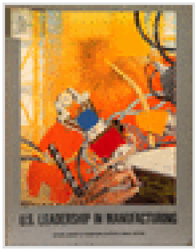

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U.S. LEADERSHIP IN MANUFACTURING

A Symposium at the Eighteenth Annual Meeting

November 4, 1982, Washington, D.C.

National Academy of Engineering

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OPENING REMARKS, KEYNOTE ADDRESS, AND RESPONSE

WELCOME

Courtland D. Perkins

This technical session, entitled "U.S. Leadership in Manufacturing," continues our tradition of the past years of having a technical session on important national engineering subjects. In 1979 the subject was energy, a broad view on the most important subject of the last decade. In 1980 we featured engineering education, an especially timely subject, which has held the center stage ever since. And last year we had a very important session on genetic engineering, an evolving technology.

This year there is nothing more timely in the minds of many of the people in the field of engineering than manufacturing and what new technology can do for us. As you know, the new technologies are robotics, computers, automation techniques, and new materials requiring new processes. We have new design techniques available, such as computer-assisted development/computer-assisted manufacturing (CAD/CAM). We have been moving from batch processing to continuous flow manufacturing.

That is the main thrust of this meeting. The preparation for the meeting was chaired by Erich Bloch of IBM, who with an able group of outstanding people has been planning for this session for many months. It has also been led, from our point of view, by our eminent associate, Kerstin Pollack, who has worked very hard to make this program possible.

Erich Bloch is Vice President, Technical Personnel Development of IBM, where he has been since 1952. He has a B.S.E.E. from the University of Buffalo in New York in 1952. He has also studied at the Federal Polytechnic Institute of Zurich, Switzerland. He is a fellow of the Institute of Electrical and Electronics Engineers, a member of the American Association for the Advancement of Science, and a member of NAE.

It gives me great pleasure to introduce Erich Bloch, who will now take charge of the program.

INTRODUCTION

Erich Bloch

Courtland Perkins described the reasons for NAE to focus on manufacturing, and I would like to set the stage with a few more comments. But before I do that, let me acknowledge at the outset the work done by the various members of the steering committee. Without their efforts and their insight into this topic--a difficult topic I should say--today's program could not have taken place.

New technologies and technological innovation are the major driving forces behind productivity increases. I can best illustrate this point by showing the result of a study by the Brookings Institution (see Figure 1) that quantifies the point that technological innovation is the biggest contributor to productivity--more than scale economics, training, and capital investment. Many times we forget this truth.

This could be the reason why, in fact, U.S. industry is experiencing a lower rate of productivity growth compared to our trading partners. Similarly, our plants are aging because our capital investment is falling behind that of other countries (see Figure 2). What is shown here are facts that we are going to discuss at length during today's program.

While employment of science and engineering people is increasing in U.S. industry, their employment in the manufacturing sector, is, at best, staying constant or maybe even decreasing (see Figure 3). This is particularly a bad sign because we are at the threshold of a significant change in manufacturing, one based more on science and technology activity. This requires the participation of science and engineering professionals in the manufacturing process more than in the past.

Let me describe, in historical terms, what is happening in manufacturing. During the nineteenth century the Industrial Revolution was brought about by harnessing energy, leading to the consolidation of manufacturing resources and their organization into activities exploiting economy of scale. In the twentieth century, and especially since World War II, we have seen and experienced further development in manufacturing disciplines utilizing methods of batch processing and automation of individual tools and focusing on better procedures for ordering, logistics, and control. The developments benefited many companies and industries that took advantage of them. Hard technologies were the driving force in this particular era.

Now we are seeing on the horizon, and it is already being implemented in isolated applications, the necessary technologies to proceed in a significant way to the next step: the total integration of the manufacturing process. This requires

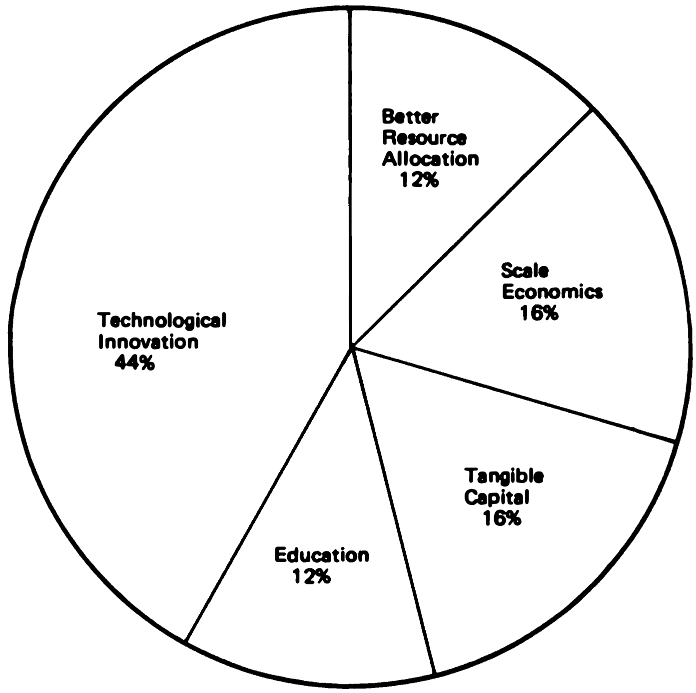

FIGURE 1 Contributions to U.S. productivity increases. Source: The Brookings Institution.

not just the use of new hard technologies, but also the extensive use of soft technologies, such as systems programming.

While robotics has captured the imagination or fear of many and computer-assisted design/computer-assisted manufacturing (CAD/CAM) has become a familiar concept, the changes in manufacturing we are seeing today and will see in the future are much more far-reaching than that. They are analogous to what, in a special way, has been accomplished in process industries for some time, namely the conversion from batch processing to continuous-mode flow processing. The technology is here to apply this concept to discrete parts manufacturing and assembly. The concepts of group technology, flexible tooling, flow production, and computer-integrated manufacturing are all technologies that are part of the factory of the future.

We need to change our model of manufacturing. Manufacturing is no longer just the physical tools and assembly lines but also the complex software programs that tie together all facets of manufacturing: in particular, the design, organizing, scheduling, and control of the whole manufacturing enterprise. These activities themselves are becoming highly automated and highly mechanized, and intertwine in real time with the hardware.

What we are experiencing, I believe, will be judged as revolutionary as what happened during the nineteenth century: In the latter case it was the harnessing of power; today it is the harnessing of information. We are trying today to focus on exactly that--the technological developments that are the cause of these changes, the significant problems that arise because of these changes, and what is required to exploit these new developments.

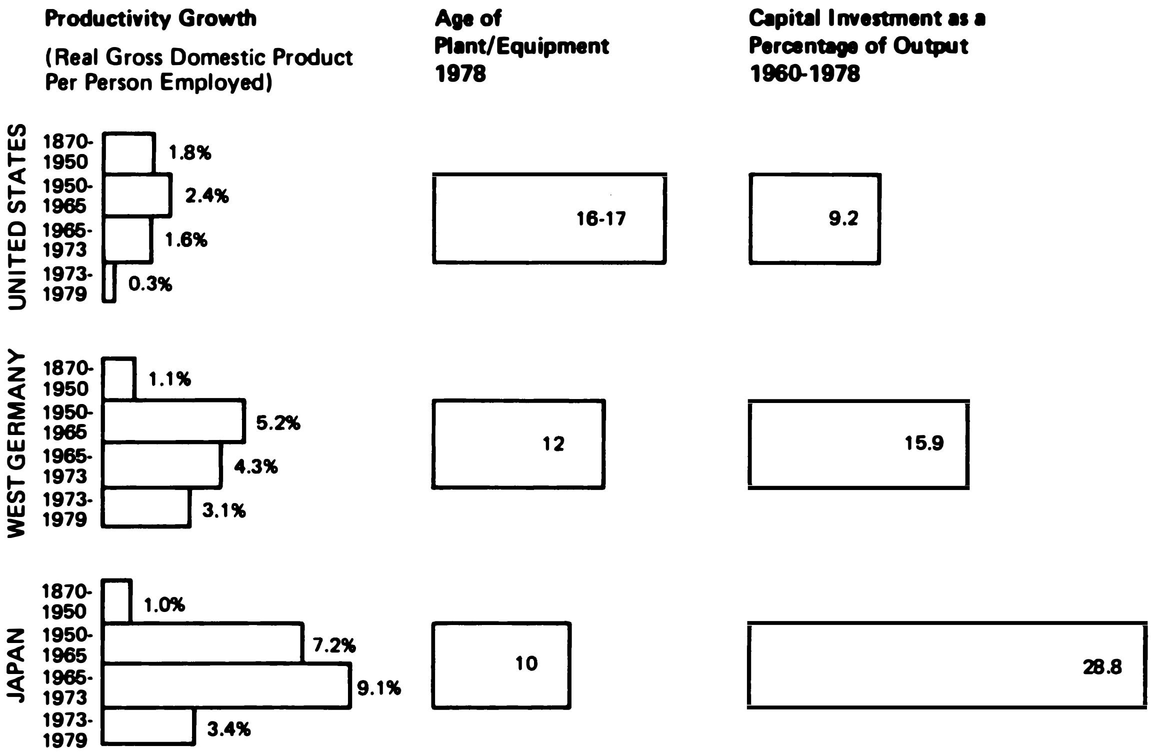

FIGURE 2 Productivity growth, age of plant and equipment, and capital investment as a percentage of output, United States, West Germany, and Japan, selected years, 1870-1979.

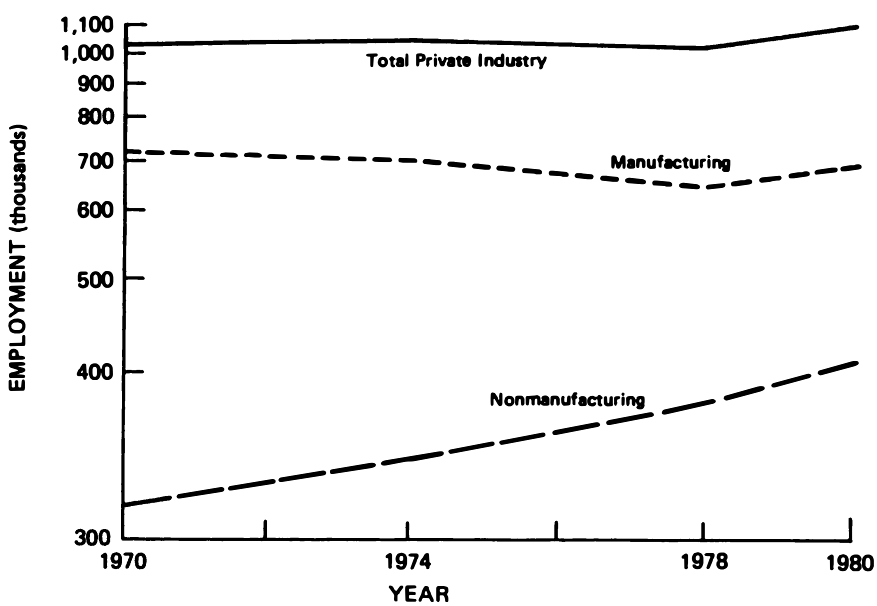

FIGURE 3 Employment of scientists and engineers in private industry by sector, 1970-1980. Source: National Science Foundation and Bureau of Labor Statistics.

To set the stage, we are fortunate to have with us our keynote speaker, James Brian Quinn, Professor of Management at Amos Tuck School at Dartmouth. He was a fellow of the Ford Foundation, a Fulbright Fellow, and the recipient of the MacKenzie Award. He will view U.S. leadership in manufacturing from an economic and academic perspective.

I also want to introduce our second speaker, Thomas J. Murrin, President of Public Systems for Westinghouse Electric Corporation. His response will be from the viewpoint of an executive active in the management of a large manufacturing enterprise. He is a physics graduate, a past member of the U.S. delegation to the NATO Industry Advisory Group, and serves on the Board of Governors of the Aerospace Industry Association. He, too, is qualified to speak about these problems before us.

OVERVIEW OF CURRENT STATUS OF U.S. MANUFACTURING: HISTORY, STATUS, IMPACT ON U.S. ECONOMY, FORCES AT WORK, EDUCATION

James Brian Quinn

In the past few years it has become clear that the Japanese can land a passenger car on the U.S. West Coast for $750-$1,500 less than U.S. companies can deliver comparable models.[1] Japanese unit shipments of semiconductors grew by 37 percent from 1980 to 1981 and dollar shipments grew by 25 percent while U.S. and European suppliers' volume grew by only 1 percent, with value down 8 percent.[2] The 1970s saw productivity growth rates slow in virtually all U.S. industry classifications and even become negative in some.[3] With the United States in its deepest recession since World War II, layoffs are common in manufacturing industries that were once dominant in the world. And some U.S. companies seem to have permanently lost their competitive edge against foreign producers. This has led to a plethora of articles criticizing American managerial and corporate performance.[4]

Does this signal the imminent decline of history's greatest manufacturing nation? Or will U.S. institutions adapt to maintain the capabilities for wealth creation and national independence that manufacturing strength has provided in the past? At the moment a dim perception of our future potentials seems dominant. Is such a forecast either justified or essential?

LONG TERM TRENDS

Unlike agriculture, U.S. manufacturing has employed a relatively stable percentage of the total U.S. workforce for some years. But like agriculture its great productivity has made other sectors' growth possible. In the early 1800s some 70 percent of the U.S. labor force was in agriculture. By 1910 close to 70 percent had moved into nonfarm activities (see Figure 1). Now, in the 1980s, service activities account for over 70 percent of the nonagricultural workforce, with only 22 percent in manufacturing. Only about 3 percent of the workforce is left on the farm. Technological innovation--largely mechanization and its modern concommitant automation--was the primary force releasing labor from each area and providing opportunities in others. From Adam Smith to modern times, philosophers have been concerned that these forces would dehumanize work and ultimately drive so many out of the workforce that there would be no consumers left for the goods machines could produce.[5]

To date the opposite has occurred. Per capita real wealth in the U.S. has continued to grow at a relatively constant rate in excess of 2.4 percent per year (see Figure 2) with vastly increased job opportunities in the nonfarm sector,

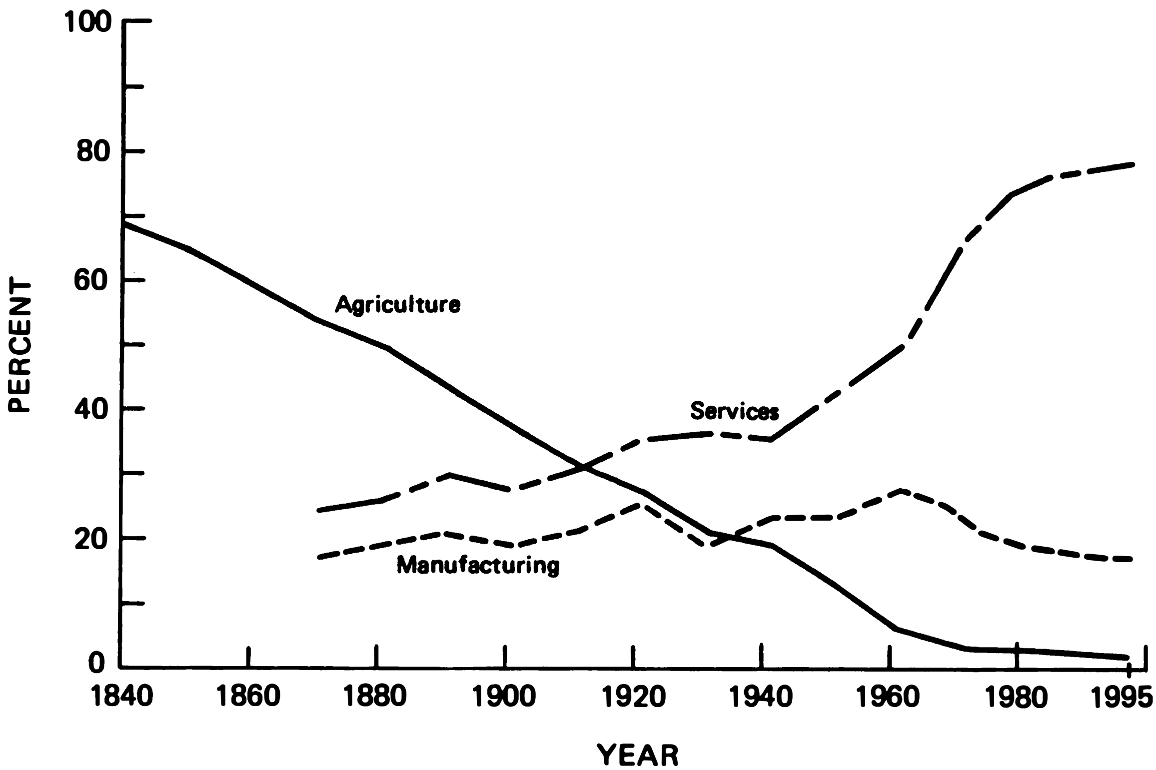

FIGURE 1 Employment as a percentage of total labor force, 1850-1995. Prepared by M. Dingman from Historical Statistics of the U.S.: Colonial Times to 1960 and Predicast, 1982.

predominantly created by imaginative use of new technologies. Factory jobs have in general become more humane as the most onerous and noxious tasks have been automated. Wealth and leisure have been redistributed as work weeks dropped from over 60 hours in the 1800s to the high 30s in the post-World War II era. And income has shifted from property holders (40 percent in 1930 to 15 percent now) to workers (60 percent in 1930 to 70 percent today).[6]

Perhaps the most surprising shift has been in the movement from goods production (manufacturing plus mining and construction) to service activities. Employment in service activities grew from 42 percent of total employment in 1950 to approximately 74 percent today, while manufacturing per se dropped from 23 percent to today's approximately 19 percent.[7] The term service activities, however, should no longer connote small retail shops, as it once did. The sector embraces worldwide banking and insurance groups; huge utilities; and sophisticated laboratory, transportation, government, and communications systems that are very similar in scale, technological complexity, management scope, and output power to large manufacturing enterprises. The health of both sectors is intimately intertwined, each as the customer and supporter of the other. It would be a mistake to design selective policies for one sector without a clear perception of their impact on the other.

About half the benefit from manufacturing R&D accrues to the service sector.[8] Conversely, lower cost and higher quality utility, banking, transpor-

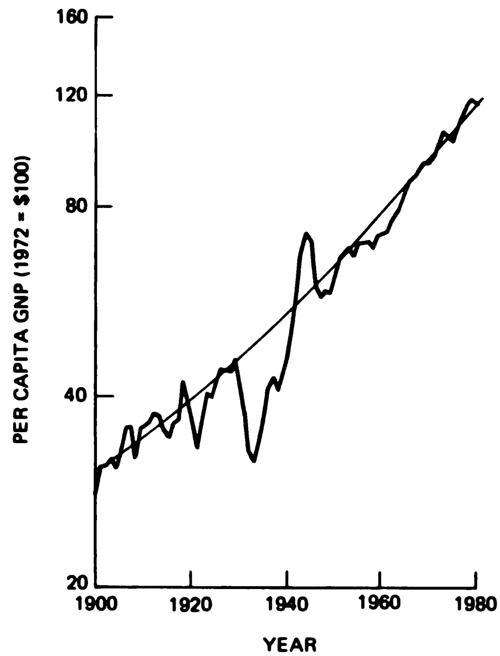

FIGURE 2 Per capita GNP. Source: Federal Reserve Board Chartbook, May 1981.

tation, communications, software, etc. services can have high leverage in decreasing manufacturers' costs in the United States. Service imports and exports also significantly affect the U.S. balance of payments and the strength of the dollar in trade. In 1980, services accounted for a $5.8 billion positive balance of trade plus some share of the $32.7 billion return on direct investment abroad--due to the technology and management contributions embodied in that flow (see Table 1). A nation conceivably could have a total services economy exporting insurance, banking, education, transportation, technology, and recreation access to others in exchange for goods. Monaco and other small principalities operate essentially on this basis. But it is unlikely that a large heterogeneous nation that values its independence could go to this extreme.

From a strategic viewpoint, how much below its current 19 percent of the workforce employed in manufacturing can the United States shrink without sacrificing (1) the vital challenges a strong manufacturing sector poses in maintaining the health of the nation's science, engineering, technical, business

TABLE 1 U.S. International Services Transactions, 1980 (Billions of Dollars)

Services Transactions	Inflow to U.S.	Outflow from U.S.	Net Difference
Travel and transportation	24.1	24.9	-0.8
Miscellaneous services	12.4	5.8	+6.6
Total			+5.8
Income on U.S. assets abroad	75.9	–	+75.9
Income on foreign assets in U.S.	–	43.1	-43.1
Total			+32.8

SOURCE: *Statistical Abstract of the United States, 1981*, Table 1492.

services, and education sector; (2) the essential jobs that manufacturing provides for the less skilled; and (3) the strategic independence and stability manufacturing offers for the United States in world affairs? Manufacturing creates important values beyond its own sales and profits. And to the extent that these values benefit the society and not producers, it may be necessary to provide compensation to keep manufacturers alive. This is the choice European countries have made for steel and other vital sectors.

Past U.S. Strategies

For historical-institutional reasons the United States has never has a formal, preplanned and stated national industrial strategy in the same sense as other nations. But U.S. strategies have nevertheless emerged[9] with profound impacts. Three strategies (of the late 1800s-early 1900s, post-World War II, and 1960s eras) are summarized in the footnotes.[10] Such summary descriptions are obviously incomplete. But there were some common and perceptible dimensions in U.S. industrial strategies during these periods. And the strategies were successful.

By the late 1960s Western allies were concerned that they could never overcome the tragically overplayed technology gap between themselves and the United States. But weaknesses in specific sectors, such as shipbuilding, were already eroding American trade dominance. As relative U.S. wage and raw materials costs rose, foreign manufacturers took over selected niches in the U.S. market and became more competitive elsewhere. When competition forced profit margins in commodity manufacturing to minimal levels, capital and talented people naturally migrated to more glamorous, higher-value-added activities--including services--where gross margins allowed more attractive wage and capital returns. The U.S. share of total world trade dropped from 25.3 percent of exports in 1960 to 17.3 percent in 1977. The effects were masked because dollar values of exports grew from $17.3 billion to $80.2 billion in that same period.[11] Many of these shifts were natural outgrowths of affluence and the fact that more countries--often with U.S. help--had entered the manufacturing arena. But it is also likely that the lack of a positive, coherent industrial strategy in the 1970s had a strong influence. No affirmative national energy policy emerged. Overconsumption--as opposed to industrial investment--was encouraged on all fronts: by huge federal deficits devoted to income transfers, by easy credit policies, by inflation rates higher than savings returns, and by tax policies that selectively encouraged real estate investment over industrial development. By 1979, $2,254 billion was invested in real estate, while the aggregate value of all the stocks and bonds on the New York Stock Exchange was only $1,421 billion.[12] And transportation, education, and other infrastructures went into a state of relative decline.[13]

Although U.S. manufacturing trade balances remained positive in most sectors (see Table 2), dominance in all could not be maintained in perpetuity. Ultimately, a strong exporting nation must import extensively, invest abroad and build its own competition, or see its currency exchange rates rise to unreasonable levels. But strategic as well as market considerations should determine which manufacturing activities are performed domestically and which abroad. It is hard to imagine U.S. strategic independence without strong steel, energy, motor vehicle, microelectronics, and aircraft industries. Yet three of these five represent serious trouble spots today. The causes of their problems differ; hence

TABLE 2 Selected Elements of Merchandise Trade Balance, 1980 (Billions of Dollars)

Merchandise	U.S. Exports	U.S. Imports	Net Difference
Total	220.7	244.9	-24.2
Food and live animals	27.7	12.0	15.7
Beverages and tobacco	2.6	2.7	-0.1
Tobacco and tobacco manufactures	2.4	0.4	2.0
Crude materials	23.8	10.5	13.3
Mineral fuels laboratories	8.0	82.9	-74.9
Petroleum	4.5	77.6	-73.1
Oils and fats	1.9	0.5	1.4
Chemicals and related products	20.7	8.5	12.2
Organic chemicals	5.7	2.5	3.2
Manufactured goods	22.3	32.2	-9.9
Iron and steel	3.1	7.4	-4.3
Nonferrous metals	4.7	7.6	-2.9
Machinery and transportation equipment	84.6	60.5	24.1
Power machinery	8.4	3.8	4.6
Special purpose machinery	12.5	4.6	7.9
General industrial machinery	10.4	3.9	6.5
Office machinery	8.7	2.9	5.8
Telecommunications	3.4	6.7	-3.3
Electrical machinery	10.4	8.1	2.3
Road vehicles	14.6	19.2	-4.6
Passenger cars, new	3.9	16.7	-12.8
Aircraft, spacecraft	12.9	1.9	11.0
Transportation equipment	28.8	28.6	0.2
Professional and scientific instruments	5.2	1.4	3.8
Clothing and accessories	1.1	6.4	-5.3
Miscellaneous manufactures	16.3	23.7	-7.4

SOURCE: U.S. Department of Commerce, *Highlights of U.S. Export and Import Trade*, December 1981.

special policies may be required to maintain each for appropriate strategic purposes.

Some Macro Trends

Fortunately, though under intense current pressures, most U.S industries still appear viable and able to maintain their health through the 1980s, given sensible national and corporate policies. Table 3 sets forth some macrotrends in the U.S. manufacturing structure and some consistent, politically neutral forecasts suggesting mid-1990s positions if current trends continue. Forecast figures are conservative in terms of reflecting possible radical shifts. Some believe electronics/communications markets will explosively expand the manufacturing sector. Others believe the steel, automobile, machine tool, and other mechanical industries may not survive. Whether such dramatic changes actually will occur is still largely a matter of choice, with built-in inertias probably slowing or offsetting more extreme scenarios in the near future.

