialization of agriculture, and not its disappearance. Today, only 3% of Americans are engaged in agricultural activities in contrast to the 90% of the workforce in the 1700s. Similarly, in the past century, we did not witness the disappearance of manufacturing, but only its automation (Tables 6 to 8). By 1999, the manufacturing sectors in the U.S.A. constituted only 18% of overall employment, while the number for Japan was down to 21%. At the same time, the services industry grew to 72% in the U.S.A. and to 63.7% in Japan. As we progress through the first decades of the information age, it is expected that globalization will cause the total entanglement of the world's economies as never before.

1.6.1 The Internet and the World Wide Web

The start of the World Wide Web (WWW), or simply the web, can be traced to the work of T. Berners-Lee at the European Particle Physics Laboratory (CERN) in Switzerland around 1989. Although the internet was already around since the 1970s, the difficulty of transferring information between locations restricted its use primarily to academic institutions. It took more than two decades and tens of dedicated computer scientists in Europe and the U.S.A. to bring the web into the forefront. The first version of the hypertext application software only ran on one platform (NEXT, developed

TABLE 6 Employment Percentage by Sector

	U.S.A.			Japan			Germany			Canada		
	1930	1970	1999	1930	1970	1990	1933	1970	1990	1931	1970	1990
Agriculture	22.9	4.5	2.9	49.9	19.9	6.9	2.9	8.5	3.5	35.2	7.6	4.3
Manufacturing	24.5	26.4	18.0	16.1	27.4	23.4	31.6	39.5	31.6	16.4	22.3	15.7
Social services/govt.	9.2	22.0	25.5	5.5	10.3	14.3	6.8	15.7	24.3	8.9	22.0	22.6

TABLE 7 Employment Percentage by Sector (Excluding Agriculture)

	U.S.A.			Japan			Germany			Canada		
	1930	1970	1999	1930	1970	1990	1933	1970	1990	1931	1970	1990
Industry[a]	43.3	33.1	25.1	40.7	35.7	33.8	56.6	48.7	38.9	37.2	29.8	23.4
Services[b]	33.8	62.3	72.0	9.4	47.4	59.2	14.4	42.8	57.6	27.6	62.6	72.3

[a] Mining, construction, manufacturing.

[b] Financial, social, entertainment, communications, government.

TABLE 8 Employment by Profession (Percentage)

	U.S.A.		Japan		Germany		France		Italy		U.K.		Canada	
	1970	1990	1970	1990	1970	1987	1970	1989	1971	1990	1970	1990	1971	1992
Goods handling	61.1	52.6	73.2	65.9	71.6	60.8	66.8	54.9	76.1	62.2	67.6	54.2	58.6	54.3
Information handling	38.9	47.4	26.8	34.1	28.4	39.2	33.2	45.1	23.9	37.8	32.4	45.8	41.4	45.7

by S. Jobs, cofounder of Apple Computer) and was released to a limited number of users in 1991.

P. Wiu, a Berkeley university student, released a graphical browser in the U.S.A. in 1992 that was capable of displaying HTML graphics, doing animation, and downloading embedded applications off the internet. The two following browsers were Mosaic, developed in 1993, and Gopher, developed at the University of Minnesota at about the same time. However, when the University of Minnesota announced that they would consider a licensing fee for Gopher, it was disowned by the academic community and died quickly. The principle at stake was the threat to academic sharing of knowledge in the most open way.

In 1994, the general public was for the first time given access to the web through several internet service providers via modem connections. The year was also marked by the release of Netscape's first version of Navigator, originally named Mozilla, free of charge. Finally, late in the year, the WWW Consortium (W3C) was established to oversee all future developments and set standards. Microsoft's version of their browser, Internet Explorer, was released bundled with their Windows 95 version after a failed attempt to reach a deal with Netscape. By 1996, millions of people around the world were accessing the web, an activity that finally caught the attention of many manufacturing companies and started the transformation of the whole industry into information technology (IT)-based supply chains (spanning from customers at one end to component suppliers at the other).

1.6.2 IT-Based Manufacturing

As mentioned above, the transformation to an IT-based economy began in the 1970s with rapid advances in computing and the continued spirit of academics who believe in the free spread of knowledge. The 1990s were marked by the emergence of the web as a commercial vehicle. Today, highly competitive markets force manufacturing enterprises to network; they must place the customer at the center of their business while continuing to improve on their relationships with suppliers. This transformation will, however, only come easy to companies that spent the past two decades trying to achieve manufacturing flexibility via advanced technologies (for design, production, and overall integration of knowledge sharing) and implementation of quality-control measures.

IT-based manufacturing requires rapid response to meet personalized customer demands. A common trend for manufacturing enterprises is to establish reliable interconnected supply chains by pursuing connectivity and coordination. A critical factor to the success of these companies will be the managing of (almost instantaneous) shared information within the company through intranets and with the outside world through extranets. The task becomes increasingly more difficult with large product-variation offerings.

Information sharing is an important tool in reducing uncertainties in forecasting and in thus providing manufacturers with accurate production orders. In the next decade, we should move toward total collaboration between the companies within a supply chain, as opposed to current underutilization of the web through simple information exchange on demand via extranets. True collaboration requires the real-time sharing of operational information between two supply-chain partners, in which each has a window to the other's latest operational status. In a retail market supply environment this could involve individual suppliers having real-time knowledge of inventories as well as sales patterns and make autonomous decisions on when and what quantity to resupply. Similarly, in supplying assemblers, component manufacturers can access the formers' production plans and shop status to decide on their orders and timing.

Whether the web has been the missing link in the advancement of manufacturing beyond the utilization of the latest autonomous technologies will be answered in the upcoming decade by manufacturing strategy analysts. In the meantime, enterprises should strive to achieve high productivity and offer their employees intellectually challenging working environments via the utilization of what we know now as opposed to reluctantly waiting for the future to arrive.