Nevertheless, the structural changes and implications these forecasts suggest are profound, and positive actions are necessary (1) to avoid more disastrous possibilities and (2) to achieve the relatively benign consequences they suggest are possible. In 1995, manufacturing is still likely to be the largest single-digit SIC

TABLE 3 Selected Industry Forecasts to 1995

	1980					1995				
Industry	GNP ($ Billions Current)	GNP ($ Billions 1972)	Real GNP Growth Rate 1970-80 (%)	Labor Force (Millions)	Labor Force (%)	GNP ($ Billions Current)	GNP ($ Billions 1972)	Real GNP Growth Rate 1980-90 (%)	Labor Force (Millions)	Labor Force (%)
Agriculture, forestry, and fisheries	77	40	1.6	3.3	3.1	210	50	1.7	2.2	1.7
Mining	94	22	1.6	1.0	1.0	420	31	2.4	1.3	1.0
Construction	119	54	0.2	4.4	4.1	431	65	1.5	4.9	3.9
Manufacturing	591	351	3.0	20.3	19.0	2,370	524	2.8	23.9	18.9
Durable goods	355	209	3.0	12.2	11.4	1,435	310	2.8	14.3	11.3
Nondurable goods	236	142	2.9	8.1	7.6	935	214	2.8	9.6	7.6
Transportation	97	53	2.2	5.1	4.8	433	85	3.2	5.8	4.6
Communications	69	55	7.8	1.4	1.3	366	137	6.4	1.9	1.5
Electric, gas, and sanitary services	68	36	3.2	0.8	0.8	357	56	3.1	1.2	0.9
Wholesale trade	148	102	3.5	5.3	4.9	845	173	3.7	5.8	4.6
Retail trade	238	141	3.0	15.1	14.1	1,075	230	3.4	19.0	15.0
Finance, investment real estate	392	236	4.3	5.2	4.8	1,530	403	4.0	6.0	4.7
Services	344	184	3.8	16.3	15.2	1,595	308	3.7	22.6	17.9
Government and government enterprises	303	176	1.4	16.3	15.2	1,035	214	1.4	21.8	17.2
Statistical discrepancy	0.7	2	–	–	–	–	–	–	–	–
Total	2,626	1,481	3.2	106.8	100	10,900	2,325	3.2	126.7	100

SOURCE: *Predicast Forecasts, 1982.*

activity, at some $2.4 trillion (current) dollars or about 22 percent of an $11 trillion economy (see Table 4). In this scenario some 3 million more workers would be anticipated in manufacturing (a 1.1 percent growth rate), but employment in services would expand by some 20 million. The largest sector shifts in GNP appear likely to be toward communications, finance and real estate, and services with greatest manufacturing output increases in electrical machinery, instruments, and chemicals and related products (see Table 5). Average per capita personal incomes would rise to over $33,000 (see Table 4), implying continuing pressures for wage increases and for tax relief at today's surtaxed levels. Most interesting, however, is the estimated $68,000 investment necessary to support each new manufacturing worker and the $45,000 per service worker.[14] These imply aggregate investment needs of $1,104 billion just to handle expected additions to the workforce by the mid-1990s. Other forecasts suggest that new plant and equipment expenditures will be running over $750 billion (current dollars) per year by 1990.[15] All figures are, of course, only scalar indicators, not precise predictions. But projected capital expenditures imply savings, investments, and new equipment markets at vastly expanded dollar levels in the late 1980s. Amounts of capital per worker employed may become ominously high. Assuming 3- to 5-year payback targets, one could hire 10 to 15 workers in developing countries before capital investment would be justified to replace one U.S. worker. With capital costs also rising, capital intensive strategies may become ever more difficult for U.S. firms to maintain in future years. But the alternatives are few.

Manufacturing Health by Sectors

Tables 5 through 10 set forth some measures of the relative health of various manufacturing sectors today. These data show that it is both unfair and unwise to

TABLE 4 Key Macro Indicators, Manufacturing and Services in the United States, 1960-1995

Indicators	1960	1970	1980	1990	1995
Gross National Product ($ billions)	506.5	992.7	2,626.1	6,785.0	10,315.0
Manufacturing output ($ billions)	143.8	252.2	591.1	1,605.0	2,370.0
Nonagriculture employment (millions)	54.2	70.9	90.4	107.3	113.7
Manufacturing employment (millions)	16.8	19.3	20.3	22.1	23.0
Gross investment per manufacturing employee[a] ($ thousands)	10.7	17.7	52.4	62.3	68.4
Total services (nonagriculture) employment (millions)	33.8	47.4	64.8	79.2	84.4
Gross investment per (nonagriculture) services employee[a] ($ thousands)	13.7	19.6	48.2	45.3	45.9
Population (millions)	180.6	204.9	227.2	247.0	256.0
GNP per capita (current $)	2,805	4,854	11,786	29,987	43,600
GNP per capita (1972 constant $)	4,081	5,295	6,517	8,036	9,062
Blue collar workers (millions)	24.1	27.8	31.4	35.6	37.3
White collar workers (millions)	28.5	38.0	51.9	61.2	64.6
Average work week, manufacturing (hours)	39.7	39.8	39.7	38.3	38.0
Average work week, nonagriculture (hours)	38.6	37.1	35.3	34.2	34.0
Personal income (current $ billions)	402	811	2,160	5,563	8,458
Personal income per capita (dollars)	2,225	3,958	9,507	22,525	33,040

[a]Calculated figures for periods 1960-1980 from *Statistical Abstract of the United States, 1981.* For 1990-1995 calculated figures on same basis from projected growth rate of new plant and equipment expenditures, *Predicast Forecasts, 1982.*

TABLE 5 Index of Production Output Changes (1967 = 100)

FRB Industrial Production	1960	1970	1980	1990	1995
Industrial production	66.2	107.8	147.2	223	258
Manufacturing	65.4	106.4	146.7	226	262
Durable manufactures	62.9	102.3	136.7	216	248
Ordinance, private and government	50.1	92.7	77.9	96	109
Lumber and products	74.7	105.6	119.3	172	181
Primary metals	72.4	106.6	101.6	161	183
Fabricated metal products	71.1	102.4	135.1	201	221
Nonelectrical machinery	56.9	104.4	163.1	258	300
Electrical machinery	51.6	108.1	172.7	295	359
Transportation	65.4	89.5	116.9	183	204
Instruments	57.8	112.0	171.1	299	361
Nondurable manufactures	69.3	112.3	161.3	240	281
Foods	78.6	108.9	149.4	199	225
Tobacco	90.5	101.5	119.8	134	140
Textile mill products	69.3	111.8	136.9	191	219
Apparel	81.7	101.4	128.3	175	194
Paper and products	68.0	115.2	151.2	211	240
Chemical and products	56.4	120.4	206.9	354	434
Petroleum	76.7	113.2	134.9	160	164
Rubber and plastics	52.2	132.3	256.1	475	592
Leather	90.2	90.4	70.1	63	59

SOURCE: *Predicast Forecasts, 1981.*

condemn the performance of all U.S manufacturing on the basis of a few industries--notably steel, autos, textiles, and leather products--that were in serious difficulty even before the sharp 1981-1982 recession. Most other (1-and 2-digit SIC) manufacturing sectors had positive trade balances (Table 2), growth rates (Table 5), productivity growth (Table 6), R&D growth (Table 7), new plant and equipment investment (Table 8), and return on equity (Table 9) profiles. Despite shifts toward the service industries, national data show that investments in manufacturing have grown at a slightly faster rate from 1960 to 1980 than those in nonmanufacturing areas (see Table 10). Other than the troubled industries mentioned above, the most disturbing measurable sector observations are (1) the heavy $70+ billion import balance in petroleum, (2) the negative productivity gains in aircraft and parts, and (3) the negative (1980) trade balance in telecommunications. But one must add to this some less measurable concerns: Japanese leadership in new antibiotic compounds and use of robotics, increased European competition in aircraft and space launches, and emergent Japanese power in RAM semiconductors and light-source technologies for fiber optics.[16]

These developments represent threats for the future that must be addressed. In the near future, however, many U.S. producing industries are performing well and will continue to provide attractive investment and employment opportunities as the recession eases. Others are currently in the doldrums, and some traditional industries will probably stay depressed because of permanent cost shifts in their natural resources. Still others can recover given enlightened management and national policies. Policy efforts should operate in a triage mode, focusing on those that can recover, future growth industries, and the few industries that are vital for strategic reasons.

TABLE 6 Labor Productivity for Selected Industries, 1960-1979[a]

Industry	1960	1962	1964	1966	1968	1970	1972	1973	1974	1975	1976	1977	1978	1979 (preliminary)
All manufacturing	0.775	0.827	0.924	0.963	1.000	1.013	1.115	1.146	1.089	1.147	1.197	1.233	1.240	1.251
Food and kindred products	0.778	0.828	0.912	0.979	1.000	1.075	1.147	1.164	1.090	1.242	1.312	1.377	1.408	1.411
Tobacco manufactures	0.808	0.899	0.868	0.929	1.000	1.095	1.266	1.242	1.278	1.370	1.435	1.488	1.457	1.561
Textile mill products	0.629	0.678	0.916	0.998	1.000	1.114	1.175	1.161	1.188	1.236	1.255	1.341	1.406	1.465
Apparel and other fabric products	0.835	0.835	0.885	0.951	1.000	1.008	1.121	1.226	1.211	1.337	1.348	1.422	1.484	1.527
Lumber and wood products	0.594	0.593	0.845	0.894	1.000	1.099	1.067	1.050	1.115	1.186	1.167	1.143	1.124	1.126
Furniture and fixtures	0.892	0.905	0.961	0.999	1.000	0.981	1.088	1.096	1.078	1.144	1.210	1.189	1.195	1.222
Paper and allied products	0.805	0.858	0.918	0.957	1.000	0.998	1.198	1.331	1.260	1.200	1.268	1.314	1.340	1.392
Printing, publishing, and allied industries	0.831	0.863	0.994	0.998	1.000	0.967	1.024	1.078	1.023	1.019	1.067	1.086	1.107	1.106
Chemicals and allied products	0.690	0.749	0.873	0.924	1.000	1.052	1.213	1.275	1.173	1.217	1.297	1.339	1.373	1.412
Petroleum refining and related industries	0.658	0.791	0.886	0.942	1.000	1.050	1.077	1.153	1.107	1.152	1.180	1.352	1.303	1.277
Rubber and miscellaneous plastic products	0.793	0.866	0.955	0.945	1.000	0.992	1.070	1.102	1.006	1.094	1.128	1.081	1.113	1.114
Leather and leather products	0.845	0.905	0.975	1.014	1.000	1.025	1.030	1.181	1.171	1.217	1.250	1.260	1.283	1.270
Stone, clay, glass, and concrete products	0.860	0.917	1.003	0.988	1.000	1.007	1.060	1.080	0.995	1.042	1.156	1.137	1.178	1.182
Primary metals industries	0.849	0.879	0.971	1.020	1.000	0.933	1.011	1.064	1.049	0.985	0.955	0.920	0.929	0.914
Fabricated metal products	0.841	0.904	0.939	0.971	1.000	0.974	1.047	1.068	0.984	1.021	1.082	1.126	1.107	1.110
Nonelectrical machinery	0.860	0.934	0.988	0.990	1.000	1.041	1.132	1.142	1.056	1.127	1.159	1.152	1.137	1.149
Electrical and electronic machinery, equipment, and supplies	0.661	0.731	0.848	0.935	1.000	1.055	1.223	1.260	1.231	1.290	1.326	1.380	1.421	1.408
Motor vehicles and motor vehicle equipment	0.681	0.731	0.841	0.920	1.000	0.884	1.098	1.017	1.007	1.132	1.312	1.452	1.480	1.424
Aircraft and parts	0.772	0.858	0.959	0.944	1.000	0.991	1.109	1.045	0.965	0.940	0.938	0.927	0.957	0.942
Professional and scientific instruments	0.759	0.805	0.861	0.955	1.000	1.013	1.117	1.131	1.017	1.146	1.170	1.135	1.115	1.112
Miscellaneous manufacturing industries	0.823	0.871	0.897	0.924	1.000	1.043	1.181	1.167	1.101	1.245	1.250	1.421	1.431	1.485

[a]Real output per hour of production and nonproduction employed labor (1968 = 1.000).

SOURCE: *Science Indicators, 1980*, and Bureau of Labor Statistics unpublished data.

TABLE 7 R&D Funds as Percent of Net Sales in R&D-Performing Manufacturing Companies, by Industry, 1968-1979

Total		4.0	4.0	3.7	3.5	3.4	3.3	3.1	3.1	3.1	3.1	3.2	3.1
Food and kindred products	20	0.5	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Textiles and apparel	22,23	0.5	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Lumber, wood products, and furniture	24,25	0.4	0.4	0.8	0.7	0.8	0.7	0.8	0.7	0.7	0.8	0.7	0.7
Paper and allied products	26	0.9	1.0	0.9	0.9	0.8	0.7	0.8	0.9	1.0	0.9	1.0	0.9
Chemicals and allied products	28	3.8	3.9	3.9	3.7	3.6	3.5	3.5	3.7	3.7	3.7	3.5	3.5
Industrial chemicals	281-82,286	4.0	4.0	4.2	3.9	3.9	3.6	3.3	3.6	3.7	3.5	3.5	3.2
Drugs and medicines	283	6.0	6.0	6.7	6.2	6.5	6.5	6.3	6.4	6.3	6.4	6.3	6.6
Other chemicals	284-85,287-89	2.1	2.0	1.8	1.9	1.7	1.6	1.6	1.7	1.7	1.8	1.6	1.8
Petroleum refining	29	0.8	0.9	1.0	0.9	0.8	0.7	0.6	0.7	0.6	0.7	0.7	0.6
Rubber products	30	2.1	2.2	2.3	2.2	2.6	2.6	2.5	2.5	2.4	2.1	1.9	1.9
Stone, clay, and glass products	32	1.6	1.7	1.8	1.8	1.7	1.7	1.7	1.2	1.2	1.2	1.2	1.2
Primary metals	33	0.8	0.8	0.8	0.8	0.7	0.7	0.6	0.8	0.8	0.7	0.6	0.6
Ferrous metals and products	331-32,3398,3399	0.7	0.7	0.7	0.7	0.6	0.5	0.5	0.6	0.6	0.6	0.5	0.5
Nonferrous metals and products	333-36	1.0	1.0	1.0	1.0	0.9	0.9	1.0	1.2	1.2	1.0	0.9	0.8
Fabricated metal products	34	1.3	1.2	1.2	1.2	1.1	1.2	1.2	1.2	1.2	1.2	1.1	1.1
Machinery	35	4.0	3.8	4.0	4.0	4.3	4.6	4.6	4.8	4.9	5.1	5.1	5.0
Office, computing, and accounting machines	357	([a])	([a])	([a])	([a])	11.1	11.6	12.6	12.0	11.6	11.9	11.9	11.7
Other machinery, except electrical	35 (Balance)	([b])	([b])	([b])	([b])	([b])	([b])	([b])	([b])	([b])	2.2	2.2	2.2
Electrical equipment	36	8.4	7.9	7.3	7.2	7.1	6.9	6.6	6.5	6.7	6.2	6.3	6.4
Radio and TV receiving equipment	365	2.2	2.2	2.7	2.4	1.6	1.7	1.7	1.4	1.4	1.4	1.1	1.2
Electronic components	367	10.9	9.7	8.2	8.2	5.9	6.2	6.2	6.9	7.3	6.9	6.6	6.5
Communication equipment	366					8.7	8.1	7.6	7.6	7.6	7.6	7.7	7.9
Other electrical equipment	361-64,389	6.8	6.6	6.6	6.4	6.3	6.3	6.3	6.0	6.3	5.3	5.3	8.1
Motor vehicles and motor vehicle equipment	371	3.1	3.1	3.5	3.1	3.3	3.5	3.7	3.5	3.2	3.1	3.2	3.8
Other transportation equipment	373-75,379					1.0	1.2	1.3	1.3	1.3	1.5	1.3	1.2
Aircraft and missiles	372,376	19.0	20.2	16.2	16.2	16.6	13.3	14.1	12.7	12.7	12.8	12.2	12.1
Professional and scientific instruments	38	6.5	6.4	5.7	5.7	5.9	6.1	6.1	5.9	6.2	6.1	6.0	6.2
Scientific and mechanical measuring instruments	381-82	4.1	3.8	3.5	3.7	4.1	4.3	4.5	4.9	5.4	5.9	5.8	6.1
Optical, surgical, photographic, and other instruments	383-87	7.4	7.4	6.6	6.4	6.6	6.8	6.7	6.3	6.4	6.2	6.2	6.4
Other manufacturing industries	21,27,31,39	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7	0.7	0.7

[a]Data not tabulated at this level prior to 1972.
[b]Data not tabulated at this level prior to 1977.

SOURCE: National Science Foundation.

TABLE 8 New Plant and Equipment Expenditures, 1960-1995 (Current $ Billions)

	1960	1970	1980	1990	1995	1980-1990 Annual Growth (%)
Total	48.63	105.61	295.63	775.00	1170.00	10.1
Manufacturing	16.36	36.99	115.81	310.50	465.50	10.4
Durables	8.28	19.80	58.91	157.50	236.00	10.3
Primary metals	1.79	3.24	7.71	18.10	27.00	8.9
Blast furnace and steel works	1.34	1.63	3.29	7.70	11.50	8.9
Machinery	1.21	3.78	11.59	32.50	48.50	10.9
Electrical machinery	1.02	3.49	9.59	30.50	45.50	12.3
Transportation equipment	1.94	4.65	18.16	47.90	72.00	10.2
Lumber and products	0.36	0.97	1.71	4.30	6.50	9.7
Fabricated metal products	0.60	1.22	2.96	6.10	9.20	7.5
Nondurables	8.08	17.19	56.90	153.00	229.50	10.4
Food and beverages	1.35	3.32	7.39	20.20	30.50	10.6
Textile mill products	0.41	0.80	1.62	3.80	5.70	8.9
Paper and products	0.77	1.74	6.80	14.10	20.80	7.6
Chemical and products	1.59	3.38	12.60	30.50	46.00	9.2
Petroleum and products	2.89	5.16	20.69	64.50	97.00	12.0
Rubber	0.34	0.92	1.73	5.40	8.20	12.1
Tobacco	0.05	0.13	1.33	3.40	5.00	9.8
Communications	3.49	10.40	26.16	84.00	134.00	12.4
Percent manufacturing to total	33.6	35.0	39.2	40.1	39.8	

SOURCE: *Predicast Composite Forecasts, 1982.*

TABLE 9 500 Largest Industrial Corporations—Selected Financial Items, by Industry, 1979 and 1980

SIC Code	Industry	Changes in Profits (%)		Sales per Employee ($1,000)		Sales per Dollar of Stockholder's Equity ($)		Return on Stockholder's Equity (%)		Return on Sales (%)		Total Return to Investors[a] (%)	
		1979	1980	1979	1980	1979	1980	1979	1980	1979	1980	1979	1980
	Total	27.3	3.6	71.6	78.1	2.97	3.00	15.9	14.4	5.2	4.8	21.3	21.1
29	Petroleum refining	78.3	25.4	356.1	441.5	3.43	4.00	19.1	19.4	6.6	5.5	61.3	53.1
10	Mining, crude-oil production	73.2	45.4	129.3	177.7	1.90	2.15	16.7	21.0	8.7	9.2	80.5	34.1
49	Beverages	18.9	3.4	92.1	129.4	3.03	2.88	15.7	15.6	5.1	4.8	1.4	18.4
48	Broadcasting[b]	9.4	-4.3	99.6	115.9	2.91	3.00	22.2	18.0	8.3	6.5	37.0	12.5
20	Food	14.5	10.9	100.2	103.0	4.89	4.58	14.4	14.5	3.0	3.0	15.4	9.8
28	Chemicals	24.0	2.7	84.2	100.5	2.48	2.44	15.2	13.9	6.0	5.2	33.9	16.7
33	Metal manufacturing	31.4	-7.6	89.6	96.0	2.94	2.81	15.6	12.9	4.6	4.1	20.6	20.7
26	Paper, fiber, wood products	25.1	-11.4	82.5	93.9	2.46	2.27	15.9	12.8	6.3	5.0	20.8	17.3
21	Tobacco	24.3	15.2	89.7	91.4	2.38	2.51	18.4	19.8	7.7	7.9	14.7	32.5
43	Soaps, cosmetics	14.7	7.6	76.6	84.9	2.83	2.90	17.4	16.9	6.4	5.9	-7.0	5.2
37	Transport equipment[c]	16.1	1.3	74.0	81.1	4.58	4.74	18.1	14.4	4.2	4.1	25.2	35.9
42	Pharmaceuticals	15.5	13.8	66.0	73.5	2.01	1.98	18.0	17.9	8.9	9.1	13.6	29.3
27	Publishing, printing	15.3	8.9	66.5	71.5	2.27	2.40	17.9	15.9	8.2	6.2	21.6	21.2
32	Glass, concrete, abrasives, gypsum	13.2	-13.4	61.7	71.3	2.74	2.63	14.0	11.3	4.9	3.7	15.0	10.5
45	Industrial and farm equipment	16.3	3.9	59.7	69.8	2.86	2.65	15.4	13.3	5.4	4.3	17.5	24.0
40	Motor vehicles	16.3	-52.7	66.1	68.8	3.80	3.27	15.7	8.1	4.1	2.6	12.0	3.4
34	Metal products	21.4	4.0	58.8	67.9	3.19	3.03	16.0	15.3	5.0	4.7	22.1	20.1
41	Aerospace	26.6	6.5	55.5	61.7	4.11	4.04	19.2	16.2	4.8	4.1	44.5	40.5
30	Rubber, plastic products	17.8	-37.6	60.1	60.6	3.60	3.64	8.2	5.0	2.8	1.5	-6.7	28.1
47	Musical instruments, toys, sporting goods	7.0	1.6	47.1	59.0	3.15	2.66	12.1	12.6	3.9	3.7	5.1	22.4
38	Measuring, scientific, photographic equipment	18.1	24.6	45.4	54.4	2.31	2.01	16.1	17.1	6.9	6.9	23.1	28.4
36	Electronics, appliances	18.4	16.6	48.0	54.0	3.29	3.10	16.3	16.2	5.2	5.3	19.8	36.1
44	Office equipment (including computers)	24.6	14.2	45.7	49.9	2.30	2.35	15.9	15.1	7.0	6.0	14.7	20.0
22	Textiles, vinyl flooring	9.1	-25.5	40.5	46.3	3.16	3.08	11.7	8.1	3.8	2.8	17.4	10.4
23	Apparel	21.2	0.9	32.9	38.8	3.03	3.49	15.6	12.8	4.4	3.6	14.7	28.2

NOTE: Figures are medians based on sales rank in 1979 and 1980. Minus sign (–) denotes decrease.

[a]Includes both price appreciation and divident yield, i.e., to an investor in the company's stock.
[b]Includes motion picture and distribution.
[c]Excludes motor vehicles and aircraft.

SOURCE: Time, Inc., *The Fortune Directory*, May 1980 issues.

TABLE 10 Average Annual Rates of Increase for Plant and Equipment Expenditures by Company-Based Industry (Percent Based on Constant 1972 Dollars)

Industry	1947-1980	1947-1972	1972-1980
Total nonfarm business	3.8	3.9	3.6
Manufacturing	3.5	2.4	3.6
Durable goods	4.4	3.5	7.3
Primary metals	2.4	1.2	6.2
Blast furnaces	1.6	0.3	5.9
Nonferrous metals	4.2	3.5	6.2
Fabricated metals	2.0	2.2	1.4
Electrical machinery	6.8	6.2	8.9
Machinery except electrical	5.3	4.2	9.1
Transportation equipment[a]	5.4	3.8	10.2
Motor vehicles	3.5	2.8	5.8
Aircraft	12.2	8.7	23.9
Stone, clay, and glass	3.0	2.4	5.1
Other durables[b]	3.8	4.7	0.9
Nondurable goods	2.7	1.5	6.5
Food and beverage	1.8	1.6	2.3
Textiles	-0.9	-0.2	-2.8
Paper	4.5	2.1	12.2
Chemicals	3.2	1.4	8.9
Petroleum	2.7	1.0	8.1
Rubber	2.2	3.3	-1.2
Other nondurables[c]	3.7	3.1	5.5
Nonmanufacturing	4.1	4.8	1.9
Mining	3.8	2.6	7.8
Transportation	0.8	1.4	-1.1
Public utilities	4.8	6.1	0.9
Trade and services	4.4	5.1	2.1
Wholesale and retail trade	2.7	3.1	1.3
Finance, insurance, and real estate	6.3	7.0	4.2
Personal business and professional services	4.3	5.5	0.7
Communications and other	4.8	5.7	2.1
Communications	5.9	6.4	4.3
Other[d]	2.8	4.6	-2.9

[a]Includes industries not shown separately.
[b]Consists of lumber, furniture, instruments, and miscellaneous.
[c]Consists of apparel, tobacco, leather, and printing-publishing.
[d]Consists of construction; social services and membership organizations; and forestry, fisheries, and agricultural services.

SOURCE: M. J. McKelvey, "Constant-Dollar Estimates of New Plant & Equipment Expenditures in the United States, 1947-1980," *Survey of Current Business*, September 1981, p. 26.

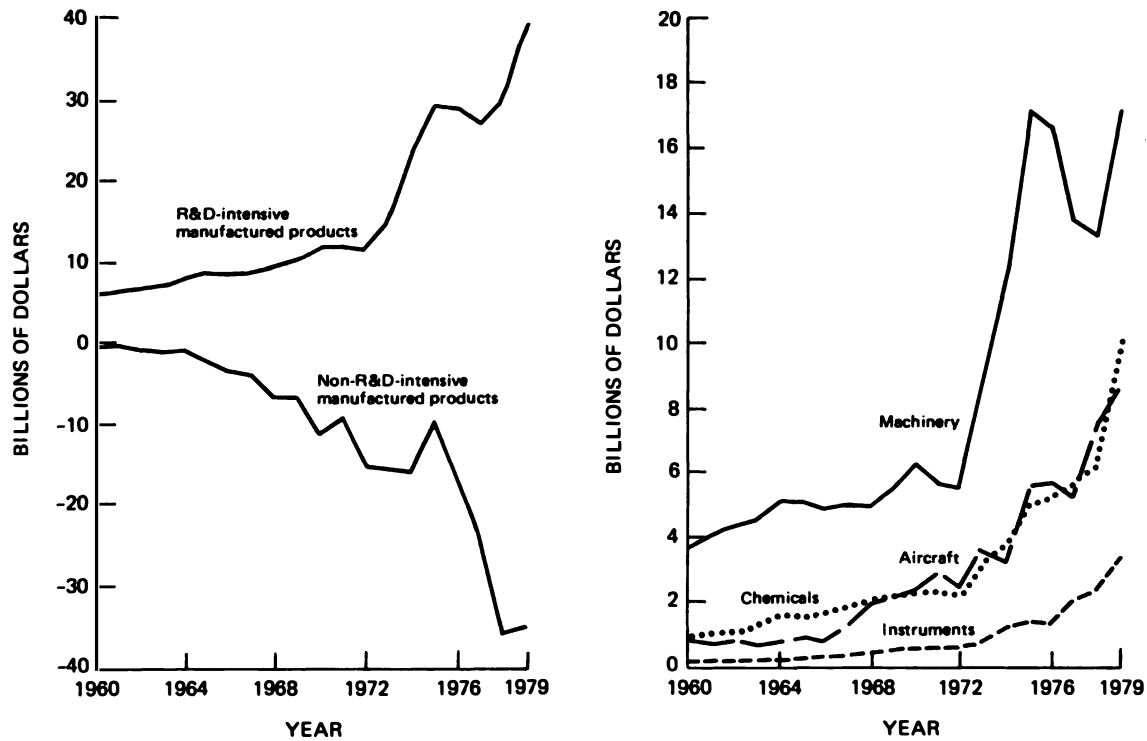

FIGURE 3 U.S. trade balance in R&D-intensive, non-R&D-intensive, and selected other manufactured product groups (exports less imports). Note: "Chemicals" includes drugs and other allied products. After 1977 the Commerce Department made revisions in the product group classifications that affected the balances of these product groups. The overall R&D-intensive balance was unaffected. Source: Science Indicators, 1980.

The Basic Challenge

Without the massive hemorrhage caused by imported petroleum, the United States would have enjoyed a strong $44 billion positive trade balance (in 1981). Expectedly, most of the positive U.S. trade balance is in technology-intensive products (see Figure 3), for which U.S. exports grew in volume (1975-1980) faster than those of any of its major competitors except Japan.[17] Overall, non-R&D- intensive manufacturers incurred a heavy trade loss. The most disturbing trade trends are (1) our increasing dependence on manufacturing exports to developing nations, which may require heavy financial support, and (2) the growing negative trade balances in R&D-intensive products with Japan since 1975 (see Figure 4).

Other than the Japanese challenge, today's core problems can be phrased relatively simply for many U.S. manufacturers. Wage rates and local environmental standards in developing countries are significantly lower than those in the United States. Product and production technologies can often move across national borders easily and have been doing so more rapidly in recent years (see Table 11). Many products can be produced to world-quality standards in a variety of countries by semi- or fully-automated techniques, and capital is relatively easily available to qualified users in most locations throughout the world. If labor

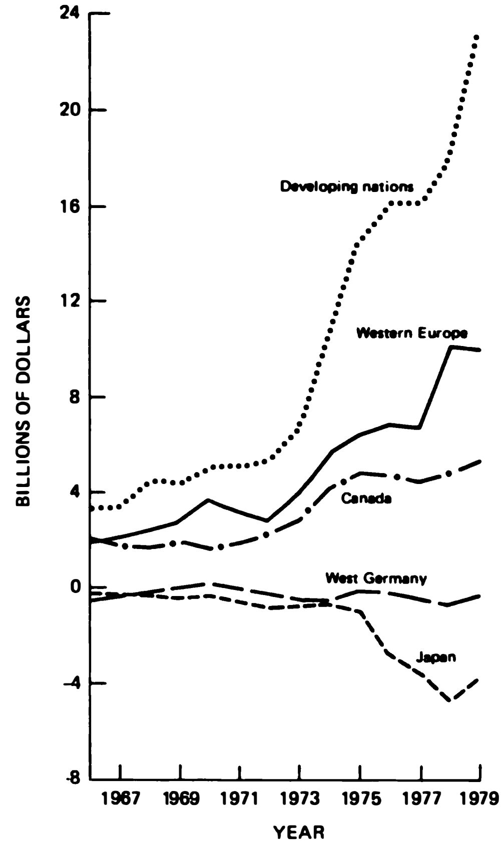

FIGURE 4 U.S. trade balance with selected countries for R&D-intensive manufactured products (exports less imports). Source: Science Indicators, 1980.

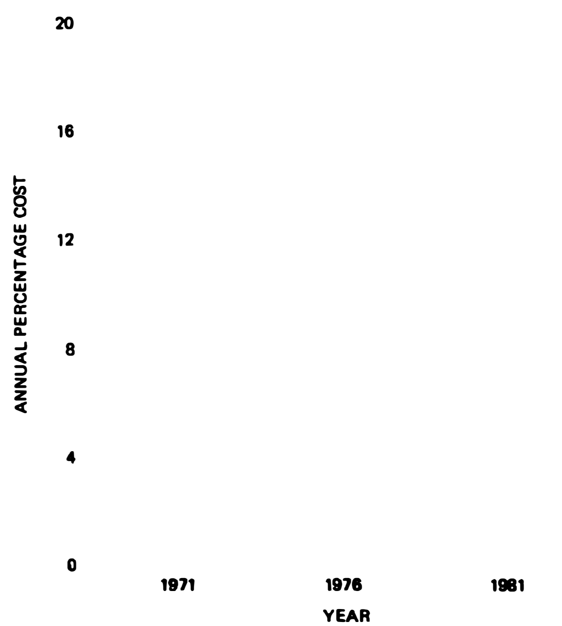

FIGURE 5 Costs of capital for industry in selected countries, 1971, 1976, and 1981. Source: An Assessment of U.S. Competitiveness in High Technology Industries, 1982.

or raw materials cost differentials in other countries are greater than shipping costs to the United States, the added margins available can be poured into quality if desired, thus giving foreign companies potentially dual advantages. Japan has had significant labor cost advantages as well as lower national overheads due to lower defense, inflation, and government spending--hence Japanese capital costs have been lower to producers (see Figure 5). Other high-discipline countries, like Singapore, Hong Kong, and Taiwan, can soon duplicate the Japanese threat on a smaller individual--but aggregatively large--scale.[18] How can U.S. companies compete under these circumstances? For an increasing range of industries, the answers are not easy.

U.S. MANAGEMENT PRACTICES

Because of increased technological substitution and transfer potentials, long-term proprietary leads based on a fixed product or process technology are probably not possible any more. With economies of scale due to capital investment also harder to justify in an era of high-cost capital and low-cost foreign labor, leadership and affluence will increasingly depend on foresight, continuous innovation, and rapid response capabilities both at the national level and in individual companies. The willingness and capability for managers (1) to make long-term strategic investments and (2) to innovate continuously (in both organizational and technological domains) will continue to be the most important factors--other than access to special resources--determining future success for most U.S. manufacturing sectors and individual companies. Unfortunately, both unwise U.S. government policies and widely accepted management practices have often militated against positive actions in both areas.

The fact that both strong and weak manufacturing sectors--and usually strong and weak companies within sectors--exist side by side suggests that much of the burden for past problems and future changes must fall on the top managers and technical leaders of individual companies.[19] One must be careful not to condemn our many well managed companies because of the shortsightedness displayed by others. But the following problem areas are widespread enough to be considered critical sources of U.S. manufacturing difficulties.

Inappropriate Strategies

While Japan exploited the high-quality, high-volume, low-cost, science and technology importation strategies of American industry in its halcyon years, many U.S. managements adopted the limited-niche, price-skimming, elitist strategies they once disparaged in European companies. Some ignored emerging world markets and concentrated on a "series of highly segmented product niches" in the United States rather than using the full potential of scale economies in aggressive international strategies. Some mistakenly focused on luxury rather than quality within their segments and overlooked until too late the potential impact of experience-curve effects in mass markets where large opportunities lay. Others defended existing investments far too long, rather than adopting more attractive new product lines or processes. These strategic errors were compounded by (1) Japan's rapid emergence based on a highly intelligent and disciplined manufacturing system with a strong motivation to export and (2) the extended capacity and willingness of competitors to diffuse manufacturing technologies to other countries.

TABLE 11 Percentage U.S. Transfers of Innovations to Foreign Manufacturing Subsidiaries and Independent Licensees, by Period of U.S. Introduction, 1945-1975[a]

	Transfers, by Number of Years Following U.S. Introduction					
Period of U.S. Introduction	Less than 2 Years After	2 or 3 Years After	4 or 5 Years After	6 to 9 Years After	10 or More Years After	Total
1945-1955 (94 innovations)						
Via subsidiaries	4.3	5.6	3.4	13.4	73.0	319
Via licensees	0.3	2.8	8.7	5.0	28.8	146
Subsidiaries as percent of total	93.3	66.7	28.2	72.9	71.7	68.6
1956-1965 (70 innovations)						
Via subsidiaries	13.4	21.8	11.7	25.6	27.3	179
Via licensees	10.4	14.9	22.4	19.4	32.8	67
Subsidiaries as percent of total	77.4	79.6	58.3	78.0	69.0	72.8
1966-1975 (57 innovations)						
Via subsidiaries	22.6	38.1	21.6	16.5	1.0	97
Via licensees	8.3	16.7	41.6	25.0	8.3	24
Subsidiaries as percent of total	91.7	90.2	67.7	72.7	33.3	80.2
Total, 1945-1975 (221 innovations)						
Via subsidiaries	10.1	15.8	8.9	17.6	49.5	595
Via licensees	4.2	9.7	22.4	14.8	48.9	237
Subsidiaries as percent of total	85.7	80.3	50.0	75.0	70.9	71.5

[a]832 transfers abroad of 221 innovations by 32 U.S.-based multinational enterprises after these innovations were introduced in the United States.

SOURCE: R. Vernon and W. Davidson, *Foreign Production of Technology Intensive Products*, Washington, D.C.: National Science Foundation, 1979.

Time Horizons

As money prices increased for a variety of reasons, corporate time horizons generally were compressed and acceptable rates of return for investments grew apace. The latter was perhaps as much a function of increased uncertainties--which higher interest rates reflected in part--as the actual price of money. But these practices tended (in the early 1970s especially) to discriminate selectively against research, development, and major investment projects that required long delays and great risks for fulfillment. Many companies sought short-term market payoffs or diversified through acquisitions (see Tables 12 and 13) to offset uncertainties and to acquire competencies rapidly rather than investing in longer-term technological or quality support programs for their existing lines. Because of antitrust policy constraints in their markets, lateral diversification became the only way many larger companies could grow as rapidly as they wished. And the stock market rewarded this behavior in the short run.

In the late 1970s, however, management horizons seemed to expand as net interest rates fell below inflation rates (see Figure 6). Real industrial R&D expenditures rose rapidly (see Figure 7) and civilian R&D expenditures as a percent of GNP began to move upward more rapidly than those of Japan and our large European competitors (see Figure 8). In the late 1970s, mergers and acquisitions slowed (see Table 12) in the manufacturing and mining sectors from an annual average of 949 in 1970-1974 to 543 in 1975-1979, although average mergers were larger. Real annual growth rates in fixed plant and equipment for manufacturers increased between 1972 and 1980 at 2.8 times the growth rate of

1947-1972 (see Table 10). Much of this was a response to new environmental laws and to the growing strength of Japanese and European incursions. Unfortunately it was also offset in international trade by the continued higher investment rates of both German and Japanese industries (see Table 14.)

Financial Measures

As large companies grew, their product lines naturally proliferated, and the complexity of most was compounded by diversification through acquisition (as noted above). Financial- and acquisition-minded managers naturally replaced manufacturing and technical top managers in these companies (see Figure 9). These managements perhaps responded more than their predecessors to the exigencies of reporting attractive quarterly or yearly earnings growth to the financial community. More importantly however, few top managers in such highly diversified companies still had the intuitive feel for their process or product technologies or the deep experience in technological innovation that bred comfort with major technological risks. Instead, financial allocation and control systems tended to emphasize near-term, surer prospects, whose results were more quantifiable and predictable.

Together with rapid executive transfers and traditional incentive systems that rewarded short-term measurable performance, these control systems often undercut more basic technology building, quality improvement, and human and organizational development activities that would have given future strength. Most devastating was the effect on the not immediately measurable aspects of product quality. Under economic pressure, individual managements (1) under-invested in processes and designs that would guarantee consistent quality; (2) pressed their operating managers to "ship product" in order to dress up end-of-period statements, letting customers and distributors worry about product failures; and (3) failed to train workers adequately or develop work attitudes conducive to quality. Some marketing groups purposely placed the labels or trademarks of former top line products on poorer quality lines and lowered the specifications on their replacements to such extremes that former quality levels--like earlier top-line plywoods--were virtually impossible for consumers to obtain. Few U.S. manufacturers chose to understand W. E. Edwards Deming's maxim that, properly managed, high quality can actually cost less. And they gave up their market share and profit margins to those who did.

World Competitve Trends

While such practices have been observable in many situations, by no means did all U.S. companies fall into these traps. Many companies have maintained their strength and foresight. But overall trends of U.S. actions versus those of other large OECD countries (notably Japan and Germany) show many points of weakness. Rates of savings and investment in the United States have been lower than in most competitor countries (see Table 14). Productivity growth rates correlate strongly with investment rates, and the U.S. productivity growth rate was fourth among the five major OECD countries between 1960 and 1980 (see Table 15). Only the growth rate of the United Kingdom was lower.

There has been a significant slowdown in output growth in most industrialized

TABLE 12 Mergers and Acquisitions–Manufacturing and Mining Concerns Acquired (by Industry Group of Acquiring Concern), 1960-1979

Industry of Acquiring Concern	1960-1964	1965-1969	1970-1974	1975-1979	1973	1974	1975	1976	1977	1978	1979
Total concerns acquired	4,366	8,213	4,749	2,717	874	602	439	559	590	610	519
Mining	209	303	258	128	34	36	27	28	26	24	23
Manufacturing[a]	3,694	6,642	3,428	1,833	578	418	288	375	393	427	350
Food and kindred products	326	538	384	198	77	40	27	42	43	53	33
Tobacco manufactures	24	37	18	18	3	2	4	1	5	5	3
Textiles and apparel	280	439	160	59	30	15	3	13	11	16	16
Lumber and furniture	109	250	175	55	31	27	7	14	12	8	14
Paper and allied products	133	175	120	53	21	30	8	10	18	8	9
Printing and publishing	158	224	158	126	28	18	21	29	24	30	22
Chemicals	443	615	334	202	65	47	44	39	46	46	27
Petroleum	78	73	34	18	6	7	3	7	2	2	4
Rubber and plastics products	74	139	71	44	12	7	2	10	16	10	6
Leather products	32	75	41	10	5	0	3	3	1	1	2
Stone, clay, and glass products	103	212	136	66	19	25	15	13	11	14	13
Primary metals	173	366	180	110	24	23	22	22	23	19	24
Fabricated metal products	225	471	214	149	45	25	24	43	29	32	21
Machinery, except electrical	397	817	413	265	59	45	48	44	51	58	64
Electrical machinery	573	1,160	478	229	67	45	35	47	47	54	46
Transportation equipment	272	483	218	94	39	31	10	12	20	32	20
Professional scientific instruments	189	407	172	94	21	18	9	20	22	24	19
Nonmanufacturing[b]	463	1,268	1,063	756	262	148	124	156	171	159	146

[a]Includes miscellaneous and ordnance, not shown separately.
[b]Includes unknown.

SOURCE: *Statistical Abstract of the United States, 1981.*

TABLE 13 Mergers and Acquisitions–Manufacturing and Mining Concerns, 1960-1979

		Large Concerns (Assets of $10 Million or More) Acquired[a]					
		Number of Mergers			Assets Acquired (Millions of Dollars)		
Year	Total Concerns Acquired	Total	Horizontal and Vertical	Conglomerate	Total	Horizontal and Vertical	Conglomerate
1960	844	51	14	37	1,535	453	1,082
1965	1,008	64	16	48	3,254	573	2,681
1970	1,351	91	12	79	5,904	1,174	4,730
1971	1,011	59	8	51	2,460	578	1,882
1972	911	60	24	36	1,885	773	1,112
1973	874	64	25	39	3,149	1,093	2,056
1974	602	62	24	38	4,466	1,417	3,049
1975	439	59	7	52	4,950	267	4,683
1976	559	81	18	63	6,279	1,031	5,248
1977	590	99	30	69	8,670	1,937	6,733
1978	610	111	35	76	10,724	4,675	6,050
1979	519	97	10	87	12,867	1,231	11,637

[a]Concerns for which financial data are publicly available.

SOURCE: *Statistical Abstract of the United States, 1981.*

countries since the worldwide recession of 1974-1975. But as output slowed, most other countries reduced employment hours thereby bolstering their relative productivity rates. The United States was the only one of the large countries that generally maintained manufacturing employment and hours since 1973.[20] From 1970 to 1980 productivity in manufacturing industries grew almost four times faster in Japan (up 102 percent) and twice as fast in France (up 61 percent) and West Germany (up 60 percent) as in the United States (up 28 percent) in 10 years. These countries were, however, improving from substantially lower productivity bases. The United States still has the highest productivity levels among these countries as measured by GNP per person employed. The productivity level in France and West Germany in 1980 was over 10 percent lower than in the United States, and the overall productivity level in Japan was over 30 percent below that in the United States (see Table 16). Nevertheless, the U.S. lead in productivity has decreased over the past decade.

Virtually all U.S. manufacturing industries exhibited slowdowns in productivity growth during this period. Printing and publishing, primary metals, lumber and wood products, and aircraft and parts were the worst relative performers. Since there seem to be different root causes in each case, no single productivity policy is likely to yield desired results across all industry.

Total U.S. civilian R&D figures as a percent of GNP have not been as high as in West Germany or Japan (see Figure 8) auguring ill for future competition with these countries after the usual five- to seven-year incubation delay for R&D results to become commercial. The United States improved its R&D-intensive trade balances with Western Europe and developing nations in the 1970s. But it has experienced a sharp loss of position versus Japan after 1975 (see Figure 4), with Japanese companies achieving almost complete competitive dominance in small autos, motorcycles, electronic home applicances, and selected other sectors during this period. Finally, both Japan and West Germany have been producing more engineers per capita than the United States in recent years (see Figure 10), again suggesting greater future competitive pressures.

STRENGTHS AND POTENTIALS

Among these bleak trends are there any positive aspects to the U.S. situation? Fortunately, yes! The higher per capita GDP of the United States (see Table 16) allows it a much-needed latitude for investment and risk taking, if properly encouraged by policy. The United States enjoys the world's most aggressive venture capital market. Its capacity to cultivate and grow the small-scale technological entrepreneurs who often introduce the most radical changes is without parallel elsewhere. And the country has the world's largest organized money markets with which to back up successful ventures, support intelligent world trade strategies, and build the huge mega projects called for in some future technologies. What other strengths exist as the basis for a future industrial manufacturing strategy?

Certain R&D-intensive industries' exports through 1980 (see Figure 3) showed strong net balances in chemicals and related products ($12.2 billion), power machinery ($4.6 billion), special purpose machinery ($7.9 billion), general industrial machinery ($6.5 billion), office machinery ($5.8 billion), electrical machinery ($2.3 billion), and aircraft and spacecraft ($11.0 billion). The best-managed U.S. companies are still in the vanguard worldwide. These companies have found ways to maintain their vision, entrepreneurial vigor, and capacities for change. The

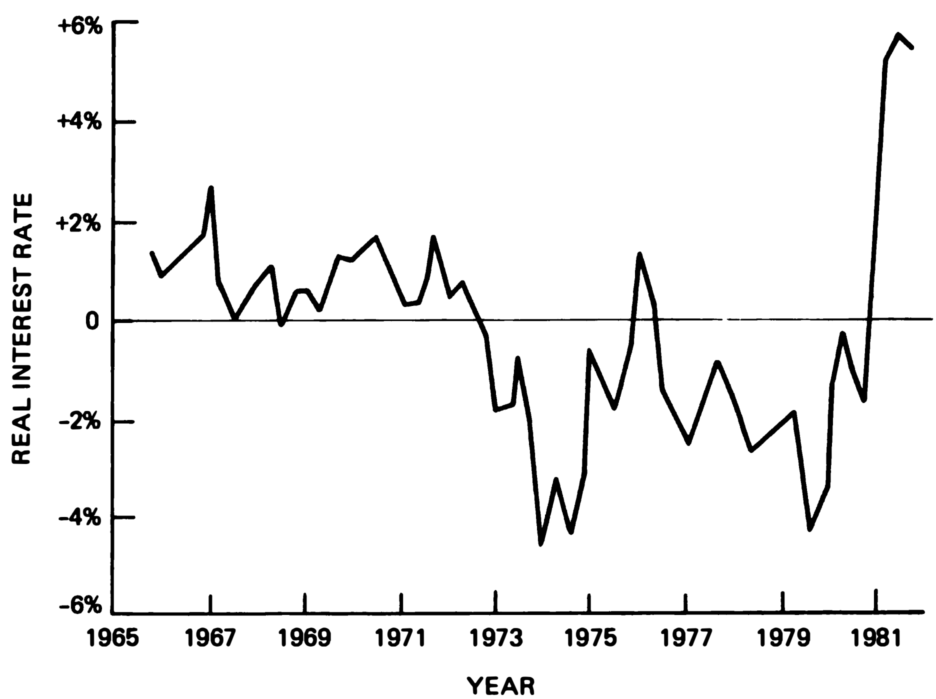

FIGURE 6 Real interest rates (average rates for three-month treasury bills less quarterly change in CPI seasonally adjusted annual rate). Source: Federal Reserve Board and Bureau of Labor Statistics.

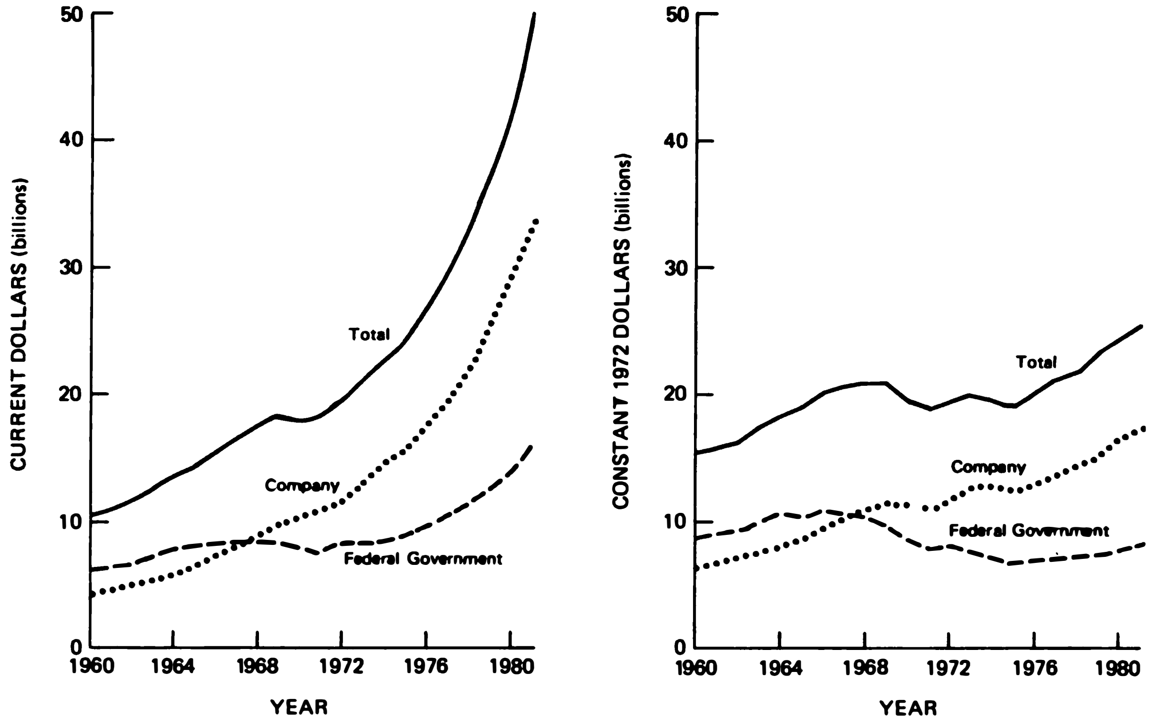

FIGURE 7 Expenditures for industrial R&D by source of funds. GNP implicit price deflators were used to convert current dollars to constant 1972 dollars. Note: "Company" includes all sources other than the federal government. Preliminary data are shown for 1978 and 1980, and estimates for 1981.