REVIEW QUESTIONS

1. Discuss recent trends in the structuring of manufacturing companies and comment on their expected operational strategies in the future, including the issue of computer-integrated manufacturing (CIM).
2. What specific advancement has contributed to significant improvements in the efficiency of modern machine tools when compared to their very early versions?
3. Discuss problems experienced with the commercial use of robots in the manufacturing industry during the period 1960 to 1990.
4. Why have vehicle manufacturing practices been very closely studied and implemented in other industries?
5. Compare Ford's passenger car manufacturing and marketing strategies in the earlier part of the 20th century to those implemented at GM by A. P. Sloan. Elaborate on the continuing use of these competitive practices in today's manufacturing industries.

6. State several benefits of the common use of computers in the manufacturing industry. In your discussion compare the state of manufacturing before and after the development and widespread use of information technologies (IT).
7. Computer users long resisted paying for software products and expected hardware makers to provide these at no cost and bundled with the hardware. What led to changes in consumer sentiments in regard to this issue, now that users are willing to pay even for the operating system and not only for specific application software?
8. What is a manufacturing strategy? Why should companies attempt to strike a balance between design innovation and process innovation?
9. Discuss manufacturing flexibility. Address the issues of vertical versus horizontal (including outsourcing) integration of manufacturing enterprises.
10. Discuss the Taylor/Ford paradigm of inflexibility and list its potential advantages.
11. State one positive and one critical aspect of manufacturing management strategies typically adopted by companies in the following world regions: U.S.A./Canada, U.K., continental Europe (excluding the U.K.), and Japan.
12. Discuss the use of IT (hardware and software) in the next two decades, where customers can effectively and in a transparent manner access the computers of the suppliers for order placement, tracking, etc.

DISCUSSION QUESTIONS

1. Most engineering products are based on innovative design rather than on fundamental inventions. They are developed in response to a common customer demand, enabled by new materials and/or technologies. Review the development of a recently marketed product that fits the above description from its conception to its manufacturing and marketing: for example, portable CD players, portable wireless phones, microwave ovens.
2. Computers may be seen as machines that automatically process information, as do automated production machines process materials. Discuss a possible definition of manufacturing as "the processing of information and materials for the efficient (profitable) fabrication and assembly of products."
3. Explain the importance of investigating the following factors in the establishment of a manufacturing facility: availability of skilled labor, availability and closeness of raw materials and suppliers, closeness of

customers/market, and availability of logistical means for the effective distribution of products.

4. Manufacturing flexibility can be achieved at three levels: operational flexibility, tactical flexibility, and strategic flexibility. Discuss operational flexibility. Is automation a necessary or a desirable tool in achieving this level of flexibility?
5. When IBM's subsidiary Lexmark moved from producing manual typewriters to electrical typewriters and, eventually, to computer-input based printers, what level of manufacturing flexibility did they have to have and why? Discuss the three levels of flexibility prior to your answer to the above question: strategic, tactical, and operational.
6. Discuss strategies for retrofitting an existing manufacturing enterprise with automation tools for material as well as information processing. Among others, consider issues such as buying turn-key solutions versus developing in-house solutions and carrying out consultations in a bottom-up approach, starting on the factory floor, versus a top-to-bottom approach, starting on the executive board of the company and progressing downward to the factory floor, etc.
7. The period of 1980 to 2000 has witnessed the dismantling of the vertical integration of many large manufacturers and rapid movement toward supply-chain relationships. Discuss the impact of recent technological and management developments on this movement: short product lives, concurrent engineering carried out in the virtual domain (i.e., distributed design), minimization of in-process inventories, etc.
8. There have been numerous significant approaches proposed during the period of 1980 to 2000 to the reduction of lead times in the production of multiprocess, multicomponent products. However, companies still face tight lead times in an economic environment of short product lives. Discuss the following options and others when faced with a possibility of not being able to meet a customer-expected lead time: expanding/improving the manufacturing facility, subcontracting parts of the work, refusing the order.
9. Fast-food outlets have been often managed via familiar manufacturing strategies that have evolved over the past century, moving from a mass-production environment to mass customization. Discuss the manufacturing strategies of several popular food chains that fabricate/assemble hamburgers, deli/cheese sandwiches, and pizza-based products. In your discussion, compare the manufacturing of these food products to other engineering products, such a personal computers and wireless phones. Do universities also employ such manufacturing strategies in educating students?

10. Computers and other information-management technologies have been commonly accepted as facilitators for the integration of various manufacturing activities. Define/discuss integrated manufacturing in the modern manufacturing enterprise and address the role of computers in this respect. Furthermore, discuss the use of intranets and extranets as they pertain to the linking of suppliers, manufacturers, and customers.
11. The widespread use of the internet, owing to significant increases in the numbers of household computers around the world, has forced companies to provide customers with an on-line shopping capability, creating e-business. Discuss the benefits of e-business as it is expected to allow customers to place/modify orders and access up-to-date information on the status of these orders via the internet, and as they progress through the manufacturing process. Briefly expand your discussion to relationships between suppliers and manufacturers in the context of e-business.
12. The 20th century has witnessed an historical trend in the strong reduction of manual labor in the agricultural industry with the introduction of a variety of (mechanized) vehicles, irrigation systems, crop-treatment techniques, etc. Discuss the current trend of the continuing reduction in the (manual) labor force involved in materials-processing activities versus increases in information-processing activities in manufacturing enterprises. Identify similarities to what has happened in the agricultural industry (and even in the book-publishing, textile, and other industries in earlier centuries) to what may happen in the manufacturing industry in the 21st century.

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