United States enjoys preeminent positions in many fields, including such key fields for the future as semiconductors, computer hardware and software, biogenetics, communications, aerospace, energy, pharmaceuticals, and medical equipment. And the management practices of its best companies could well be emulated by others. Whether they will be in the future is the open question. Groups like McKinsey and Company, through its "Excellence in American Management" and "Excellent Company" series, are actively attempting to distill and report on outstanding management practices in critical fields to provide potential models for others.[21]

Structural Strengths

The outlook for manufacturing depends largely upon the way in which U.S. institutions use their potential strengths and respond to key challenges. The important point is that with intelligence, foresight, and flexibility many attractive options remain for a healthy manufacturing sector. The United States has some impressive structural strengths for industrial strategies. It has the world's largest truly integrated market (see Table 17), with special transportation access, cultural understanding, and psychological advantages for its own companies. Unfortunately this very advantage has sometimes in the past led to a parochialism and complacency that damaged the United States in world competition. But a significant change in management outlook seems to be taking place in response to current competitive pressures. In the past when the U.S industrial system has been sufficiently pressed, it has proved itself capable of an awesome response. The current competitive trauma may be precisely what is needed to keep U.S industry's sclerosis from moving into terminal phases.[22]

U.S. industry has a range in scale of companies, diversity of products, and raw materials access enjoyed by few other countries. The United States has perhaps the greatest known--though not most easily recoverable--energy resources of any nation. Its workforce is highly disciplined, mobile, and well educated compared to most others. And recent studies report that American workers enjoy perhaps the highest degree of job satisfaction and pride in their work of any industrialized nation's workforce.[23] European managers have often noted that U.S. union leadership has been more flexible and less politically dogmatic than its counterparts elsewhere. In terms of cost pressure, U.S. wages--though starting from a higher base--have grown at only 5.9 percent per year from 1970-1980. Corresponding figures for other countries are France, 12.5 percent; West Germany, 13.4 percent; Japan, 11.3 percent; and the United Kindgom, 14.5 percent. Real hourly compensation in the United States grew at the slowest rate of these major countries (0.7 percent). Others grew as follows between 1970 and 1980: France, 4.7 percent; West Germany, 5.6 percent; Japan, 4.6 percent; and the United Kingdom, 3.3 percent.

Although total national R&D expenditures shifted downward as a percentage of GNP relative to other industrialized countries through the late 1970s, U.S. industrial R&D, at 1.91 percent of industry GDP (as of 1977), remained higher

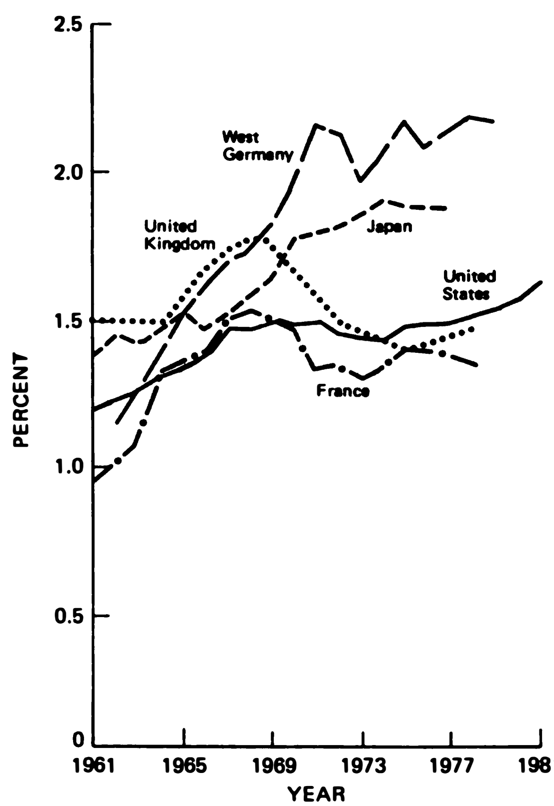

FIGURE 8 Estimated ratio of civilian R&D expenditures to GNP for selected countries. Source: Science Indicators, 1980.

TABLE 14 Comparative National Performance, by Country

	Savings as % of GNP 1970-1980	1962-1980 Average Investment as % of GNP	Government Spending as % of GNP[a]	Average Annual % Increase Real GNP	Average Annual % Increase Total Productivity	1980 Maximum Capital Gains Tax (%)
Japan	32.6	32.5	8.7	7.9	7.8	0
Belgium	21.5	21.5	15.0	3.9	6.6	0
Netherlands	22.3	23.6	16.8	4.1	6.4	0
Italy	20.2	20.6	15.4	4.1	5.6	0
France	22.9	22.9	13.8	4.4	5.4	0
Germany	19.6	20.6	17.5	3.6	5.2	0
United Kingdom	18.7	18.4	18.7	2.3	2.7	30.0[b]
United States	17.6	17.8	20.6	3.5	2.2	28.0

[a]Federal, state, and local current spending excluding transfer payments and capital spending.
[b]Applies to both short-term and long-term gains.

SOURCE: J. P. Grace, speech before the Center for International Business, Houston, October 21, 1981.

than that of major OECD countries and Japan.[24] But if past trends continue, Japan will soon have neutralized this comparative strength (see Table 18). While U.S. government R&D expenditures (as a percentage of GNP) dropped after a 1964 peak, industrial expenditures grew as a percentage of GNP by a factor of 25 percent from 1964 to 1981 (see Table 19). And a current study shows that U.S. firms raised R&D expenditures by 16 percent in 1981 and intended to raise them by 17 percent in 1982 to $59.7 billion despite the recession.[25]

Profit and Trade Positions

In 1980, total returns to investors in the 500 largest U.S. industrial corporations averaged 21.1 percent. Petroleum, aerospace, transportation equipment (other than motor vehicles and aircraft), and electronics appliances were leading with returns well over 30 percent. All single-digit SIC industries had positive ratios of profits to stockholder equity until 1980, when the automotive industry became negative (see Table 9). Highest performers were fabricated metal products, electrical and nonelectrical machinery, aircraft guided missiles and parts, tobacco manufactures, printing and publishing, pharmaceuticals, and petroleum refining and production. The weakest sectors in 1980 were passenger automobiles, textile mill products, rubber and miscellaneous plastics products, and iron and steel. 1980 has been used as the indicator year for most major trends because (1) more comparable data exist for that year and (2) 1981-1982 have been arbitrarily and heavily depressed by anti-inflation policies.

To look ahead, large U.S. companies have leadership positions in key technologies--energy, computer software and hardware, microelectronics, extreme environments, aerospace, communications, foods, health care, and genetics--that will be central to growth in the next decade. Individual companies also have very strong technical and market positions in pharmaceuticals, chemicals, plastics, power equipment, military technologies, construction, and other fields. And these areas of strength can be exploited by U.S. companies in related supplier and user industries.

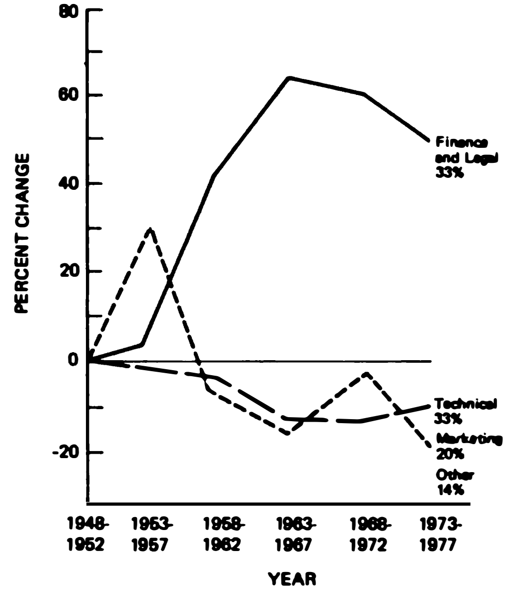

FIGURE 9 Percentage changes in professional origins of corporate presidents from baseline years 1948-1952--100 largest U.S. companies. Source: Golightly & Co. International, 1978.

The United States is still a recognized leader in product innovation in most fields, the greatest exceptions involving the strong Japanese emergence in motorcycles, electronic consumer durable products, and small passenger cars. The highly individualistic training and outlook of American technologists; a responsive, affluent U.S. marketplace; and an aggressive venture capital system will probably contribute to continued U.S. product innovativeness in the future. Although there is some indication of a slowdown in inventiveness as measured by the number of patents granted (see Figure 11), this may be a function of the lack of patent protection in frontier areas like health, genetics, electronics, and software, as well as the courts' tendency to break up or prevent enforcement of strong patent positions in other fields. The individualistic management style of American companies lends itself to the fast decisions necessary for new product introduction, especially in smaller companies. And being first to market in new product areas offers potentially important experience-curve advantages when strategically exploited. The small-company entrepreneurial structure of the United States will probably be a continuing strength to build on unless government policies unintentionally and arbitrarily discriminate too heavily against such companies--as specific, high-investment environmental regulations and the overuse of high-priced money for inflation control unfortunately have.

FUTURE MARKETS

Many recent articles express considerable pessimism about the future, discounting new market potentials and emphasizing the possibility of continuing world stagflation. Yet strong demands exist, which if properly channeled and developed, can serve as bases for leveraging U.S. manufactures into other areas. Consumer goods markets that now appear relatively saturated will undoubtedly encounter the 1980s' own innovative equivalents of video tape records, video games, automated appliances, and home computer centers, which were certainly not recognized as near-term markets in the early 1970s. Service sectors will begin to automate, pushing their capital investments from the $3,000 per person levels common for office personnel today[26] toward the $50,000 per person levels found in manufacturing, thus helping expand other equipment and durables markets.

In addition, recent studies suggest that more than $1 trillion is needed in the next decade to refurbish the aging U.S. infrastructure of roads, sewers, water supplies, flood control systems, public buildings, etc.[27] Major banks now predict that more than another $2 trillion will be required by the U.S. energy industry over the coming decade, with more than another trillion being invested by the energy industry worldwide.[28] U.S. manufacturing companies should be major beneficiaries of the materials, supplies, and equipment markets created. Between 1980 and the year 2000, a new population approximately the size of the world's total population in 1940 will have to be fed, housed, clothed, and cared for. Since North America will increasingly be the buffer source of food supplies for the world, a large new infrastructure will be necessary to store and ship food to areas of need around the world. Although most of this will be for production and distribution structures overseas,[29] these structures should present large opportunities for equipment, services, and trade support activities of American manufacturers. U.S. food trade and its financial support to developing nations should also offer access to crucial raw materials through counter trade relationships.

TABLE 15 Productivity Growth (Output per Hour) in Manufacturing Industries of Selected Countries, 1960-1980 (1977 = 100)

Year	United States	France	West Germany	Japan	United Kingdom	USSR
1960	60.1	40.0	40.0	21.7	58.3	55.9
1961	61.7	41.9	42.1	24.6	58.8	57.9
1962	64.4	43.8	44.7	25.7	60.3	59.9
1963	69.0	46.4	46.8	27.7	63.5	62.1
1964	72.4	48.7	50.3	31.5	67.9	64.4
1965	74.6	51.5	53.5	32.8	69.9	66.6
1966	75.4	55.2	55.4	36.1	72.5	68.7
1967	75.4	58.2	59.0	41.4	75.6	70.8
1968	78.1	64.8	63.0	46.6	81.2	73.0
1969	79.4	67.2	66.9	53.9	83.1	75.3
1970	79.2	70.6	68.5	60.7	83.2	77.6
1971	84.1	74.3	71.6	63.3	86.1	81.3
1972	88.3	78.6	75.9	69.6	92.2	84.3
1973	93.1	82.9	80.4	77.6	97.5	89.1
1974	90.9	85.8	85.2	80.8	97.2	92.9
1975	93.5	88.4	89.3	84.0	95.0	96.3
1976	97.7	95.7	95.0	91.9	98.8	97.7
1977	100.0	100.0	100.0	100.0	100.0	100.0
1978	100.9	104.9	103.8	106.8	103.2	102.3
1979	101.9	109.8	110.3	115.5	105.8	104.0
1980 (preliminary)	101.4	113.4	109.5	122.7	104.4	NA

SOURCES: Department of Labor, Bureau of Labor Statistics, International Comparisons of Manufacturing Productivity and Labor Costs, *Preliminary Measures for 1980*, May 20, 1981, mimeograph. Productivity figures for Soviet Union were provided by Francis Rushing of SRI International.

An aging population in the industrialized world will demand more in health care, recreation, personal support, housing, and other specialized facilities than it can produce itself. With its high health care, social standards, and affluence levels, the United States should have a natural lead in identifying and satisfying these needs. Concepts of health delivery are undergoing radical changes, with important new technologies and market opportunities appearing constantly. Further hundreds of billions of dollars are also needed to maintain and modernize the capital base of key U.S. industries that could utilize new technologies to regain competitiveness. Capital investment markets are forecast to grow at more than 10 percent per year through the next decade if government policies or catastrophic economic downturns do not intervene. To avoid deterioration of the environment, more billions will annually go into markets to prevent and capture the effluents of modern society. All of these demands will call for structures, equipment, and supplies requiring manufactured goods on a scale rarely encountered before.

Developing many of these markets effectively demands more carefully conceived government policies than we have often seen in the past. Most important are: (1) approaching public expenditures and regulations for environmental or safety purposes as aggregative markets[**] that compete at the margin for the public's limited expenditure or investment dollar and (2) developing federal capital accounting, reporting, and budgeting systems--which literally do

TABLE 16 Real Gross Domestic Product per Employed Person for Selected Countries, 1960-1980 (United States = 100)[a]

Year	United States	France	West Germany	Japan	United Kingdom	Canada
1950	100	42.7	37.5	15.6	54.0	85.0
1955	100	45.7	45.1	18.9	52.8	88.3
1960	100	54.2	56.6	24.1	54.5	90.4
1965	100	60.2	60.1	31.3	52.5	89.4
1966	100	61.0	62.3	32.9	51.9	87.7
1967	100	63.4	61.5	36.2	53.8	87.9
1968	100	64.0	63.8	39.5	55.0	89.0
1969	100	67.2	67.6	43.8	55.6	90.5
1970	100	71.1	71.3	48.7	57.6	92.6
1971	100	72.7	71.3	49.4	57.5	94.0
1972	100	74.8	72.3	52.6	56.1	94.1
1973	100	76.5	74.2	55.2	56.8	94.2
1974	100	80.3	77.8	56.5	57.4	96.0
1975	100	81.0	78.6	57.2	57.1	94.9
1976	100	82.9	81.7	59.1	57.9	96.3
1977	100	82.7	82.7	60.2	57.2	95.1
1978	100	84.9	84.4	62.7	58.7	94.9
1979	100	87.5	87.1	65.5	59.0	93.9
1980 (preliminary)	100	89.4	88.7	68.4	60.5	92.1

[a]Output based on international price weights to enable comparable cross-country comparisons.

SOURCE: Department of Labor, Bureau of Statistics, Comparative Real Gross Domestic Product, Real GDP per Capita, and Real GDP per Employed Person, 1950-80, May 1981, mimeograph.

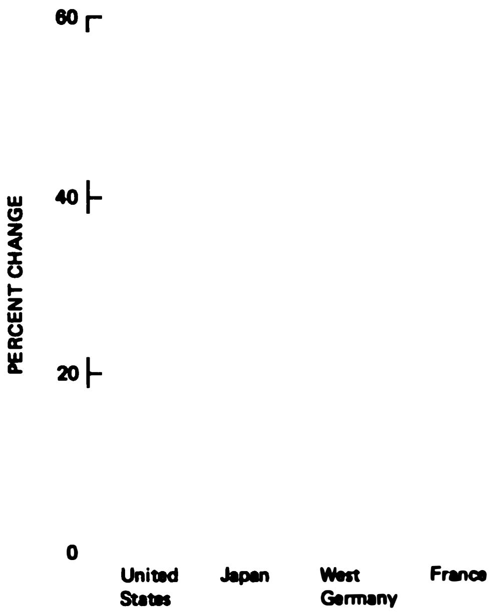

FIGURE 10 Growth in scientific and engineering personnel, 1970-1979. Source: An Assessment of U.S. Competitiveness in High Technology Industries, 1982.

not now exist.[31] Properly developed public markets and investments can create added values substantially in excess of their costs--just like any other markets--and can be important productivity contributors and demand stimulators for manufacturing.

New Process Technologies

In another realm, new process technologies and their associated inventory control, quality development, and supplier and market coordination systems also offer new areas of emphasis for production innovation in both large and small companies. Radical innovations have traditionally come from smaller companies.[32] But recent studies suggest that larger companies have accounted for an increasing percentage of important innovations.[33] Their much-discussed consensus style may offer large Japanese companies some advantages for large process innovations in which coordination and cooperation among many disciplines and units may weigh more heavily than in product innovation. But critical elements of this style can be easily adapted if desired and applied to developing those process technologies of the future where the United States has natural potentials.

Most important for U.S. manufacturing in the short run is the aggressive use of electronic automation technologies. Although Japan has about three times the number of robots in use, the United States probably leads in robotics design and research.[34] Companies that have not yet committed can catch up quickly if they choose. Costs of electronics capabilities of a given power are dropping some 30 percent annually. Hence, later entrants, if they move with a strategic sense, may even have a systems costs advantage, as did Japan and Germany with their delayed entries into mechanically automated industrialization in the recent era.[35] With genetics, health, and communications technologies also offering potential radical product changes, American companies that move in a timely fashion can still be at the frontier of a wide range of automated modern industries

TABLE 17 Comparative Gross National Products, 1980 Dollars (Billions), at International Exchange Rates

Country	1980 GNP
United States	2,626
Belgium	118
France	653
West Germany	823
Italy	394
Netherlands	160
United Kingdom	519
Japan	1,040

in which wages are not a high percentage of total cost. For greatest impact, however, many need to reconceptualize the basic nature of their supplier, office, factory, quality achievement, workplace behavior, and man-materials-machine relationships in a true systems sense. As Goldhar and Burnham's paper will suggest, these are profound and exciting challenges that can offer strategic, productivity, and innovation leadership potentials to U.S. companies for the next two decades.

Since scientific results in such frontier technologies are likely to be shared worldwide, key elements will be (1) maintaining close and imaginative relationships with leading thinkers in science and the universities and (2) aggressively innovating at the applications level. Here U.S. manufacturers should have comparative advantages. U.S. science maintains world leadership in a broad range of inquiries, dominating the Nobel Prizes and publications in many fields (see Table 20).

STRATEGIES FOR THE FUTURE

Given these potential strengths and the very real threats outlined above, what strategies can engineers, manufacturing managers, and government policymakers realistically adopt? Unfortunately, most solutions lie in the realm of attitudes, incentives, and political changes that will be hard to effect, rather than in specific and more easily impelemented policy changes. But systems that have been put in place by humans can be changed by humans.

Positive Visions of the Future

A genuine expectation of continuous and real economic growth could have important effects on U.S. innovation. In Japan the predictability of government economic policies is an acknowledged factor affecting the willingness of businessmen to make long-term investments, where any variability increases risks.[36] Technology also responds to demand. And expanding markets are very forgiving, decreasing the actual (and perceived) risks always involved in investment and innovation. Rapid growth stimulates both selective innovations and the broader restructuring of industries. As overall demand grows, small niches appear for highly specialized solutions. Innovations satisfying these frequently become desirable for wider applications (as did plastics and semiconductors), creating

TABLE 18 Industrial R&D Expenditures and Expenditures as a Percentage of the Domestic Product of Industry, 1967-1977 (National Currency in Millions)

Country	BERD[a]	DPI[b]	BERD/DPI (%)
United States			
1967	16,385	659,200	2.49
1971	18,314	862,700	2.12
1975	24,164	1,223,200	1.98
1977	29,907	1,563,000	1.91
United Kingdom			
1967	605	30,212	2.00
1971	697	NA	NA
1975	1,340	76,739	1.75
1977	NA	102,663	NA
West Germany			
1967	5,683	444,070	1.28
1971	10,521	682,350	1.54
1975	14,469	912,660	1.59
1977	16,717	1,016,730	1.64
France			
1967	6,292	442,700	1.42
1971	8,962	695,297	1.29
1975	15,617	1,140,204	1.37
1977	19,999	1,476,848	1.35
Japan			
1967	378,969	45,315,500	0.84
1971	895,020	80,914,400	1.11
1975	1,684,846	141,173,000	1.19
1977	2,109,499	163,449,000	1.29

[a]Business enterprise R&D (total industrial R&D expenditure).
[b]The domestic product of industry.

SOURCE: Organisation of Economic Cooperation and Development, *International Survey of the Resources Devoted to R&D by Member Countries. International Statistical Year, 1971*, Paris: OECD; and unpublished tabulations from OECD, 1980.

whole new industries and fueling potential future growth. Growth eases the problems of substituting new industries for old maturing ones and encourages a more modern competitive base to satisfy future demands. Productivity also tends to improve as markets grow. While layoffs are delayed during economic declines, thus decreasing productivity, new hires are delayed during upturns with just the opposite effect.

The rest of the world still looks on the United States as offering a most attractive investment environment, and much of other countries' interest is in U.S. manufacturing. Foreign corporate investments in the United States are increasing. The largest component of the $65.5 billion investment in the United States in 1980 was in manufacturing. Overall 37 percent of all foreign investment in the United States is in manufacturing with another 15 percent in petroleum. The remainder is in service areas. Obviously, foreign companies find U.S. markets and manufacturing bases of significant interest for the future.

As noted, there is a plethora of constructive manufacturing and related service opportunities for U.S. industries if managers and engineers can convince the public and its political institutions to seize them. Seeing and communicating these to a public nurtured on current crises and doomsday forecasts will be a

TABLE 19 National R&D Expenditures and as a Percent of GNP, by Source, 1960-1981 (Dollars in Billions)

	Current Dollars					Constant 1972 Dollars[a]					As a percent of GNP			
		All R&D by Source			Basic and Applied		All R&D by Source			Basic and Applied	All R&D by Source			Basic and Applied
Year	GNP	Total	Federal	Other	Research	GNP	Total	Federal	Other	Research	Total	Federal	Other	Research
1960	506.5	13.5	8.7	4.8	4.2	737.3	19.6	12.7	7.0	6.1	2.67	1.72	0.95	0.83
1961	524.6	14.3	9.3	5.0	4.5	756.7	20.6	13.3	7.2	6.4	2.73	1.77	0.95	0.86
1962	565.0	15.4	9.9	5.5	5.4	800.2	21.8	14.0	7.8	7.6	2.73	1.75	0.97	0.96
1963	596.7	17.1	11.2	5.9	5.7	832.6	23.7	15.6	8.2	7.9	2.87	1.88	0.99	0.96
1964	637.7	18.9	12.5	6.3	6.4	876.3	25.9	17.2	8.7	8.8	2.96	1.96	0.99	1.00
1965	691.1	20.0	13.0	7.0	6.9	929.4	26.9	17.4	9.5	9.2	2.89	1.88	1.01	1.00
1966	756.0	21.8	14.0	7.9	7.4	984.9	28.4	18.2	10.2	9.6	2.88	1.85	1.05	0.98
1967	799.6	23.1	14.4	8.8	7.8	1,011.4	29.2	18.2	11.1	9.9	2.89	1.80	1.10	0.98
1968	873.4	24.6	14.9	9.7	8.4	1,058.2	29.8	18.1	11.7	10.2	2.82	1.71	1.11	0.96
1969	944.0	25.6	14.9	10.7	8.8	1,087.7	29.6	17.2	12.4	10.1	2.71	1.58	1.13	0.93
1970	992.7	26.1	14.8	11.3	9.2	1,085.5	28.5	16.2	12.3	10.1	2.63	1.49	1.14	0.93
1971	1,077.6	26.7	14.9	11.8	9.4	1,122.4	27.8	15.6	12.2	9.8	2.48	1.38	1.10	0.87
1972	1,185.9	28.4	15.8	12.6	9.8	1,185.9	28.4	15.8	12.7	9.8	2.40	1.33	1.06	0.83
1973	1,326.4	30.7	16.3	14.4	10.5	1,255.0	29.1	15.6	13.5	10.0	2.32	1.23	1.09	0.79
1974	1,434.2	32.8	16.8	16.0	11.4	1,248.0	28.8	14.8	14.0	10.0	2.29	1.17	1.12	0.80
1975	1,549.2	35.2	18.1	17.1	12.4	1,233.8	28.2	14.5	13.7	10.0	2.27	1.17	1.10	0.80
1976	1,718.0	38.9	19.8	19.1	13.9	1,300.4	29.5	15.0	14.5	10.6	2.26	1.15	1.11	0.81
1977	1,918.0	42.9	21.7	21.2	15.3	1,371.7	30.7	15.5	15.2	10.9	2.24	1.13	1.11	0.80
1978	2,156.1	48.0	23.9	24.1	17.2	1,436.9	32.0	15.9	16.1	11.4	2.23	1.11	1.11	0.80
1979 (preliminary)	2,413.9	54.2	26.6	27.6	19.4	1,483.0	33.3	16.3	17.0	11.9	2.25	1.10	1.14	0.80
1980 (estimate)	2,626.1	61.1	29.3	31.8	21.9	1,480.7	34.5	16.6	17.9	12.3	2.33	1.12	1.21	0.83
1981 (estimate)	2,920.0	69.1	32.7	36.4	24.1	1,498.1	35.5	16.8	18.7	12.4	2.37	1.12	1.25	0.83

NOTE: Percentages are calculated from unrounded figures. Detail may not add to total because of rounding.

[a]GNP Implicit price deflators used to convert current dollars to constant 1972 dollars.

SOURCE: National Science Foundation, *National Patterns of Science and Technology Resources, 1980* (NSF 80-308), and unpublished data; and Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business* and *Commerce News*.

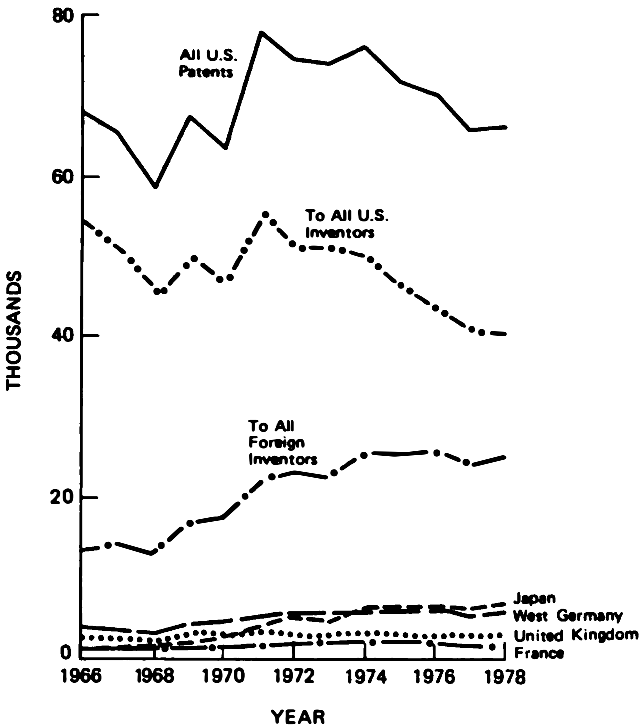

FIGURE 11 U.S. patents granted to inventors from selected countries, 1966-1978. Source: Science Indicators, 1980.

major challenge. But developing more positive visions of the future is a vital first step in instilling the morale and commitment to effect changes. Just as anticipation of inflation can feed inflation, so can positive visions of the future set the climate for accomplishment.[38] It is anomalous that knowledgeable people talk gloomily about future market demands when the government had to intervene so forcefully to quench these very demands through its monetary policies.

Lower Capital Costs

Lowering capital costs is a key to any U.S. strategy allowing high wages relative to the rest of the world. Critical components are: (1) lowering inflation by greater use of fiscal and productivity policies, rather than through monetary policies which selectively impact longer term investments, new entrepreneurial ventures, and hence the technological innovation that leads to new market opportunities and productivity growth; (2) greater emphasis in government expenditures on productivity-producing infrastructures (education, transportation support, disease prevention, disaster control) that, by employing people productively and creating values higher than their factor costs, actually decrease total national costs; and (3) less emphasis in controlling inflation through unemployment techniques, which quench demand, but lower productivity by removing people from the workforce while maintaining a great portion of their demand potential through transfer payments. Other countries have proved that, properly managed, high employment levels need not be inflationary. One key is a significantly increased capital formation and savings rate (see Table 14).

TABLE 20 U.S. Percentage of the World's Scholarly Articles

Field	1973	1975	1977	1978	1979
All Fields	39	38	38	38	37
Clinical medicine	43	43	43	43	43
Biomedicine	39	39	39	39	40
Biology	46	45	42	42	43
Chemistry	23	22	22	21	21
Physics	33	32	30	31	30
Earth and Space Sciences	47	44	45	45	45
Engineering and Technology	42	41	40	39	41
Mathematics	48	44	41	40	40

SOURCE: *Science Indicators, 1980.*

There is a multiple cost to high priced money used as an anti-inflation tool. A high interest rate itself represents a cost increase for producers and buyers. When carried to extremes, it creates layoffs, causing a labor surplus. This lowers the relative cost of labor versus capital. Hence, companies do not invest to replace labor, and a productivity slowdown occurs. The purchase price of new equipment fell relative to wages and fringe benefits by 2.7 percent between 1948 and 1965, encouraging investment. If energy is included, the cost of physical capital relative to labor fell 2.9 percent between 1948 and 1965. But if interest is included it fell only 1.1 percent between 1948 and 1965. From 1972 to 1978 the cost of physical capital (including energy) actually increased relative to labor costs by 2.9 percent. Including interest, the cost rose 4.2 percent between 1972 and 1978.[39]

Beyond this, high monetary prices discriminate against small businesses. Higher monetary prices for debt drive down P/E ratios, making equity too expensive in terms of ownership and shifting financings toward high debt ratios inappropriate for small businesses. The potential scale of new ventures is decreased, and risks escalate for all involved. This discourages the innovativeness that has traditionally come from small businesses and their capacity to pressure larger enterprises toward productivity and innovation. Companies with fewer than 100 employees have accounted for some 81 percent of new jobs (see Table 21) in recent years,[40] but this growth is now being severely impaired by high money prices and the recession they have created. While larger companies can survive economic downturns, heavily leveraged small enterprises cannot.[41] Otherwise viable enterprises are currently being permanently lost along with their innovation, product, and jobs potentials. One doubts that such extensive use of monetary policy--as opposed to fiscal policy coupled with productive government investment--is compatible as an anti-inflationary tool with the historical U.S. strategy of increasing personal wealth and opportunity through capital investment, innovation, and entrepreneurial endeavor.

New Cooperative Arrangements

All the great national industrial strategies of this century--Swedish, Japanese, postwar German, Austrian, and even U.S.--have depended on new collaborative relations between institutions, predominantly labor, management, universities,

TABLE 21 Net New Jobs Created, by Size of Firm, 1969-1976

Number of Employees in Each Firm	Total New Jobs Number	Total New Jobs As % of Total
20 or fewer	4,459,815	66.0
21-50	759,509	11.2
51-100	288,997	4.3
101-500	353,201	5.2
501 or more	897,381	13.3
Total	6,758,903	100.0

SOURCE: D. L. Birch, "Who Produces the Jobs," *The Public Interest*, Fall 1981.

and/or government.[42] In wartime, the U.S. government has stimulated and tolerated highly imaginative collaborations between a wide variety of normally hostile institutions. Similar creativity and latitude in seeking national economic goals now seems appropriate. German, Japanese, and French financial structures for directing investment to new growth areas have been cited as desirable for the United States. Except in areas where adequate market incentives do not exist, I personally doubt whether significant government direction of investment in the United States would be more effective than the aggregate wisdom of our combined technological and financial communities. To the contrary, past government attempts to shore up "sunset industries" rather than to stimulate "sunrise industries" have actively misdirected capital allocations.

However, there are a series of new forms of cooperation at the industry-university-venture capital level that do deserve stimulation and support. The Hoechst-Massachusetts General Hospital-Harvard Medical School support program provides one model in genetics. The du Pont-Harvard Medical School, Monsanto-Rockefeller University, and Genertech-University of California at San Francisco-City of Hope Hospital relationships provide others. The Center for Integrated Systems at Stanford brings some 17 microelectronics firms together in joint endeavor with university talents. Similar institutes are beginning at Massachusetts Institute of Technology and Rensselaer Polytechnic Institute, with specialized company support in other fields, like chemicals research. In Arizona, Minnesota, and North Carolina, university and industrial funds are being supplemented by state support; Westinghouse and Carnegie Mellon University have started a robotics institute, and so on.[43] Mechanisms for cooperation at the development level are also being created, especially between microelectronic producers and customers, like Intel and IBM to gain some of the advantages of the Japanese integrated supplier-customer-trading company complexes. And giant cooperative mega projects among competing oil companies have been increasingly allowed for synthetic fuel programs and other overseas development programs beyond the capabilities of one energy company.

Maintaining the objectivity, freedom, and integrity of academic research in specific circumstances poses some profound issues--as does maintaining competitiveness among participants in cooperative development programs.[44] But new world competitive structures should force redefinition and reinterpretation of antitrust laws to recognize and foster world--not just U.S.--competition in the public interest. In recent years universities have never been entirely free of competitive, commercial, or government pressures on their resources. There is little reason to believe that earlier models of these institutions' relationships have perpetual validity and that even better new models cannot be negotiated.

These developing coordinative structures are an initial response to world challenges. But there are others.[45] There is evidence that some U.S. unions recognize the seriousness of the current challenge and are willing to be more helpful in offsetting foreign competition. In exchange, workers will doubtless demand and deserve an adequate voice in the pacing and nature of changes and the institutional arrangements for protecting or retraining when displacements occur. Already many newer companies, like their Japanese counterparts, are trying to eliminate distinctions between owners, managers, and workers so that all share in the benefits and costs of change. "Export trading company" legislation is underway to facilitate coalitions between banks and American manufacturers comparable to those enjoyed by competitor nations. And a number of possible models for R&D consortia are under discussion in the Department of Commerce to aid in developing costly technologies of common interest to a number of companies. The list is long.

With flexible and visionary leadership a variety of new institutional structures could develop, allowing the United States to match and outperform similar institutional structures in other nations. Most of these merely require that government give permission for private initiatives, not that government drive or direct these initiatives.

Education

A refocus on technical education at public school and university levels is also badly needed. Until this year, SAT and MAT scores had fallen for nearly two decades. Half of all U.S. high school students have been taking no mathematics at all after the 10th grade. Only one junior or senior in six takes a science course. Only one in fourteen takes physics, and one in three takes chemistry. In 1981 a survey of state science supervisors revealed a shortage of high school chemistry teachers in 38 states, mathematics teachers in 43 states, and physics teachers in 42 states. In the 1970s the annual average number of new science and mathematics teachers produced by colleges and universities plunged: science teachers by 64 percent, math teachers by 78 percent.[46]

There are some 2,000 vacancies in U.S. engineering faculties today, with particularly glaring weaknesses in computer sciences, chemical engineering, and electrical engineering. And even in a recession, 17,000 unfilled entry-level engineering jobs exist coast to coast. Much of the equipment in university laboratories is outmoded, obsolete, or worn out. To bring it up to industrial standards has been estimated to cost between $1 billion and $4 billion.[47] The Japanese are already outproducing the United States per capita in engineers by more than two to one. Between 1965 and 1977 the number of scientists and engineers in R&D nearly doubled (per capita in the workforce) in Japan. In the United States the ratio fell. Although the United States still leads in science and engineering professionals per worker, the Japanese and Germans will probably exceed us within a few years (see Figure 12). While the current recession and some more constructive national attitudes toward science and technology are causing a resurgence of undergraduate engineering, companies express such disappointment with graduate training that many choose to hire at the BS level and train their own engineers.[48]

A massive, joint industry-government effort is needed to refocus and refund graduate engineering and to set meaningful targets and standards at the state level for training and hiring competent science teachers at high school levels.[49] The Massachusetts High Technology Council has called for a "Morrill Act Update" with a $1 billion federal grant to match industry programs to update engineering. The council has also put together a model program to retrain unemployed high school teachers as computer programmers. It is also working closely with Northeastern University on a masters degree program in engineering for technically trained women whose career development was interrupted by family obligations.[50] Similar imaginative endeavors are needed as a stopgap to meet shortages, but longer term commitments from federal and state groups are required to ensure a flexible, healthy, U.S. educational structure. Limited funding could cause concentration of quality engineering education into 25 to 50 research-supported universities, which could not flexibly meet all future needs.[51]

This is an area where government action is necessary. The market mechanism for directing people to science and engineering has worked only moderately well. Salaries offered to technically trained students remained higher than in any other fields for college graduates during the 1970s. Technical graduates also received more offers than their nontechnical compatriots. The Deutsch/Shea/Evans high technology recruitment index from 1970 to 1980 showed a relatively continuous rise from 60 to approximately 140, with downturns occurring only in 1971 and 1975. But available labor market indicators have showed consistent patterns of shortages for engineers and computer specialists. There have been ample supplies of social and life scientists. The market for physical scientists has been improving, and supply and demand seemed relatively balanced in mid-1980. But in recent years employment in science and engineering has grown more slowly (2.5 percent per year) than total U.S. employment and GNP (4 percent per year), indicating shifts in national activity patterns and also a relative shortage of trained scientists and engineers. Though limited, indicators show that the quality of the science and engineering workforce has not declined. For example, the proportion of scientists and engineers holding doctorates has increased, and test scores of prospective graduate students have remained high.[52]

New Structures for Systems Design and Management

Both university and corporate structures need revision to utilize revolutionary new genetics and electronics technologies most effectively. Fortunately, these technologies are highly compatible both with (1) emerging social trends and (2) what is known about productive and innovative management structures in advanced societies. In specific situations both technologies can allow design of smaller, cleaner, more flexible and humane production units with greater potentials for monitoring and controlling undesired effluents. They also permit more complex design processes integrating all aspects of product, process, plant, production, quality, and environmental monitoring and control systems. The traditional discipline-oriented faculty structures at engineering schools are ill-adapted for this, as are company organizations that separate product, process, plant, environmental, and computer engineering groups. Revised classroom approaches and major facilities changes will be needed at most universities to research and teach

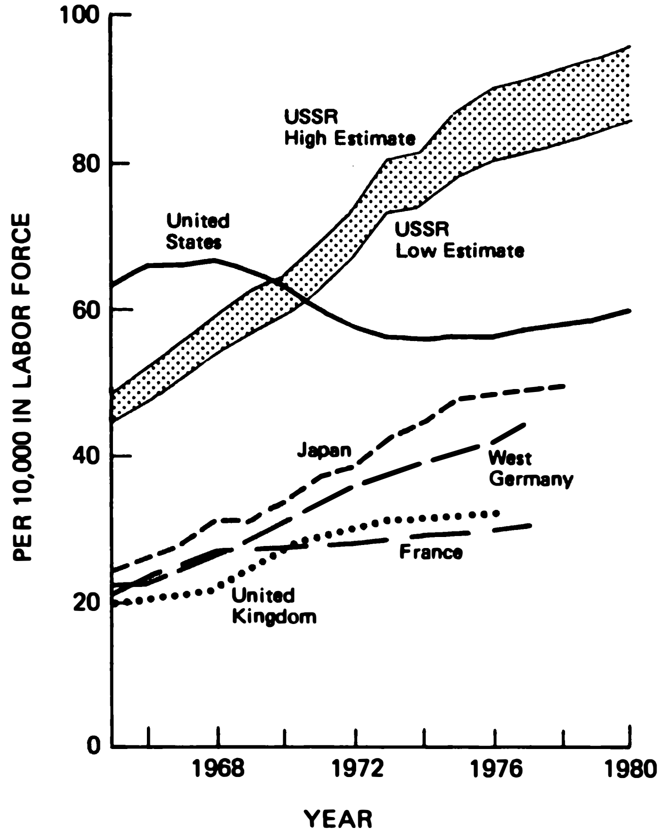

FIGURE 12 Scientists and engineers engaged in R&D per 10,000 labor force, by country, 1966-1980. Data are for all scientists and engineers on a full-time equivalent basis. Data for Japan include persons employed primarily in R&D. Data for the United Kngdom include only persons employed by government and industry. Data for USSR are estimates. Source: Science Indicators, 1980.

integrated design effectively. Such facilities are very costly and easily outdated. This is a special area where consortia of companies can work effectively as associates with universities, providing projects and facilities support on a quid pro quo basis creating benefits for all parties.

In industry, competitive pressures will soon demand integrated product, process, and plant designs to minimize manufacturing, distribution, and full life-cycle costs to the producer and customer. Using robotics, communications, and automation capabilities, industry can integrate relatively small-scale plants with flexible, dispersed, supplier or feeder networks to minimize joint inventory, labor, and fixed investment costs in ways not possible in less advanced countries. Some Japanese companies already operate such systems with only a few days of net inventory--as opposed to weeks in the U.S.--and have installed automated and robotized self-checking systems to assure quality on a first-time-through basis. Properly modified by U.S. industry, small-scale automated plants can help to achieve more personal identity and self-fulfillment in more challenging work situations. Using the full capacities of a more intelligent U.S. workforce both to operate such plants and to seek the many small incremental productivity improvements that in the long run are most easily protected may provide one of the few real bases for outstripping less motivated or less well trained competitors abroad.[53] Some well-managed U.S. companies, like Intel, have already built such concepts into their strategies, cultures, and organizational structures.

Leadership, Incentives, Rewards

Such broad-ranging innovative changes will require the same kind of farsighted risk-taking leadership that earlier made U.S. industry the envy of the world. Without such vision all the national policy shifts and opportunity potentials imaginable will come to naught. What most differentiates an innovative enterprise, a great manufacturing company, or a productive society is a leadership that (1) is talented, (2) is farsighted, (3) rewards positive innovation, and (4) values excellence in human performance and products for its own merit.[54]

Companies produce fine products largely because the people at the top care about the product per se, elevate product or innovative people to strategic levels, and commit resources behind them.[55] Company managements that look at technology or manufacturing activities simply as money mills to be compared against the financial advantages or disadvantages of hoarding silver or owning banks are unlikely to create the internal pressures or atmosphere that keep their organizations strong, processes current, quality high, and technologies at the forefront. Financial measures rarely reflect these crucial aspects of performance until years after the most critical actions have been taken or ignored. Sony has been an innovative leader because Messrs. Ibuka and Morita are talented and have long cherished innovation and quality products per se.[56] Pilkington's float glass innovations occurred because Alastair Pilkington wanted to invent, and its top management had long time horizons, understood the need for innovation, and empathized with the chaos and risks involved.[57] Japan has emerged largely because its leaders had vision, patience, and a high regard both for technological advance and for building the worth of their human resources.[58]

Until boards appoint and reward top managers for being innovation oriented and interested in the company's future product and cost positions, U.S. manufacturing companies and industries will suffer. Fortunately, when plans are well conceived and communicated, the stock market does reward progressive companies with high P/E ratios, the basic method of allocating less expensive capital in the United States. To be effective, this longer-term focus must also be reflected in the full control and reward systems of the company. Properly developed, multiple goal "management-by-objectives" (MBO) systems, combined with carefully designed strategic portfolio plans and controls, provide available mechanisms for orienting lower-level decisions toward the future. Unfortunately, too few companies use these mechanisms to their full capability, relying mostly on short-term accounting and return on investment (ROI) controls instead. Smaller companies often have longer-term horizons because their owner-managers look to future stock market yields rather than to more current rewards. A greater use of measures and rewards that generously compensate large company executives for their units' total performance five years later might engender very useful effects.

Government Policy Changes

The kinds of policy changes needed at government levels will be harder to implement. The key issue is not simply more government sponsorship of R&D, except perhaps at the university level where--if regarded as a human resource investment--R&D can yield especially high rewards. Here, society gets multiple benefits of (1) the research results themselves, (2) faculty retention and upgrading, and (3) enhanced course quality and student development.

The President's Domestic Policy Review on Innovation in the United States indicated many other facets of government activity that vitally affect innovation. This (and other) current studies[59] indicate that governments can make their greatest contributions by (1) aggregating demands that individual purchasers cannot effectuate, (2) creating or guaranteeing initial markets to meet important social needs, (3) supporting scientific and technical education, (4) making technical support infrastructure investments, (5) breaking down bottlenecks to change, (6) allowing amalgamations of private resources for large-scale systems development, (7) taking unusual risks beyond the capacities of private parties, (8) encouraging institutions to extend their time horizons through enlightened incentives, and (9) easing the distress and human costs of change. Selectively applied, these, rather than subsidies, trade barries, or direct support of industries, should be the cornerstones of future policies for manufacturing.

Most important, however, are incentives. The direction of any society is established by the net vector of its values and incentives, and government is the most powerful single arbiter of both. Its most important direct actions can be taken on incentives. Changing relative propensities to save and invest in innovation and productivity improvements is critical. Increased savings simultaneously decrease current expenditure pressures, increase investable funds, help lower money costs, and thus encourage productive investments. Some excellent adjustments in federal policy have occurred in the last two years, but uncertainties still persist for small investors who need safe posttax yields above inflation rates. Research limited partnerships and small business tax decreases have helped offset some of the special advantages government policy once offered real estate investments. But neither is as important for innovation as a confident, high P/E stock market--which depends in turn on reduced inflation, low interest rates, and an optimistic economy.

Fortunately, the venture capital market has recently been explosively reinstated by relatively small but enlightened changes in capital gains taxes (see Table 22). The stock market could reestablish its potentials if governments could control their deficits and interest rates could move lower. But this requires a conscious withdrawal from the overexpenditure policies of the 1970s. Government deficits have increasingly crowded out private capital in the money markets (see Table 23). And other actions have passed on to future generations the repayment of trillions of dollars in national debt and future fixed commitments voted during the last dozen years.[60] These have been root causes stimulating the recent inflation and its associated high money prices. Such forces must be reversed as a portion of any coherent future industrial strategy.

Government actions can significantly help or retard needed innovations. But they should not be made the sole or critical focus of the national endeavor. The driving pressure for change must come from the industry managers, concerned citizens, and educators whose own futures and effectiveness are most vitally affected. Government should be more a catalyst than a reagent in most cases.

TABLE 22 Equity Capital Raised by Companies Having a Net Worth of Under $5 Million ($ Millions)

Year	Offerings	Current $	Constant 1980 $	Maximum Capital Gains Tax Rate (%)
1968	358	745.3	1,643.3	25.0
1969	698	1,366.9	2,869.5	25.0
1970	198	375.0	747.3	29.5
1971	248	550.9	1,044.5	40.0
1972	409	896.0	1,631.2	45.0
1973	69	159.7	274.8	45.0
1974	9	16.1	25.3	45.0
1975	4	16.2	23.2	45.0
1976	29	144.8	197.0	49.1
1977	13	42.6	54.8	49.1
1978	21	89.3	106.9	49.1
1979	46	182.9	201.1	28.0
1980	135	821.5	821.5[a]	28.0

[a]Up by 3,288 % over 1974.

SOURCE: J. P. Grace, speech before the Center for International Business, Houston, October 21, 1981.

But any successful future strategy must contain certain minimum dimensions requiring joint support: (1) a widely shared positive vision of a future society attractive to a large majority, (2) incentives to defer current expenditures and invest for the future, (3) a commitment to maximum development of human intellectual and personal resources, (4) a willingness to innovate constantly in both organizational and technological terms, (5) a genuine national policy to ease the distresses of change and to retrain individuals displaced, and (6) an acceptance of social and infrastructure investments as valid markets in themselves, as well as being potential contributors to national productivity and well being.[81] Setting forth such dimensions is not hard to do; implementing them is the difficult process. One of the challenges of this meeting and its work groups is to specify more clearly how these visions might be realistically attained.

CONCLUSIONS

As the Economist recently said, "Policy makers keep hoping that technology can rescue their economies. Actually it is the economies that need to be got right first. Technology needs economic policies that lead to expectations of high growth and profits, low interest and inflation rates. . . . What is good for investment is generally good for [technology]. . . . Purchasing promotes innovation best when the purchaser is pursuing self interest. . . . Setting the right regulatory climate is another way governments can help innovation. . . . Setting high standards can help to make an industry more competitive by forcing it to deploy modern technologies. . . . This should be a trustbusting climate that discourages monopoly (allowing bright young companies to compete) and avoids inordinate delays in letting technology be implemented, e.g. by imposing realistic standards."[82]

TABLE 23 Federal Government Crowds Private Investment (Billions of Current $, Average of Period)

Years	Total Credit Market Borrowings	Federal Borrowings	Federal as % of Total
1955-1959	43.2	2.4	6
1960-1964	60.6	5.3	9
1965-1969	98.7	10.0	10
1970-1974	193.8	27.8	14
1975-1979	375.2	91.1	24
1980	434.1	126.8	29

SOURCE: J. P. Grace, "Energy and the Economy," Eighth Annual Energy Technology Exposition, Washington, D.C., March 1981.

These are excellent guidelines if coupled with a true vision of a better tomorrow and a commitment to maximum human resource development supporting that vision. Today most of the limits as to what can be done are set by imagination and institutions. Never in history have science and technology offered so many options to improve living standards and life styles for humans. Somewhat like politics, engineering is the science of the possible. The challenges are (1) to release scientific, engineering, and managerial imaginations and (2) to eliminate institutional barriers to meeting future demands. If these can be accomplished, there need be no insurmountable limits to the potentials of manufacturing and its compatriot service sectors in satisfying U.S. and related world needs for production goods, life quality, and environmental protection.

NOTES

[1] National Research Council, The Competitive Status of the U.S. Auto Industry, Washington, D.C.: National Academy Press, 1982.

[2] Dataquest Inc., SIA Japanese Ministry of Finance, March 1982.

[3] Base data are from U.S. Department of Commerce, Productivity Measures for Selected Industries 1954-80, Bulletin 2128, and National Science Foundation, Science Indicators 1980, Washington, D.C.: National Science Foundation, 1981.

[4] R. Hayes and W. J. Abernathy, "How to Manage Our Way to Economic Decline," Harvard Business Review, July-August 1980, and R. Hayes and D. Garvin, "Managing as if Tomorrow Mattered," Harvard Business Review, May-June, 1982, are two much-quoted examples.

[5] D. Micheals, Cybernation the Silent Conquest, Santa Barbara, Calif.: Center for the Study of Democratic Institutions, 1974, provides a classic of modern concerns. V. Leontief, "The Distribution of Work and Income," Scientific American, September 1982 presents both concerns and possible policy alternatives.

[6] Leontief, 1982, op. cit.

[7] E. Ginsberg, "The Mechanization of Work," Scientific American, September 1982, Using series with other definitions, Ginsberg shows increases in services from 46 percent in 1940 to 68 percent in 1980. Specific numbers are not as important as scales and trends.

[8] F. M. Scherer, Research, Development, Patenting, and the Micro Structure of Productivity Growth, Report to NSF, June 1981.

[9]Many strategies in major organizations do "emerge" in this fashion. See H. Mintzberg, D. Raisinghani and A. Thoret, "The Structure of Unstructured Decision Processes," Administrative Science Quarterly, June 1976, and J. B. Quinn, Strategies for Change: Logical Incrementalism, Richard D. Irwin, 1980.

[10]In the late 1800s and early 1900s the United States imported cheap labor to exploit natural resources, applied and adapted science developed abroad, encouraged savings and private enterprise, developed literacy and a high-school-trained workforce, built transportation and communications instrastructures, allowed capital to substitute for and add value to labor inputs, and initiated research programs in agricultural and mechanical areas of vital interest to these two key production sectors of the era.

Early post-World War II (1945-1960) strategies further exploited low U.S. raw material and energy costs, helped develop new world markets through trade agreements, controlled inflation, kept money costs low, applied technologies built up in war years, utilized scale economies to attack mass markets worldwide, educated returning veterans to college levels, developed professional management cadres, and drove U.S. technology through military and atomic leadership. In the 1960s strategies shifted. Various government actions developed U.S. science through R&D support for universities and national laboratories; expanded middle class demands through wealth transfers, massive public expenditures, and support of trade unionism; drove technology frontiers in human health, space, and other unexplored environmental domains; provided mass education at the university level; and encouraged institutions for multinational trade and stability.

[11]Statistical Abstract of the United States, 1981, Washington, D.C.: U.S. Department of Labor, Table 1425.

[12]Real estate is a special case of allowing consumption (enjoyment) along with tax-stimulated investment gain. Adam Smith, Paper Money, New York: Dell, 1981, develops shifts toward real estate investment in detail.

[13]See P. Choate and S. Walters, America In Ruins, Washington, D.C.: Council of State Planning Agencies, 1981.

[14]These investment figures appear conservative, but one must remember that some 81 percent of the new jobs will be in enterprises employing fewer than 100 people.

[15]The U.S. Economy Outlook Through 1995: 1983 Edition, Cleveland: Predicast, 1982, p. 101.

[16]An Assessment of U.S. Competitiveness in High Technology Industries, Cabinent Council on Commerce and Trade, May 19, 1982.

[17]Ibid.

[18]R. Hofheinz and K. Calder, The East Asia Edge, Basic Books, Inc., New York, 1982, develops the nature of this threat in some depth.

[19]Five Year Outlook on Science and Technology, Washington, D.C.: National Science Foundation, 1982, places the blame for current problems squarely on U.S. managers and government policies.

[20]L. Thurow, "The Productivity Problem," Technology Review, November-December 1980.

[21]See "Findings from the Excellent Companies," New York: McKinsey, June 1981; and T. Peters and R. Waterman, In Search of Excellence: Lessons From America's Best Run Companies, New York: Harper & Row, 1982. My current study on large-scale innovation is attempting to do this within a selected problem area.

[22] M. Olsen, The Rise and Decline of Nations, Economic Growth. Stagflation and Social Rigidities, New Haven: Yale University Press, 1982, suggests that in democracies, producing and user groups form coalitions with specially protected positions. If these are not forced to change by external traumas they go into slow certain decline.

[23] International Herald Tribune, May 20, 1982, p. 3, reports on an international study by Gallup and CARA, Washington, D.C.

[24] J. D. Lewis, "Technology Enterprise, and American Economic Growth," Science, March 5, 1982, cites this as one of several important strengths of the U.S. position, but also notes that R&D is not the core issue. Longer time horizons, better use of human resources, and the social context of innovation had higher impacts.

[25] 27th Annual McGraw Hill Survey of Business Plans for Research and Development Expenditures, 1982-85. New York: McGraw-Hill, 1982.

[26] The difference between this and the average $45,950 investment cited above is caused by the huge investments of utility, transportation, etc. fields included in the broad "services" definition.

[27] P. Choate and S. Walter, America in Ruins, 1981, op. cit., state that $700 billion is needed for nonurban highway rehabilitation and reconstruction in the 1980s and another $75-$110 billion for waterways. If past annual public sector construction expenditures of $9-$12 billion on public buildings, $2-$3 billion on conservation development, and $2-$4 billion on sewer systems are added, the sum exceeds $1 trillion for the 1980s.

[28] Bankers Trust and Chase Econometrics estimates reported in Oil & Gas Journal, October 12, 1981, p. 48, and November 9, 1981, p. 146.

[29] Food and Agriculture Organization, Agriculture: Toward 2000, Rome: FAO, 1979, and Food and Agriculture Organization, Research Report #10, Investment in Input Requirements for Accelerating Food Production in Low Income Countries by 1990, Rome: FAO, 1979, estimate total needs for the next 10 years as $1.8 trillion worldwide, of which the largest structures component is in irrigation: $15-$20 billion for essential electrification, $150 billion for agricultural machinery, and $130 billion for irrigation equipment and installation.

[30] H. M. Peskin, P. R. Portney, and A. Kneese, Environmental Regulation and The U.S. Economy, Resources for the Future, Baltimore: Johns Hopkins Press, 1981, and J. B. Quinn, "Public Markets: Growth Opportunities and Environmental Improvement," Technology Review, June 1974.

[31] P. Choate and S. Walter, America in Ruins, 1981, op. cit., note the need for data bases to make capital accounting possible, annual analyses of public works needs related to overall economic performance, a phased capital budget relative to cyclical and long term needs, and economic linkage analyses to understand the impact of construction expenditures outside the geographical area where the construction takes place.

[32] J. Jewkes, D. Sawers, and R. Stillerman, The Sources of Invention, London: Macmillan, 1958.

[33] Innovations in Britain Since 1945, Science Policy Research Unit, Sussex University, England, 1981.

[34] An Assessment of U.S. Competitiveness, 1982, op. cit.

[35] E. Ginsberg, "The Mechanization of Work," Scientific American, September 1982.

[36] An Assessment of U.S. Competitiveness, 1982, op. cit.

[37] Statistical Abstract of the United States, 1981, op. cit., Table 1499.

[38]"Economic Report of the President of the United States," February 1982, pp. 52-54.
[39]L. Thorow, "The Productivity Problem," Technology Review, November-December 1980.
[40]For amplification see D. L. Birch, "Who Produces the Jobs?" The Public Interest, Fall 1981 and Dun and Bradstreet Reports, November/December 1981, p. 11.
[41]Dunn and Bradstreet reports business failures for January-September 1981 at an annual rate of 24,000, the highest rate in the postwar era. This does not include another estimated 4,000 weekly that pay off their debts and close their doors without formally notifying authorities.
[42]E. Ginsberg, 1982, op. cit.
[43]See the series in "News and Comment," Science May 28, 1982; June 11, 1982; June 18, 1982; and August 6, 1982.
[44]"Can the Law Reconcile the Interests of the Public, Academe, and Industry? Learning from Experience in Biotechnology," Association of the Bar of the City of New York, April 21, 1982.
[45]R. M. Coloton, "National Science Foundation Experience with University-Industry Centers" Technovation 1, 1981, outlines experiences with some other alternatives.
[46]P. D. Hurd, "State of Precollege Education in Math and Sciences," Convocation on Precollege Education in Mathematics and Science, Washington, D.C., May 12-13, 1982, summarizes many of the better surveys of this problem.
[47]J. R. Opel, "Education, Science, and National Economic Competitiveness," Science September 17, 1982.
[48]C. Perkins, "Graduate Engineering Education and Problems of Innovation," Conference on Cooperative Research, MIT, February 19, 1980.
[49]See National Academy of Engineering, Science and Mathematics in the Schools: Report of a Convocation, Washington, D.C.: National Academy Press, 1982, for specific suggestions, and National Science Foundation Science and Engineering Education in the 1980's, Washington, D.C.: NSF, 1981.
[50]Also see "A New Slant on Engineering Training," Science, October 15, 1982.
[51]J. G. Truxal and M. Visich, "Engineering Education and National Policy," Science, October 8, 1982.
[52]National Science Foundation, Science Indicators, 1980, Washington, D.C.: NSF, 1981 and A. Hansen, Scientists, Engineers, and National Security: An Educational Perspective, American Defense Preparedness Association, December 11, 1980.
[53]J. D. Lewis, 1982, op. cit. points out the high impact of these changes and the essential nature of innovative climates needed to support them.
[54]R. N. Foster, "A Call for Vision in Managing Technology," Business Week, May 24, 1982 summarizes some McKinsey & Co. findings in this regard.
[55]It is telling that for almost three decades no production-engineering person has been chief executive officer of a major U.S. automobile company. In many U.S. companies the manufacturing activity does not have its own strategic plan at corporate levels (as marketing often does), and manufacturing is not widely regarded as a route to top executive responsibilities.
[56]N. Lyons, SONY Vision, New York: Crown, 1976.
[57]See J. B. Quinn, Pilkington Brothers Limited case Hanover, N.H.: Amos Tuck School, 1981.

[58]"How We See Each Other: A Special Survey of Chief Executive Officers in U.S. and Japanese Firms," Fortune, August 10, 1981.

[59]See especially R. Rothwell and W. Zegveld, Industrial Innovation and Public Policy: Preparing for the 1980's and 1990's, Westport, Conn.: Greenwood Press.

[60]P. Petersen, "No More Free Lunch for the Middle Class," New York Times, January 17, 1982, p. 40.

[61]J. B. Quinn, "Public Markets; Growth Opportunities and Environmental Improvement," Technology Review, June 1974.

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RESPONSE TO THE KEYNOTE SPEECH ON THE CURRENT STATE OF U.S. MANUFACTURING

Thomas J. Murrin

It is a privilege to have this opportunity to comment on a highly important subject--the current state of U.S. manufacturing and methods of improving it. In my view there is no more important issue, for it is vital to the economic survival of our nation and to our national security.

Let me recognize at the outset that our American engineering capabilities, in general, are excellent and that the National Academy of Engineering is to be applauded for its wise leadership in directing our engineering expertise to the now crucial subject of manufacturing. But the challenge to American industry, and consequently to the American economy and our people's security and prosperity, is awesome. In industries in which America was preeminent--steel, ship-building, motorcycles, automobiles, consumer electronics--our leadership has been stripped away.

To illustrate this situation, let me cite the following information from a recently published report on the automobile.

> Ford Motor Company's better plants turn out an average of two engines a day per employee using 777 square feet of plant space; the plants have up to three weeks of backup inventory, and use over 200 labor classifications. In contrast, a Toyota plant turns out nine engines a day per employee, or more than four times as many as Ford's; it uses only 454 square feet of plant space per engine, or less than 60 percent of Ford's. A Toyota plant has only one hour of backup inventory and only seven labor classifications, less than 4 percent of Ford's.

According to our studies, such manufacturing sophistication is typical of the Japanese in all of the segments on which they have concentrated. And this automobile comparison does not cite what may be the biggest competitive secret to success of the Japanese--continuous total quality improvement.

Implicit in such an example is the shocking reality that two of our long-time manufacturing "standards of excellence"--so-called acceptable quality levels and economical ordering quantities--are no longer excellent. In fact, they are no longer competitive. They have been rendered obsolete by the Japanese.

Of vital concern to the future health of other key segments of our American economy is the current targeting by the Japanese on microelectronics, computers, communications, machine tools, robots, and bioengineering--the next industries for Japanese world dominance. In regard to robots, for example, Japan has in place several times the number that the United States has, and it is far in advance of the rest of the world. By 1981 the Japanese had installed over 60,000 robots, while we in the United States have installed about 4,000.

There are now over 200 companies in Japan producing robots. Last year they produced some 24,000 and they expect to double that number this year. Their typical robot producer is apparently planning to triple production over the next four to five years, suggesting that by then their output will be 150,000-200,000 robots per year.

Furthermore, at a recent international conference on fifth-generation computer systems, the Japanese unveiled a master plan for the development of computers to meet the needs of the 1990s. Here is a mobilization on a national scale that is aimed at the domination of the world computer market, and most of their advanced computer concepts were originally developed by three American universities.

An unusually clear insight into the attitudes and ambitions of the Japanese is provided in the recent book, Japanese Technology, by Masanori Moritani. His closing paragraphs state:

> The time has finally come when Japan will be called upon to take the lead in technology and pave its own unique road to the future. Simply following up on principles and ideas invented in America will not be enough to convince other countries. It is time Japan graduates from playing catch-up on products germinated in American society. Japan must discover the real needs of its own people in its own society, enlarge upon these needs in its own fashion, and convince the peoples of the world that these are their needs as well.
>
> The memory is still fresh of the toughness of Eric Hayden, the American speed skater who performed so magnificently at the 1980 Winter Olympics. Hayden's giant body was a mass of muscle, his thighs were almost abnormally large.
>
> America in the 1950s and 1960s was Hayden personified. America in the 1950s accounted for almost half the Free World's GNP and foreign reserves. Year after year it racked up gigantic trade surpluses. Its outlays for R&D overwhelmed those of the Soviet Union and West Germany, and it led the world in productivity. Truly it was a five-time gold medal winner.
>
> But what of America today? Ten years later, it still has a giant frame, yet its muscles are weakening and its arms and legs no longer move as it wills. Its heart flutters, and it gasps for breath as it skates. It is no longer intimidating. Even Iranian "athletes" scoff at it.
>
> Japan has grown to its present stature through America's grace. Is it not just a little cruel to force the United States to skate in the lead from beginning to end, taking the full brunt of the wind on its giant body? The age when Japan must be prepared to take its turn at the head of the pack and share the leaderships with America in every field is not merely close at hand. It has already begun.

While we in the United States has the technology, the people, and the other resources to meet these economic challenges, our response will probably be insufficient if we continue on our present course. Therefore, doing things the same way we have always done them will no longer be sufficient.

Accordingly--on a national scale--business, government, labor, and academe in America can no longer maintain an attitude of indifference toward the industrial and technological policies of other nations, nor can our institutions any longer continue in their present roles and relationship and expect to witness anything other than the continuing decline of America's productivity, international competitiveness, and military security. A truly effective response to our economic problems requires an unified effort by these key segments of American society. We need a national commitment and an explicit strategy for American productivity improvement and international competitiveness, with particular emphasis on manufacturing.

I am not suggesting that we must copy our competition's political systems. Rather, the challenge is to find in ourselves a uniquely American response--a response that calls upon our creativity and ingenuity--to protect our standard of living and to assure our national security.

To that end, a national strategy for American productivity improvement and international competitiveness, with emphasis on manufacturing, should focus on fundamental changes and actions in several areas, including the following:

- Technology. We must increase R&D spending and more rapidly and effectively bring the results to the marketplace, the office, and the factory.
- Education and training. We must fill the unsatisfied demand for new skills and for more engineers and scientists. We must also encourage more mathematics and science courses in our grade schools.
- Global trade and investment strategy. We must ensure that American firms are on an equal competitive footing with their trading partners.
- Domestic savings and investment policy. We must increase long-term savings and ensure capital resources for our critical growth industries.
- Policy formulation strategy. To achieve these changes, we must develop a consensus-based process for policy formulation to bring together the leaders of government, industry, labor, and academe on common ground, in pursuit of common, crucial goals.

To the National Academy of Engineering and to our nation's engineers I would like to make several suggestions:

- Realize more fully that you and your expertise represent a rare and crucial national resource, one that can and must contribute greatly to our country's current industrial and military challenges.
- With a real sense of urgency, assign top-priority emphasis to manufacturing, and consider the manufacturability of the products you design to be as important as their function. For example, encourage outstanding design engineers to transfer to manufacturing for about a year, so they will appreciate professionally the crucial need for the improved manufacturability of their designs.
- Become more familiar with powerful quality and reliability techniques-- for example, to evaluate and improve components and materials through a vigorous, statistically based procedure and to optimize production processes by use of advanced design-of-experiment methodologies--in order to increase composite yields in manufacturing and mean time between failure in ultimate use.
- Make certain that you are very familiar with the state of the art in your field on a worldwide basis, particularly in Japan if your responsibilities relate to semiconductors, computers, communications, machine tools, robots, or bioengi-

neering. In doing this, you will better appreciate, for example, that the next generation of robotic systems will embody state-of-the-art technology from several sophisticated disciplines, such as advanced sensors, novel mechtronics, and artificial intelligence, and that, therefore, we must have many of our most outstanding engineers working in manufacturing.

- In your workplaces, assume a leadership role in developing joint efforts between engineering, manufacturing, purchasing, marketing, and service in order to exploit outstanding opportunities in quality, manufacturability, reliability, and cost reduction. The emergence of such advanced American technologies as CAD, CAM, and CAT--and of advanced foreign manufacturing systems, such as Kanban and OPT--requires radical changes in the interrelationships between the different functions in our organizations.
- Finally, promote and participate in programs to enhance our nation's engineering and manufacturing capabilities through synergistic cooperation among government, business, labor, and academe, such as DOD's current VHSIC program, as well as the emerging major R&D joint ventures on semiconductors and computers.

I hope that these comments are of real interest and value and that this National Academy of Engineering meeting helps you and your engineering associates to make even more significant contributions to our nation's prosperity and security.

SESSION I

NEW MANUFACTURING TECHNOLOGIES

Session 1 participants. Left to right: George H. Schaffer, Susan Foss, Session Chairman Joseph Harrington, Jr., William D. Beeby, and Joseph F. Engleberger.

INTRODUCTION

Joseph Harrington, Jr.

In the keynote address and the response to it James B. Quinn and Thomas J. Murrin have given us a challenging overview of the current state of manufacturing in the United States, particularly vis-a-vis manufacturing in other parts of the world, and they have outlined some impressive challenges to engineers, to managers of manufacturing, and to government policymakers.

If there was a doubt in anyone's mind, it was dispelled by that opening. Change is inevitable, and when dealing with change, there are three things to be done. You ask, where am I or where are we? Which way are we going? And what ought we to be doing about it?

That, in essence is the structure of the next sessions of this meeting. This first session will address the problem of where we are, what is the state of the art? The steering committee was not able to consider state-of-the-art reports on all the important technologies of manufacturing; thus, they selected four essential ones. The first is the manufacture of parts, parts production; the second is the testing and quality control problems that go with manufacturing; the third is the assembly of parts; and the fourth the integrating factor. The latter is my theme too--the use of the data technology to integrate or to reintegrate all of these many components of our industry.

Everything that we do in manufacturing, every act that transforms raw material into finished products, can be represented by data. We generate data. We transform it. We transmit. And we are at present blessed with the most powerful data processing equipment that has ever been known.

The medium by which we will be reintegrating our industry is obvious. It is not uncommon to find people discussing the acts of manufacturing, the shaping of parts, inspection and assembly, and testing and the relationship to data flow, numerical control, and things of that nature. On the other hand, they speak as if on another plane about the management of those acts, the planning, the scheduling, the data collection and correction activities. And they are, indeed, discussing two different planes so far as the technologies are concerned; but the data that move in those two planes are the same data. The data move back and forth from one plane to another, and that is the important message here. This data flow is the medium by which we integrate and control our manufacturing technology. It is becoming a science. If we understand, we can measure. If we measure, we can control. And if we can control, we should be able to succeed.

NEW MANUFACTURING TECHNOLOGIES: PARTS PRODUCTION

George H. Schaffer

James B. Quinn has eloquently addressed some of the main challenges facing engineers, manufacturing managers, and policymakers. It seems to me that among all the challenges facing those concerned with parts production, there is one common thread, a common denominator--that parts production must operate in a climate of constant change. The challenge is to operate economically in the face of smaller lot sizes, shorter product cycles, greater model proliferation, socio-economic pressures, and political realities.

Fortunately, the crescendo of change confronting today's manufacturing manager is accompanied by the rapid emergence of technological options that can provide the flexibility and fast response time needed to meet the challenges. The basic metalworking processes are not likely to change fundamentally, but their organization and control definitely will. I would like to explore some of these technologies and their effects on the tools of production.

The American industrial genius has been to create mass production systems on an unprecedented scale and efficiency. With its specialized machinery, mass production depends to a large degree on the existence of stable markets and long production runs. But the days of the black automobile and the white refrigerator are long over. The requirement today is for product diversification and fast response to the changing demands of the marketplace. Mass production, as we know it, is not compatible with these requirements.

In fact, according to some, the limits of expansion of mass production manufacturing have probably already been reached for all but the most mundane products, and batch production is on the rise. The choice of production mode--whether piece production, batch production, or mass production--is clearly influenced by the need for flexibility and the size of the production run. It stands to reason that the call for increased flexibility and the trend toward smaller production runs will result in a further concentration on batch manufacturing.

We tend to think of modern mechanical manufacturing as a highly productive and efficient process. Nothing could be further from the truth. A classic and much-quoted study of batch manufacturing at what is now Cincinnati Milacron found that the average workpiece spends only 5 percent of its shop time on the machine tool: For 95 percent of the time, it is being moved around or is waiting for work to be done. And of the 5 percent spent on the machine, less than 30 percent is spent in actual metal removal. Machine positioning, loading, gaging, and idle time constitute 70 percent of the time on the machine. Although this study is old by now and other figures may vary, the dimensions of the problem of unproductive time are undoubtedly significant.

There is another problem. The seemingly conflicting demands for greater product diversification, higher quality, improved productivity, and lower prices cannot be met in the climate of organized chaos that is so characteristic of batch manufacturing. Manufacturing management frequently involves nothing more than solving one crisis after another by using the most expedient solution avail- able at the time. Such management by crisis is hardly conducive to achieving an optimum manufacturing system.

These are structural problems that can be solved only by taking a new look at parts production. We need to consider the entire production process--from the design to the field support and service of product--as a continuing spectrum. As Joseph Harrington has put it so aptly, manufacturing is an indivisible continuous fabric extending from first conception of a product through design, production, and distribution to field maintenance. Of course, this continuum is composed of an incredibly complex, fine structure of many individual functions, each inextricably connected to and dependent on every other.

It is the close interdependence, the symbiotic relationships within the fabric of discrete-parts manufacturing, that makes it so susceptible to chaos. But diverse as the various parts of manufacturing may seem, there is a common element governing all manufacturing activities: What we call manufacturing is, in the ultimate analysis, a series of data processing operations or data transformations. All of manufacturing involves creating, sorting, transmitting, analyzing, and modifying data.

Therefore, everything done in manufacturing, whether in the physical act of material transformation or in planning and management, is part of a continuum of data processing. This data processing activity is the conceptual key to what is now referred to as computer-integrated manufacturing (see Figure 1). Ultimately,

FIGURE 1 Computer-integrated manufacturing (CIM) closed loop system.

computer-integrated manufacturing attempts to achieve a closed-loop feedback system whose prime outputs are finished products. It comprises a combination of software and hardware that includes product design, production planning, production control, production equipment, and production processes.

According to some of the best authorities, computer-integrated manufacturing has already demonstrated greater potential for improving manufacturing capability than has been shown by all other known types of advanced manufacturing technology combined. Unfortunately, computer-integrated manufacturing is not a shelf item readily available for application, nor can it be achieved by management fiat. It is continuing evolution, a goal that can be achieved only by planning from the top down and implementing from the bottom up. Unquestionably, the computer is emerging as a dominant--perhaps the most dominant--manufacturing tool.

That dominance started with isolated applications that have evolved into islands of computer-based systems. Although the applications vary in scope and complexity, they feature a common characteristic: Invariably, computers are used to provide more accurate and more timely information than is possible with current manual systems.

The basic information-handling tasks required during the life cycle of a product are evolving into a series of computer-based systems that form the basis for computer-integrated manufacturing. First in this interdependent chain of information systems is the means for capturing the information generated during design. Much of that information deals with geometric data, which are readily transformed into a geometric model, a representation of shape and size in computer memory, through the use of computer graphics systems. Such computer-aided design (CAD) is clearly taking over the design of products.

The geometric model can be used to generate fully dimensioned engineering drawings but is also the key to a host of related design/engineering/manufacturing functions, many of which can be performed concurrently, greatly compressing the product development cycle. Some of these activities are now being called computer-aided engineering (CAE) and are intended to automate the entire mechanical product development process. Starting with the geometric model of a prototype, CAE uses the computer early in the design process to simulate performance of the proposed product.

More directly related to manufacturing, numerically controlled (NC) parts programs are readily generated from geometric models with most of today's computer-graphics systems. The computer alone enhances the programmer's capability in a number of ways:

- It provides calculation capability beyond that of the machine's NC system and removes from the programmer the burden of manual calculations and geometric constructions.
- Program reliability is enhanced because the programmer has fewer opportunities to make errors.
- The programmer's need for intimate knowledge of the idiosyncrasies of each NC machine and its specific coding requirements is greatly reduced because the computer typically uses a shop-oriented language.
- The computer is not restricted to generating NC codes. It can also provide management information for estimating and planning, including tool management.

Such computer-generated NC programs can then be verified by three-dimensional graphic simulations.

One of the most significant emerging information systems, sometimes referred to as the "glue" of computer-integrated manufacturing, is group technology (GT). It is a manufacturing philosophy, an organizational principle with far-reaching implications. The underlying principle is relatively simple and not particularly new: Identify and bring together related or similar components and processes to take advantage of their similarities in design and/or manufacturing.

GT uses well-structured classification and coding schemes and associated computer programs to exploit the sameness or similarity of parts, processes, and equipment. On the one hand, this reduces duplication of engineering effort; on the other hand, it affords an opportunity to group similar parts and processes, thereby achieving economies of scale otherwise not possible in batch manufacturing.

The grouping principle can have a profound effect on virtually every aspect of the manufacturing cycle (see Figure 2). This effect is particularly true in batch-manufacturing operations, which typically involve seemingly endless variations of parts and processes. By helping to identify select similarities, GT can provide considerable benefits for most of the functional areas in a manufacturing organization: product engineering, manufacturing engineering, production control, and procurement.

In product engineering, GT can reduce part proliferation, encourage design standardization, provide manufacturing feedback, and facilitate cost estimating.

GT can help manufacturing engineering with process selection, tooling selection and grouping, machine procurement, facilities planning, materials flow, and materials handling. It can also help to bring newly available technology to the attention of planners by automatically including recently acquired applicable equipment or capabilities as processing alternatives.

FIGURE 2 Functional areas affected by group technology (GT).

In production, GT can reduce lead times, production delays, and setup times. It can also help with asset utilization, materials-handling decisions, and equipment selection to achieve appropriate quality levels.

Production control can use GT for scheduling, stock accountability, expediting, and reducing work-in-process inventory. Buy-or-make decisions and the establishment of economic order quantities can also be handled through GT. Ultimately, GT can affect customer support by improving the handling of dealer inventory and by shortening delivery times.

All of these benefits are achieved by identifying and assessing an array of information, then retrieving and grouping designs, parts, or processes on the basis of select attributes.

Although GT implies the establishment of manufacturing cells to handle families of parts, those cells need not necessarily involve the physical rearrangement of a facility. Most of the benefits of GT can be realized through administrative means, without such physical rearrangement.

Closely related to GT and another key factor in effecting computer-integrated manufacturing is computer-aided process planning. A planner must manage and retrieve a great deal of data and many documents, including established standards, machinability data, machine specifications, tooling inventories, stock availability, and existing process plans. This is primarily an information-handling job, for which the computer is an ideal tool.

There is another advantage to using computers to help with process planning. Because the task involves many interrelated activities, determining the optimum plan requires many iterations. Because computers can readily perform vast numbers of comparisons, many more alternative plans can be explored than would be possible manually.

A third advantage in the use of computer-aided process planning is uniformity. It has been said that if you ask ten planners to develop a process plan for the same part, you would probably end up with ten different plans. Obviously, they cannot all be the best plan. This also means that essentially the same job planned at different times will be done differently. Which plan will govern facilities planning? Which will be used for estimating future work? Which plan will be used for scheduling and shop loading?

There are basically two approaches to computer-aided process planning: variant and generative. In the variant approach, a set of standard process plans is established for all the parts families identified through GT. The standard plans are stored in computer memory and retrieved for new parts according to their family identification. Again, GT helps to place the new part in the appropriate family. The standard plan is then edited to suit the specific requirements of a particular job (see Figure 3). A generic variant approach is illustrated by the computer-aided process planning system developed under the auspices of Computer Aided Manufacturing-International Inc. (CAM-I).

In the generative approach, an attempt is made to synthesize each individual plan using appropriate algorithms that define the various technological decisions that must be made in the course of manufacturing. In a truly generative process planning system, the sequence of operations, as well as all the manufacturing process parameters, would be established automatically, without reference to prior plans.

No such system exists, however. So-called generative process-planning systems are still specialized systems developed for a specific operation or a

FIGURE 3 Computer-assisted process-planning system of Computer Aided Manufacturing-International Inc. (CAM-I).

particular type of manufacturing process, and probably will be for the foreseeable future. The logic is based on a combination of past practice and basic technology.

Another fundamental requirement for computer-integrated manufacturing is an effective manufacturing control and manufacturing planning system. These systems are typically modular and address such functions as materials requirements planning (MRP), inventory control, capacity planning, scheduling, forecasting, and cost control. To be effective, the modules must be linked to an overall management information system.

What effect will the advent of computer-integrated manufacturing have on the tools of production? Clearly, there is a move to flexible manufacturing systems (FMS)--programmable production systems consisting of two or more machine tools linked by materials-handling elements, including robots, and supervised by a computer-based scheduling and control system.

The recent International Machine Tool Show demonstrated that manufacturers who want to make this move will find the machine-tool industry ready with the necessary cells, systems, and peripheral equipment. A major emphasis at the show was on fitting each machine or accessory into flexible, electronically controlled, automated combinations with other units.

In fact, implementing FMS was the recurrent theme at the show. Virtually every new NC lathe or machining center or punch press offered the ability to be readily incorporated into a multimachine cell or a fully integrated manufacturing system. Robot loading was a common element (see Figure 4).

FIGURE 4 Robot loading machine, part of a flexible manufacturing system.

FIGURE 5 Flexible manufacturing system at Mazak machine tool factory near Cincinnati.

FIGURE 6 Front panel of a computer-numerically-controlled machine tool.

The most impressive FMS demonstrated was a multimillion-dollar, five-machine system that Yamazaki is now installing at its Mazak machine tool factory outside Cincinnati (see Figure 5). Unlike most previous FMSs, which have been designed to handle either rotational or prismatic parts, the Mazak system carries both types of parts around on lazy-Susan pallets, which are slid off wire-guided carts at turning stations and machining centers to be plucked by loader robots. Tool storage capacity of 120 tools is divided among four interchangeable carousels.

Control is the key to any flexible manufacturing system and is achieved, particularly at the machine level, with computer numerical control (CNC). The use of CNC is such systems is increasing, but a parallel and more visible development, as amply demonstrated at the 1982 International Machine Tool Show, relates to its increasing versatility in stand-alone job-shop machines.

Virtually all of the CNCs exhibited featured direct-programming capability at their own user-friendly front panels (see Figure 6). The user that the control builders have in mind is the person operating the machine, and the friendly features include full-color-graphics/CRT displays, interactive menu-driven program development, soft-button function assignments and, in some instances, aspects of computer-automated process planning; the new MPC II grinder control from Landis Tool even included a voice synthesizer to enunciate and confirm keyboard entries as they are made.

Another necessity for FMSs is the emergence of untended machines, which carries its own imperatives: tool management, for instance--ensuring that the right tool is at the right place at the right time and that dull tools are automatically replaced. For example, the emergence of untended lathes has shifted the emphasis from swapping cutter styles, which have always been available with tool turrets, to renewing dulled edges. The Sandvik Block Tool System was incorporated by Cincinnati Milacron into an 84-tool chain-type magazine, which itself can be brought to the lathe by wire-guided cart to be swapped automatically for a magazine of used tools.

As machine tools become untended, the means for checking cutting tools and for monitoring the manufacturing processes in a timely fashion also becomes essential. Virtually all of the manufacturing systems at the International Machine Tool Show included some form of in-process or postprocess inspection. Much of the former, particularly for tool verification, was accomplished with on-the-machine probing systems.

Tucked away in the magazine of many tool changers was a probe that could be brought into play just like any other tool. Most of these were touch-trigger proves used to automatically adjust tool offsets, correct for home position errors, and detect and compensate for material variations, such as those encountered in castings.

Not all the probes were mounted in the tool changer. The J&L FMS lathe uses two retractable touch-trigger probes to verify tool locations after automatic tool changing. And there is an analog probe, a tool-changer-mounted electronic plug gage from Federal Products that provides dimensional data for automatic adjustment of a DeVlieg Microbore boring cartridge while the cartridge is in the tool magazine.

In many instances, robots serving manufacturing cells or full-blown manufacturing systems alternated between feeding blanks to machines and presenting the machined part to a postprocess gaging station, whose dimensional data were used to make corrections in the machining program.

There is a need for diagnostic devices that reliably predict a failure--of a bearing or tool, for example--just before it occurs, instead of identifying the component after it has failed.

Untended machines will also work harder, racking up more continuous operating time in a given period than conventional machines. That means earlier replacement. And, of course, technological obsolescence also has a tendency to reduce the useful life of machine tools.

In summary, the flexibility and fast response needed to meet the challenge of constant change facing manufacturing must be addressed on two levels. First, organizational computer-based technologies, such as group technology, and automated process planning, must transform the organized chaos of manufac- turing into continuous-process-like, fast-response systems. Second, the physical tools of manufacturing must be provided with flexibility and control capabilities to tie into a systems-oriented production environment.

ASSEMBLY

Joseph F. Engleberger

Our keynote speakers both referred to robotics. I will consider only one segment of robotics--assembly.

In the 1936 movie "Modern Times," Charlie Chaplin blew the whistle on the abuse that we handed our working force in the modern assembly plant. At the time of that film, of course, labor was cheap, it was plentiful and, goodness knows, it was intimidated. None of those situations exists today, but even that far back we did have some technology to get assembly done automatically. Rotary turntables, for instance, represent the various automatic machines that would put pieces together (see Figure 1).

Professor Boothroyd, University of Massachusetts, outlined characteristics that one would ordinarily expect to have in part of an assembly so that classical, or what we often call "hard automation," could be used:

- Volume of at least one million per year
- Steady volume of production
- Market life of at least 3 years
- Size on the order of 0.5 to 20 inches with individual parts to be automatically assembled generally between 0.05 and 5 inches in their maximum dimensions
- Consisting of parts that do not deform significantly under their own weight or will not break when dropped from a height of about 3 inches onto a hard surface

If one considers these things, he will see many restrictions. A steady high volume is needed. The product needs to be around for quite awhile without undergoing change. Certain limitations on size are needed because these parts are sorted out by tumbling them. Moreover, the parts should not be squishy, such as cloth; they cannot change their charateristics as they tumble.

Thus, there are serious limitations to the kinds of things that can be done with hard automation.

Let me take one example from an industry that has espoused robotics more than any other, and that would be in the assembly of a speedometer. In an automotive speedometer there is the odometer. Every company in the world makes odometers on hard automation machines that spit them out one every second or so. But every company in the world then assembles the speedometer with people sitting on a line and putting them together, including those odometers. Why? Because the designer intervenes. He wants the speedometer long

FIGURE 1 Rotary index machine.

or he wants it round, he wants gas gauges, he wants "idiot lights"; so every model auto needs a special speedometer assembly.

We simply cannot use hard automation. Not only are the parts too variable, but they are becoming obsolete in every model year.

Robots come into the act in the programmable automation area by taking over some of the activities now done by humans and some of the activities now done by hard automation. Consider a robot that can simply replace the human on the line and give the robot the same sphere of influence, the same speed, the same accuracy, and let it stand on the line to replace a human. If such a creature were available to manufacturers, they might hark back to that hard automation machine and say, "Well, instead of just having these feeders, I am going to have programmable automation standing around the rotary table." Thus a range of products can be assembled on one flexible system. Group technology, which has been mentioned more than once, certainly can permeate the assembly process as well as the parts manufacturing process (see Figure 2).

Perhaps, however, there is something in this assembly that requires judgment, so that a human must be in the loop. Therefore, we use a conventional assembly with which people and foremen are very comfortable. It is a line on which pallets with tooling index along in one-second jumps. Each pallet stays about eight seconds in station. At the moment, this sort of a line has human operators stationed along it. Some stations, however, can be operated by robots, perhaps two at the station if there is hand-to-hand coordination necessary (see Figure 3). There may be a process in which we must have human judgment, and the human is in that station; or perhaps the human is in the station only for a period of time until we can iron out some of the processing for that station.

FIGURE 2 Group technology manufacturing system.

What are the economic issues? Figure 4, for instance, is from the robot group at Draper Laboratories, which is examining costs in assembly in an attempt to determine where programmable automation can best be used. One can assume that once the learning period is over, manual labor is going to be constant, no matter how many assemblies are made. One can also assume that if hard automation is used, the costs will decrease as the quantity increases. Once hard automation is created, it spits assemblies out at high rates.

There is an area, though, in which programmable automation comes into play. If only one of something is being manufactured, no kind of automation works efficiently, but programmable automation may offer the best economics.

Inexorably the two straight lines are going higher in this plot, and the curved line is going lower because programmable automation, robotics, group technology, and CAD/CAM all have economy-of-scale benefits. Thus, there is ever-growing opportunity for the use of robotics.

Where is the technology going that will be significant for the use of robotics in assembly? Essentially there are two critical areas. One is vision and another is tactile sensing.

In terms of vision, a camera may be mounted looking down on the scene. It understands that scene in world coordinates, the X, Y, Z, and θ of a part or parts, and it communicates these coordinates to a robot arm, telling it where to put its hand to find the part. However, an eye in a robot does not have to be in the ceiling or in a head; it can actually be in the palm. The eye may project its own beam of laser light, and it looks at a scene with a vidicon camera and analyzes that scene. This eye, then, is in the palm, and the palm essentially roams over the workpiece to examine what is happening in that scene, what is different about this set of parts.

If, for good economic reasons, we do not make parts so that they are very precise, we need humans with eyesight to weld those parts. However, the robot with some eyesight can examine a scene and then do very much as the human would in performing the welding job.

Tactile sensing is also a lovely development. It has come out of academia, and there is an interesting story behind it. In Draper Labs a student getting his Ph.D. degree in computer science was telling his colleagues (with equations) how he was building a wrist-force sensing system that, through zeroing all torques and forces, would enable an assembly to be made by a robot. One of the mechanical engineering Ph.D. students looked at all this and said, "Hell, I could build something like that mechanically," and he did. This is strictly a passive device that essentially makes parts float together without the help of a computer.

One more feature of the robots is their mobility. Some robots can traverse a floor for 40 feet, arrive within 2 inches of destination, go through a docking procedure, and lock into the dock. The arm performs a job there, and the robot moves to another station as needed.

Now, we have all these attributes, all of the programmability that I spoke of before, and you say, "Gee, it must be easy, isn't it, to do assembly with robots?" Just so that you can see how difficult it still remains, I want you all to be able to do what I call "play the robot assembly game." You can do this at home; it is a low-budget game.

First, rub petroleum jelly on your glasses, and then tie one hand behind your back. If this particular assembly job requires two hands, get a friend to rub

FIGURE 3 Assembly line with human and robot operators.

FIGURE 4 Comparison of costs for manual, hard automation, and programmable assembly.

petroleum jelly on his glasses and tie a hand behind his back. Next, put a mitten on that one hand and then pick up chop sticks. You now have every attribute of an assembly robot today, and all you do is to assemble something according to detailed instructions.

So, we still have some work ahead of us to beat the assembly game.

On a serious point, I would say one other thing. The robot is actually pretty good at assembly. The trouble we have in programmable assembly is with the peripheral activity of presentation of the parts, particularly if they are small parts. If human intervention is necessary, the human might as well put the parts together. Therefore, you need either a vast depth of black art with feeders, or you need a robot with the ability to do something it cannot do yet, which is to look into a tub and pick out randomly-oriented parts. That is called the "bin picking problem" or, among the technical types, the "occulsion problem." It has not been solved.

Joseph Harrington and I were talking earlier about a grave manufacturing deficiency. Almost everything in the world was once oriented in a factory. Someplace somebody took each part out of a machine or a station and threw it in a

TABLE 1 U.S. Export Competitiveness

Country	Hourly Compensation ($ U.S.)
United States	12.61
Sweden	11.17
Netherlands	10.91
Belgium	10.11
West Germany	10.06
Canada	9.36
Denmark	8.10
France	7.57
Britain	7.35
Italy	6.97
Japan	5.72

box. If you had a scrap ticket for every time you lost orientation in a factory, people would pay more attention to the blessing of orientation and preserve it. About 65 years ago the catch phrase of Detroit automation became "never drop a part." I can tell you that is obeyed mostly in the breech.

So, if we can rationalize the workplace and we can use CAD/CAM and group technology and say that we are not going to drop the parts, we will be able to do a lot more with programmable assembly.

Table 1 is extracted from a recent Wall Street Journal. It tells something about the problem in this assembly arena. U.S. labor is most expensive (yen were about 265 to the dollar when this was created; they are now about 278 to the dollar). We have more than a two-to-one range between our toughest competitor and us.

Let me continue on the Japanese because Japan was emphasized by our keynote speaker. I have gone to Japan every year for the last 15 years, and about 5 years ago I asked, "How about robots for assembly?" The Japanese said, "Oh, no way. We are not going to do that. The Japanese are perfect people for assembly. We are extremely conscientious, we are quality-conscious, we are fast, we are small, and we can put little parts together very quickly. We are not interested in robots for assembly."

Last year on my trip the projections that the Japan Industrial Robot Association had for all the robotic activities they saw through 1990 forecast the single largest class of robot activity as being assembly. I said, "What happened?" "Well, we made some demographic studies; we concluded that we will never have enough people; we are a monolithic society; we have a fixed population; we want people to retire earlier. We will never have enough labor. We plan to make this country a country of only knowledge workers." Then they said something that was very important to me. They said, "Of course, when we use the robots we will not do assembly the same way anymore."

We talk to people in the United States about using assembly robots, and they say, "Oh, we do assembly on one shift. There is no economic justification for robots. What do you need? You need a roof; you need some benches and some little tubs—virtually no capital investment. You just sit a girl at the bench and have her assemble."

The Japanese immediately saw, as implementers, that if you start to do assembly with programmable automation you have a capital-intensive activity, and when you have a capital-intensive activity you are going to run it around the clock. That is going to be a hard sell unless attitudes change in this country.

I am going to close with a sociological observation that tickled me. Most of you, probably in college, read Orwell's 1984. I read it again a few years after college, and I found out by reading Futurist Magazine that a tremendous number of his predictions have come true. In fact, the magazine listed 137 predictions, of which 100 have already come to pass: Rapid access to and retrieval of information, data banks containing detailed personal information, think tanks where experts plan future wars, poisons capable of destroying vegetation (like Agent Orange), disease germs that are immunized against antibodies, lack of heating fuel and electricity, merging of the genders. Now, one wonders, is Orwell going to be right completely? Is his accuracy ever going to end? What will still come to pass in the next year-and-a-half?

Eric Fromme, the philospher/psychiatrist, observed, "George Orwell's 1984 is the expression of a mood, and it is a warning. The mood it expresses is that of near-despair about the future of man, and the warning is that unless the course of history changes, men all over the world will lose their human qualities, become soulless automatons and will not even be aware of it."

Orwell wrote 1984 in 1948. All he did was transpose the last two numbers. By 1948, as a well-read person in scientific literature and science fiction, he had to know about RUR, Rossum's Universal Robots, a successful play in 1922. He had to know about Issac Asimov's early stories, his I, Robot stories. He had to know about Russian science fiction. And yet, I can assure you, never once in this predictive book did he mention the word "robot." He did not because his worst nightmare was that people would be automatons, that people would become robots. There is not any way that we in the robot business could possibly compete with a human who has been robbed of his personality as a human being. A robotized human is the cheapest possible labor there could be.

So, I put it to you that there is hope. There is only a year-and-a-half left, and if everyone gives the robot industry sufficient support, people are not going to become automatons, and we will have exorcized that particular Orwellian nightmare.

TESTING AND QUALITY

Susan Foss

The introduction of global products within our marketplace has taught us a valuable lesson: that we cannot sell a product based on price alone. Quality in the product gives the competitive edge.

Currently, the manufacturing philosophy of this country utilizes an appraisal-oriented assessment for product quality. I call this assessment "after the fact." Over the past 20 years the use of this type of open-loop system has escalated. From present indicators, however, this method is not working, or as is often heard, "you cannot inspect quality into a part."

The preceeding suggests that a new philosophy needs to be implemented, one using a prevention-oriented or before-the-fact approach. It should be a total closed-loop system that starts with the product conceptual stage and continues through postwarranty. Emphasis at the onset should be on quality of the product in concept/design, processing, warranty, and postwarranty stages. There should be an information-flow system that allows pertinent data to be available wherever needed throughout the product flow.

The closed-loop approach would change the present inspectors, as we know them today, so that they would be more like auditors, not necessarily auditing the part but auditing the machine tool capability. This would change the present in-line measuring machine function from distinguishing between good parts and bad parts to one of feeding information back to the machine tool for needed corrections. The machine operators would again be asked to serve partly as machine managers, since they know best the functional capabilities of each of their machines.

The expansion of this closed-loop approach would automatically lead to the life-cycle dimensioning concept. Needed information or data is shared from product concept to product mortality. Emphasis is placed on using what we know and on learning from it.

In moving from an appraisal approach to the prevention method, several tools are necessary. Computer-aided design/computer-aided manufacturing (CAD/CAM) provides a consistent base for part definition. As known today, it operates in the design, manufacturing, and some concept and assembly stages.

Closed-loop inspection provides dimensional history of machine tools and/or parts. It needs to operate from concept through postwarranty stages, with total feedback at the pertinent functions. Statistical analysis techniques should be an integral part of this system. Concept/design quality simulation provides compatibility of design and processes and provides quality information from concept through assembly functions using simulation techniques. We have the technology and the ability to implement this approach. Today I will discuss two tools already mentioned: closed-loop inspection and concept/design quality simulation.

Deere & Company has a computer-aided inspection and reporting system (CAIR), which presently uses a man-closed loop. It performs the normal inspector operation, monitors process capabilities, and determines machine trends by part dimensions. It provides Deere with a rapid and accurate means of obtaining a data base for parts and machine tool dimensional data and also provides analysis routines to assist in interpreting this data.

CAIR operates in 16 North American and 3 European facilities. Presently it contains 26 multitasking minicomputers that communicate with 87 digital devices. A typical CAIR system has a multitude of digital input devices. These include:

- Manual and computer-controlled measurement machines

- On-line digital gaging

- Engine test cells

- Theodolites, which are surveyors' electronic transits used in place of measurement machines for measuring large frames and fixtures

- Booms on excavators or frames for large motor graders

Typical output devices include:

- Printers and cathode ray tubes (CRTs) for analysis and/or inspection reports

- And within one year, direct feedback to the machine tool

CAIR offers, in addition to an inspection report, a series of analysis programs or routines to assist with data interpretation. These routines can on-line, real-time analyze the "just captured" data from the operating process and instantly display the results on the CRT or printer. For instance:

- A histogram displays the frequency distributions as a bar chart and prints pertinent statistical results of the parameter that is under investigation. A normal curve is used because experience has indicated that this closely approximates manufacturing processes.

- Trend analysis displays the actual measured dimensions of the part versus the number of pieces measured. A best-fit line is drawn through the data points with a 99.7 percent confidence band constructed around this line. Real-time process variations can now be readily seen, and needed adjustments can be made.

- Feature analysis analyzes bidirectional data--in particular, the X and Y locations of bores. This routine displays the relative locations of actual measured data, indicated by the x's, with respect to the bore print specification indicated by the target circles. All the x's exceeding the circles are outside the print specifications and indicate bore location shifts. Previously, extensive time had been consumed in trying to sort through tabulated data to establish this shift.

- With this routine the features are visualized and required machine tool adjustments can be readily seen and made (again by the x's, now inside the target circles).

Extensive use of this analysis technique has been made when setting up new flexible machining lines at several of our facilities. It alone has provided substantial cost avoidance by significantly reducing delays encountered with machine tool deliveries. Daily use of this routine is made to monitor existing manufacturing processes and provide process control information.

In addition to the analysis routines, CAIR can provide the product engineer with

- A historical dimensional data base for experimental parts
- A way to select tolerance bands
- Increased knowledge for modifying part dimensions
- Tolerance degradation effects on part performance
- Vendor process capability

For the manufacturing engineer CAIR provides

- A dimensional data base for fixtures and tooling
- Process capability information

- Assistance in modifying tooling and fixtures
- Tolerance degradation of these items
- Machine auditing capabilities

The benefits of CAIR are being demonstrated daily. A time savings of 7:1 is realized in our inspection operations, and process capability studies have been increased by a factor of 15.

A second tool needed to achieve a prevention system was developed by Chevrolet Division of General Motors. It is called variation simulation modeling (VSM), and uses a closed-loop approach.

This system provides General Motors with a probablistic approach for early detection of component variation problems as new product designs are developed. This includes the process as well as the concept/design areas.

VSM presently resides on a large main frame computer system and is available throughout General Motors Corporation through interaction with the Chevrolet Division VSM team. A typical VSM system consists of

- Cathode ray tubes for input
- Mainframe computer
- Printers and CRTs for analyzing results

Variation Simulation Modeling operates in the following manner:

- A mathematical model is constructed that establishes the relationship between the components of the assembly and imitates the assembly operation involved in putting the components together. This model describes the relationship between the parts of the system and how the system operates on the parts.

• Each component of the assembly is defined by its specific nominal and associated tolerances. For the concept/design area this would be blueprint values, and for the process area this would be measured data. In addition, a probability distribution function is associated with each dimension. Available functions include Normal, Uniform, Constant, and Random.

• The use of these density functions allows the random selection of component dimensions by having a random number generator pick a number between 0 and 1 (such as 0.5843) and generate an associated component dimension based on its nominal values and tolerances. The cumulative distribution function (CDF) portrays the area under the probability density function, and this area also varies from 0 to 1. This CDF is used to simulate the process operation of an operator randomly picking a part from a bin.

• Once the assembly is modeled and appropriate distributions chosen for each of the component dimensions, a simulation can be run for whatever sample size is desired and an analysis conducted. This will indicate the statistics for the sample run and the percentage out of spec as predicted by the model if the assembly as such is designed and/or processed.

If the simulation analysis shows that our system is not meeting design intent, a determination must be made as to which variable(s) at the component level is significantly contributing to the overall variation. This is done by means of a tolerance sensitivity analysis. Once this variable or variables are determined, they are held at their nominal values by eliminating the random selection process, and the model is rerun, the object being to make percentage out of spec equal to zero.

For the design engineer, VSM

- Provides a substantial cost avoidance during concept/design and process stages
- Ensures correct tolerance interactions
- Aids with assigning tolerances
- Makes the probablistic approach practical
- Minimizes potential quality problems
- Reduces prototype builds

For the manufacturing engineer, VSM

- Provides substantial cost avoidance during concept/design and process stages
- Minimizes potential quality problems
- Aids process change decisions
- Aids machine tool decision
- Ensures a smooth flow from design through process stages

The benefits of VSM are many. A few of these are:

- Reduction in concept/design time by a factor of ten
- Cost avoidance by reducing prototype builds and rebuilds
- Cost avoidance by identifying potential quality problems prior to prototype builds

In summary, computer-aided inspection and reporting and variation simulation modeling, when merged with CAD/CAM, will provide the needed tools for a prevention approach. CAIR provides the dimensional history of machine tools and/or parts, VSM provides compatibility of design and processes, and CAD/CAM provides a consistent base for part definition.

The competitive edge against global products within our marketplace begins with quality, be it in the agricultural, the automotive, or even the aircraft industries. By using the important tools currently available, quality will start within the conceptual stage of design.

MANUFACTURING INFORMATION FLOW

William D. Beeby

About seven years ago, we at Boeing had done a lot of experimenting and testing of various applications of the computer for doing individual jobs in design and manufacturing. Our top management began to realize the amount of money that we were spending and requested that we come up with a total concept of how we were going to put this all together and make it pay off. The basic presentation I am giving today was actually used seven years ago. It will relate some of the successes we have had in integrating engineering and manufacturing and also some of our failures.

I must comment now that most of our failures have not been technical failures. They have been psychological failures because of our inability to convince people that there is a new way of doing business. One has to think differently in this new world of computers and automation.

We started with a concept, a master concept that the manufacturing business was data intensive. Every function we performed was done because of data that were passed from one organization to another, whether we were doing very preliminary design or actually going into production. The same data supported assembly or detailed design, release and control of that design, and manufacturing. Each of these areas needed the same data.

The data that started in preliminary design were merely enriched, modified, improved, and used by various organizations in doing their jobs. We developed a system that would use a common data base; and all organizations, from preliminary design all the way to customer support, would have that data available to accomplish their tasks.

We started describing this process by saying that when we received a go-ahead for a preliminary design, the engineer would actually start to load three different data bases. We broke it up into three data bases seven years ago because at that time no one could conceive of a single data base that could accomplish all the functions we felt had to be accomplished. So we set up a data base that was to be used for business systems--for production control, parts lists, inventory control, etc. Then we developed a geometric data base for handling the master models and the geometry of the product. For the business systems we used an off-the-shelf data manager, but for geometry we were unable to find a commercial data base manager, and it became necessary for us to develop and build a geometric data base that would handle all of the coordinate systems, the centerline data, preliminary geometry, and our master models.

We also created some cases in which, from a surface program, we could generate a mathematical surface definition that could then be automatically fed to a machine tool that would in turn create our wind tunnel models. It would also give us results of testing instantaneously. We could then make corrections or improvements to the product and try it again. Because we passed this data to other designers, we also needed a data base that could store our design analysis data. This data base now holds our specifications and the results of analysis tests so that the data will be available for other people to check against.

When the go-ahead for a new product was given, we would extract the data that preliminary design had stored and start from that baseline to develop a more production-oriented model. We gave the engineer local storage space and his own stress analysis and fatigue analysis programs. This allowed him to analyze his work as he completed the assembly and installation design. We also made the data available for the technical staff analysis programs so we could verify that the design we were creating matched the specifications.

As the design progressed, the detail designer was able to use the data already in the geometric data base and start putting in the effectivity, the parts list data and the used on notes in the business system.

Here was a case for which we have had a substantial success in that the detail designers completely accepted the use of computer data for doing their detail design. Over 40 percent of all the designs released on the 768 and 757airplane programs were released using this data base system. They actually came out of the computer and were described mathematically rather than on paper drawings. We still have paper drawings, however, because many of our subcontractors cannot use computer data.

We committed ourselves to developing a number of special programs that would allow the design engineer to create flat patterns automatically and to develop hole patterns from design criteria, giving dimensions, finishes, and material specifications. Putting such data in the computer allowed the engineer to specify the material he was using and the conditions it had to withstand; the computer then selected the optimum finish per the Boeing design manual. Special programs were also developed to help the engineer in weight and stress analyses.

Previous papers have discussed group technology. I want to add that at Boeing we have forced this group technology approach back up into engineering so that we can use it in selecting standard parts, to avoid new designs when old ones are already available. We have developed an automated system to help the engineer find these designs in the computer.

One of the most critical areas of development was the release and control of design information. It is very hard to convince an engineer that what he sees on a piece of paper is actually stored on a disk and that nobody has changed it. We had a very difficult problem in establishing an engineering release system that would permit very tight control of computer data. It has been done, and manufacturing now considers the data in the computer as having the same authority as the paper drawing.

Manufacturing planning is able to extract from these two data bases all of the material requirements, the number of parts to be built, and the types of assemblies. They are also able to call up a copy of the geometry and modify it for their needs. In other words, they are able to add more material if they need it to grip a part for stretching or if they need certain holes left blank for an assembly operation later on. This allows them to release a manufacturing drawing without the need to copy any pertinent engineering information. The data are then stored in the geometric data base for use in fabrication and assembly work.

I wish to stress again that there is only one data base common to both engineering and manufacturing.

Quality control then begins to look at the part data and to decide what controls are necessary and how they are going to monitor the part. They will add the necessary information to the manufacturing plan and create a quality control drawing for fixtures necessary to control quality. All the data are then passed to the tool designer. He can now start to design the tooling--the dyes, jigs, holding fixtures, etc.--around the engineering geometry without having to reinterpret the engineering drawing.

Tool design was one of the areas that turned out to be the most surprising and satisfying in the design and building of the 767 and 757. Tool design was quite skeptical of the ability of engineering to store geometry data and control it and then to allow them to use it. But there was a big drive to use computer-assisted design/computer-assisted manufacturing (CAD/CAM) in the tooling department, and it resulted in a large reduction in the number of designers required to design tools for the new product.

Of course, at the same time, the numerical control (NC) programmer made big strides when the data was properly defined by the design engineer. When the design engineer did not have a thorough understanding of the way in which the NC programmer needed the data structured, however, the data became almost useless. The communication gap between the manufacturing engineer and the product design engineer is probably the most difficult thing that has to be dealt with in total integration of manufacturing systems.

In the fabrication of detail parts, the common data base has proved to be extremely valuable. In some cases the data have actually been transferred from engineering through a manufacturing postprocessor directly to NC machine tools. The same data were used by quality control to fabricate inspection devices.

Initially we did not consider subcontracting a very important link in this total integration process. It was not until we started releasing design information on the 767 that we began to realize that over 60 percent of the fabrication was accomplished by subcontractors. On the 757, which followed the 767 by about eight months, we did start an extensive program with four major subcontractors to furnish them not only drawings but also tapes that would give a complete mathematical description of the parts and assemblies they were to build.

Integrating the subcontractor will probably be the biggest effort that we have to make in the future. The success of the communication with the subcontractor is dependent upon standards. There is a strong move within this country to accept IGES as a standard communication of geometry. Although it is not wholeheartedly supported by all companies at this time, in the near future there will be enough demonstration of this standard that all industry will move to accept it.

The next important area after subcontractors is subassembly, in which we are doing some automation for our wire bundles as well as controlling cube storage for the component parts. We are doing all of the extractions for quality control processing from the computer data base. We have begun to use a few robots experimentally.

We are doing more and more with automatic machines in the major assembly areas. They are flexible manufacturing machines, primarily for drilling and riveting, which is the major activity in the assembly of aircraft. The data to drive these machines are being supplied directly by the engineering data base. One of the largest of these machines drills and rivets all the skins and stringers on the wing panels. On the first 767 this machine accepted all of the geometry data directly from the engineering data base, and manufacturing merely added the sequence for drilling and riveting. This installation required over 33,000 holes to be drilled and rivets to be driven. The operation was completed without a single error. This is the kind of performance that can be expected when employing extremely accurate data that can be used without the need for human interpretation.

SESSION 2

INTEGRATION OF THE MANUFACTURING SYSTEM

Session 2 participants. Left to right (standing) D. C. Burnham, Frank Daley, Session Chairman Gordon H. Millar, Robert P. Clagett, (seated) M. Eugene Merchant, Joel D. Goldhar, Arnold M. Kriegler, and James E. Ashton.

INTRODUCTION

Gordon H. Millar

This session will build on what we heard this morning and will examine the whole concept of the integrated manufacturing system. For years and years we looked at manufacturing as a means by which human effort was used to convert material and other resources into a finished product. The concept of manufacturing is broadening today, so that manufacturing includes the concept of the product, its design, its manufacture, and its delivery to customers--a total reiterative, closed-loop process that ends up with substantially improved utilization of resources in order to refabricate in North America the competitiveness of manufacturing that built this nation.

CHANGING CONCEPTS OF THE MANUFACTURING SYSTEM

Joel D. Goldhar and Donald C. Burnham

INTRODUCTION

Computer-aided design and computer-aided manufacturing (CAD/CAM), robots, international competition, productivity, "working smarter," quality--these are key words today in the newspapers, trade journals, and popular magazines. All who read, or watch TV, are to some degree aware of the challenges facing U.S. industry, the technological frontiers of manufacturing, and the pervasive application of computers to every conceivable work task.[1] They are also constantly reminded of the human problems, workforce dislocations, and potential unemployment associated with increasingly sophisticated and more prevalant competition and automation.

Few, however, fully understand how the new technology, worldwide competition, and changing customer demands are combining both to require and to make possible new styles of competition, greater attention to customer requirements, and new-concept factories of the future. These factories will be capable of delivering levels of efficiency, speed, variety, quality, and reliability not possible using the last generation of production technology, organization, and strategy.

Our paper will examine the way that this new generation of mechanical technology, computer-based information systems, and electronic process controls creates the factory of the future. Further, we describe how these advances will fundamentally change the economics and operating characteristics of the traditional piece-parts and assembly factory and, indeed, the organization and competitive strategy of the entire company.

A recent article in the Wall Street Journal called this change in technology a revolution and outlined its impact:[2]

> A revolution in manufacturing is completely transforming the economics of production. It is doing so by reducing the cost penalty of product diversity. Within companies, the traditional conflict between marketing, which wants to offer customers more models, and the factory, which has wanted to limit product line variety for the sake of production efficiency, is becoming a thing of the past. . . .
>
> Setups that used to take hours can now take minutes as a result of new, sophisticated machine tools and microprocessor control and sensory technologies. The faster setups are the key to collapsing the structure of downtime, inventory and overhead cost that plagues the conventional factory. . . .

The marketing and competitive implications of these new plant economics are powerful. Because product variety costs less now, there will be more of it. . . . Shorter setups increase effective plant capacity and reduce the cycle time it takes for the complete model mix to move through the factory. This allows the manufacturers to increase their model range in finished goods stock and keep their delivery lead time constant without raising their inventory costs. . . .

Full-line producers with smaller market shares may suffer less manufacturing disadvantage than before. . . . The strategic payoff from the investment lies in marketing and in better control of competitors. Shorter setup times enable a company to serve distribution channels better and to capture, at acceptable cost, higher-price, low-volume products. Broad-line producers everywhere will have to reckon with these new economics of diversity.

TRENDS

Before discussing the technical aspects of computer-integrated manufacturing (CIM), we need to examine the trends in the economy today that are the driving forces behind the need for change:[3]

- Computers are increasingly used to perform the paperwork of all manufacturing tasks as well as process control.
- Products are being designed for "manufacturability" as well as product function.
- Flexible automation is starting to replace fixed automation for the manufacture of families of similar parts in a single factory. Batch processes are being replaced by continuous flows of parts and information.
- Robots and automatic handling equipment are making computer-controlled machines into completely automated work cells.
- Individual work cells are starting to be tied together by the computer into a manufacturing system.
- The cycle time through the manufacturing process is being shortened and work-in-progress inventory is being drastically reduced.
- Consistent high quality is being recognized as a productivity and cost improvement.
- Product life cycles are becoming shorter and new product designs more frequent.
- More sophisticated customers are demanding high quality and some degree of uniqueness in the products they purchase.
- Many products are becoming more complex and technologically sophisticated with each succeeding generation, thus requiring more sophisticated and complex manufacturing techniques and systems.

All of these trends affect to some extent all businesses and their manufacturing systems--from chemical process plants and oil refineries, to assembly lines for automobiles or appliances, to batch systems for clothing and machine tools, to one-at-a-time specialty fabrication shops. Of particular interest to us are the ways the application of computer and information technology to manufacturing has changed all types of production, but the greatest observable impact is on the traditional batch-process factory that today uses people, stand-alone machine tools, or other unit operations and assembly lines to produce small to medium quantities of a variety of components and finished goods. These are gradually becoming continuous process systems as the computer and new mechanical technology increase the speed of throughput while reducing the time gap between successive units of output.

All manufacturing systems begin to approach the operating characteristics of a chemical plant; however, the economies in the production of products based on mechanical technology will come from the variety and flexibility inherent in computerized information and process control systems. Manufacturing, like chemical processing, is becoming a "high-science" activity.

Several key scientific trends underlie the major advances in manufacturing technology described above: (1) We are gradually gaining a fundamental understanding of how solid materials behave and change under process conditions; (2) measurement science and technique and control theory applications are advancing rapidly, allowing us to control physical processes; and (3) artificial intelligence offers great promise for the next generation of advances, even over the increasingly sophisticated information science in use today.

INTEGRATION: KEY TO THE FACTORY OF THE FUTURE

The new-concept manufacturing system is at its most powerful when our increased knowledge of material and process behavior and improved measurement techniques are used with the computer to control and integrate all of the production process operations with systems for managerial control of the factory and a wide range of corporate business functions. This is commonly called computer-integrated manufacturing (CIM) and is generally what we mean when we refer to a factory of the future. CIM can best be defined as:

> the combination of hardware, software, and data base and communications to provide:
>
> 1. On-line variable program (flexible) automation
> 2. On-line moment-by-moment schedule and performance optimization
> 3. Closed loop control of material flow and operations
> 4. Dynamic coordination and reallocation of resources
>
> The computer makes it possible to analyze and describe the unit operations or unit processes of manufacturing, to utilize sensors to ascertain process conformance with analytical predictions, and to optimize and adapt performance with feedback and control mechanisms.[a]

The range of business and production functions that can be integrated with manufacturing is shown in Table 1.

Table 2 illustrates the flow of information within the total manufacturing system.

The technologies making CIM possible are smart machines, sophisticated sensors, flexible and multipurpose tools, a common engineering and manufacturing data base, process-control information encoded in software rather than built into

TABLE 1 CIM: Total Manufacturing Integration

CIM Business Planning Functions
Forecasting
Long-term (master) production scheduling
Intermediate production scheduling
Bill of materials processing
Material requirements planning
Finished parts, raw material inventory control
Purchase order processing/followup
Receiving, inspection, recording
Invoicing
Accounting
Short-term production scheduling
CIM Business Execution
Quality control
Short-term schedule execution
In-process inventory control
Production tracking
Materials handling
Inspection and testing
Production monitoring
Work station control

SOURCE: Scott M. Staley and Mohamed O. Ezzat, "CIM: Total Manufacturing Integration," CAD/CAM Technology, Spring, 1982.

the hardware of machines and material movement systems, and the use of computers to automate the "knowledge work" of manufacturing and to integrate production planning and control and shop floor control with similar automated systems for accounting, purchasing, logistics, personnel, and other business functions.[5] The result can be a factory of the future that is computerintegrated, close coupled, continuous flow, paperless, and highly flexible. It can economically and efficiently produce a wider variety of products in smaller batches than is now feasible.

Lead times for new product introductions or improvements will be drastically reduced; work-in-progress inventories will practically disappear; costly final goods inventories used to buffer the factory from the uncertainties of the marketplace will not be necessary; and both direct and indirect labor will be substantially reduced.

IMPACT ON THE FACTORY

Following the analogy to a chemical plant and the logical consequences of the changing economies of production described by Hunt and Stalk in their *Wall*

TABLE 2 CIM: Total Manufacturing Integration

CIM Manufacturing Management	Direction of Information Flow
Business Planning and Support	
Economic simulation	
Long-term forecasting	
Customer order servicing	
Engineering Design	
Computer-aided drafting	
Computer-aided tool design	
Group technology	
CAD	
Manufacturing Planning	
Process planning systems	
Parts programming	
NC graphics	
Tool and materials catalog	
Material requirements planning	
Production line planning simulation	
Bill of materials processors	
Machinability data systems	
Computerized cutter, die selection	
Materials/parts inventory management	
Manufacturing Control	
Purchasing/receiving	
Shop routing	
Methods and standards	
In-process inventory	
Short-term scheduling	
Shop order follow system	
Shop Floor Monitoring	
Machine load monitoring	
Machine performance monitoring	
Man-time monitoring	
Materials/stores monitoring	
Preventive maintenance	
In-process quality testing	
Process Automation	
NC, DNC, CNC	
Adaptive control	
Automatic assembly	
Automatic inspection	

SOURCE: Scott M. Staley and Mohamed O. Ezzat, "CIM: Total Manufacturing Integration," CAD/CAM Technology, Spring, 1982.

Street Journal article, we can suggest a number of design characteristics that will differentiate the factory of the future from traditional manufacturing. They are:

- High fixed costs approaching 100 percent
- Product design and process control information encoded in machine readable form
- Tools, machine "centers," other process and assembly operations, and material movers that are all flexible, adaptive, multifunction, and smart
- Low-cost intelligence and memory hardware

These four characteristics--fixed costs, machine readable information, smart tools, and cheap computing--lead to a factory that behaves in a different fashion. It will exhibit:

- A relatively flat learning curve for a specific product configuration after the software is debugged. Emphasis shifts to an "experience curve" for a family of similar products over time
- Short-run average costs that approach the long-run average

The CIM factory will have computerized production planning and control systems (the "paperless factory") and computer control and integration of all manufacturing operations, production management, engineering, and business activities. We will see relatively few, but highly skilled, human beings who in their operating mode will resemble airline pilots with responsibility for the operation, according to plan, of a complex technological system. Engineers and managers will need to adopt a systems emphasis in place of their traditional unit operations thinking. New analytical tools for analyzing and optimizing factory design and operations in advance of actual commitment to capital expenditures will be readily available. These new-concept plants will have high levels of investment in software and in computer programming, operations, and maintenance capabilities--perhaps greater than their investment in machines.

The economic basis for the CIM factory is economy of scope that allows for low-cost variety in addition to the usual economy of scale resulting from aggregation of resources. Economies of scope exist when multiple products can be more cheaply produced in combination than separately; i.e., when the same equipment can produce multiple products (or at least variations on a theme in a family of products), the potential for economies of scope exists. For example, a computer-controlled machine tool with a tool changer does not "care" whether it works on a dozen units of the same design in succession or a dozen different product designs in random sequence (again, within the range of a family of designs--but that range gets broader with each new generation of tools). The changeover time and cost are almost negligible, since changeover involves simply reading a different computer program with electronic speed. The variable costs of product-line breadth move "back" to the design process, where computer-aided design systems are increasing engineering productivity by orders of magnitude. In a sense, the traditional idea of economy of scale is now vested in the design and engineering effort.

Economies of scope directly affect such decisions as length and breadth of the product line and the types and amounts of inventory in the production-distribution-delivery chain. This in turn leads to a switch in emphasis from minimum cost to maximum competitiveness, with objective functions for manufacturing that emphasize:

- Minimum changeover costs and time
- Maximum flexibility and quick turnaround capability
- Minimum downtime for maintenance
- Maximum product "family" range
- Ability to adapt to variability in materials and process conditions
- Ability to handle increasingly complex product designs and technology
- Ability to integrate new process technology into the existing system at minimum cost

These are the new variables by which we will evaluate the factory of the future. That is, we will look for a factory's ability to provide a competitive weapon for the market environment of the future in place of the narrow focus on cost per unit that has led to long runs of standardized products that no one seems to want to buy.

Given these characteristics we can gain an overall concept of the CIM factory if we consider it as a combination of the following three ideas:

1. A continuous flow of product--as in a chemical plant--but with economy of scope allowing the production of a variety of similar products in random order in addition to the economy of scale derived from overall volume of operations.

2. A computer system with machine tools, robots, and other process equipment as the "peripherals" in place of printers, plotters, terminals, and disc packs. The organization, management, maintenance, and operating problems of the new concept factory will closely resemble those of our computer systems. The ongoing discussion of the pros and cons of centralized vs. decentralized production facilities and product vs. process factory focus are exactly analogous to the centralized vs. distributed computing and data processing argument; indeed, it is the same technology.

3. A response to the demand for greater variety, customized designs, rapid response, and "just-in-time" delivery. We are gradually switching from the production of large volumes of standard products on specialized machinery to systems for the production of a wide variety of similar products in small batches (perhaps as small as one). These small batches will be produced on standard but flexible machines that are reconfigured by their software to the required process for each different product design.

These combinations of computer systems and chemical plants with their attributes of scope, flexibility, close coupling, control, and speed will allow U.S. industry to respond profitably to market pressures for increased variety and customization of products, close-coupling/minimum-inventory linkages between suppliers and customers, greater variety in consumer goods, increased reliability and quality, and the "demassification" of the marketplace as described by Alvin Toffler in The Third Wave.[6]

However, making effective use of this technology will require new marketing styles and corporate strategies emphasizing rapid design change, variety and customization of products, and new techniques for the design and management of factories that take into account the unique features of computer-integrated manufacturing. We also need to rethink all of our traditional concepts of factory organization, plant layout, facilities location, choice of process technology and equipment, production planning and control techniques, standardization of product designs, size of batch or length of run, line vs. staff responsibilities, the means for introducing new technology into existing systems, measures of productivity and performance, training and required skills of managers and professionals, and so on. A major research effort is needed to determine which tools and techniques will remain the same, which will disappear, and how others can be modified to be useful in managing the computer-integrated factory of the future.[7]

This leaves us with a factory whose operating characteristics are very different. For example:

- Economic order quantity (the batch size for cost-effective production of a particular product design) will approach 1.
- Variety will have no cost penalty at the production stage.
- Costs per unit will be highly sensitive to total production volume because fixed costs will approach 100 percent.
- Joint cost economics will be the rule--the value of the system will be a function of the "bundle" of products it produces, and the marginal cost of a particular product will be difficult, if not impossible, to calculate.
- Rapid response to changes in product design, market demand, and production mix will not only be possible, they will be required.
- Nearly unmanned operation will become the norm, much like the chemical plant.
- Close-coupled and highly integrated production systems will be used, as well as supplier-user linkages, resulting in minimal inventory levels and little slack for errors in timing or judgment.
- Consistent high levels of quality and process accuracy and repeatability will introduce higher levels of certainty into the production planning and control activity allowing for higher levels of process optimization.
- The managerial emphasis will be on extensive and expensive preproduction activities to eliminate errors and bugs before the machine goes into action.
- Traditional line management responsibilities will move toward staff and engineering activities.

SOME EXAMPLES

These characteristics can already be seen in operation to a greater or lesser degree in a variety of real production environments. These are mostly standalone modules or partial factories, but there are also a significant number of true CIM systems reported in the literature. The evidence for expecting this technology to perform as advertised is now too great to ignore. It only remains for American industry to make a commitment to a revolution in its manufacturing technology. The factory of the future is no longer always in the future.[8]

Current examples include the following:

- At Messerschmitt-Bolkow-Blohm (MBB) in Augsburg, West Germany, the most advanced flexible manufacturing system (FMS) in the world has been in full operation since 1980 to machine titanium and other materials into components for the Tornado fighter aircraft. Twenty-four machining stations fed by robot carts are controlled by a single large computer that also manages storage, supply, and removal systems for tools, workpieces, and fixtures. At a cost of about $50 million the total system has cut lead times 26 percent, reduced the number of machines by 44 percent, and has cut floor space requirements by 39 percent, personnel by 44 percent, and total annual overall costs by 24 percent compared to a traditional system. The machines in the FMS cut metal 75-80 percent of the time, in contrast to the 15-30 percent typical of stand-alone machines. The lead time for the Tornado is 18 months, compared to 30 months for an equivalent aircraft in a conventional system. Finally, the required capital investment was 9 percent less than would be needed for a conventional system. (Reported in American Machinist, March, 1981 and Innovative Manufacturing Technology, a position paper of the American Association of Engineering Societies, January 1982.)

• A Swedish household appliances company invested in a robot line for parts manufacturing with the following results:

	Conventional Line	Robot Line
Number of operators	28	6
Floor space	1700 m^2	300 m^2
Lead time	3-4 weeks	4 minutes
Investment costs	$601,200	$1,135,600
Savings through shorter lead-time		$ 120,250
Pay-off time		1.5 years

(Reported in the Promotion of Robotics and CAD/CAM in Sweden, Ministry of Industry, October, 1981.)

• Lockheed-Georgia Company is currently installing an advanced DNC machine tool system that will include quality assurance, maintenance, and shop floor control functions. It will manage 60 NC tools of various types and will collect performance data from between 20 and 200 sensors on each machine tool. These diagnostic sensors will allow machine parameters such as coolant temperature, vibration, spindle speed, motor coating, cutter wear, and cutting tool temperature to be monitored constantly in order to predict when a machine will fail. This system sets the stage for real-time control of the machining process at a future date (Metalworking News, June 14, 1982).

• A new machining system being installed at the Oldsmobile diesel engine plant in Delta, Michigan, is an unusually flexible 22-station palletized transfer machine for making connecting rods. The system will produce connecting rods suitable for either V-8 or V-6 gasoline engines or the thicker and heavier configuration required for V-8 or V-6 diesels. The system can turn out up to 670 parts per hour and has the ability to repair its own parts. Off-spec parts can be recycled through the system a second time (Metalworking News, January 19, 1981).

• In Nagoya, Japan, the Yamazaki Machine Tool Company operates two fully automated machine lines served by computerized self-propelled carts, an automated pallet storage system, and overhead units that automatically replace tool changer magazines when necessary. Yamazaki reports spending about $18 million on the installation and expects to recover $3.9 million in labor cost savings and $3 million in reduced work-in-progress inventory in the first year of operations. The system of 18 machine tools, 12 persons, and 30,000 ft^2 of space turns out a mix of 74 different products in 1,200 variations. In contrast a comparable manually controlled system would require 68 machines, 215 persons, and 103,000 ft^2 of space to do the same job. Yamazaki has opened a similar plant to produce its line of automated machine tools in Florence, Kentucky, in the near future (Metalworking News, October 26, 1981, and December 14, 1981).

STRATEGIC IMPACTS

The future is already here--at least in pieces--and we can expect an acceleration of the rate of technological change.[9] The challenge lies in developing new technology, having the will to apply it effectively to existing manufacturing systems, and managing the new plants for effective competition. This requires a new approach to competitive strategy, new organizational designs and manage- ment procedures, different techniques for capital investment decision making, and broad-thinking and innovative managers able to cope with increasingly science-based process technology, rapid change, and new kinds of corporate strategy.

The CIM factory will require competitive strategies that build upon the strengths inherent in the technology. These strategies will include deliberate efforts to:

- Proliferate the product designs
- Truncate the life cycle
- Use distributed processing locations closer to customers
- Emphasize quality and reliability as a measure of value
- Customize products to users' specifications
- Fragment the market into segments that are too small to support traditional facilities or allow "cherry-picking" marketing tactics by competitors
- Provide a variety of product lines to a broad range of market segments
- Increase the rate of change in product design and product complexity
- Develop the strong engineering and distribution capabilities required to implement computer-integrated manufacturing as the distinctive competence of the firm
- Develop a rapid response capability to take advantage of changing market demands and/or competitor lapses

All the above are to some extent counter-intuitive because they are contrary to the strategies that worked well when factories used traditional hard-tooled automation. Some markets and products will still support traditional dedicated automation and traditional strategies using "long runs of standard products to get down on the learning curve and be the cost leader." The trend, however, will be toward broader, more fragmented markets and rapidly shifting demands that require both the new-concept factories and the strategies that justify their investment.

MANAGEMENT STYLE AND ORGANIZATIONAL IMPACTS

These new strategies will also require that we adapt our organizational structure and management styles to accommodate a more innovative and free-wheeling operation.[10] In particular the trends will be as follows:

- Fewer, higher skilled, better paid, more autonomous people will require new policies for training, motivation, and rewards.

- The responsibility for productivity and profitability will shift from line to staff.
- Manufacturing technology decisions that are treated as corporate strategy issues and, conversely, a carefully articulated and widely disseminated corporate strategy will be required in order to obtain the full benefits of the computer-integrated factory.
- We will see long time horizons for planning; better and more integrated R&D, production, and marketing planning; and new algorithms for capital budgeting that emphasize benefits derived from new ways of doing things and doing things that have not been possible with the traditional factory. The issue is not the return on investment of a CIM. The questions are "What will be my competitive position and the return on investment of the firm as a whole in 5 or 10 years if I do not make these investments today? What if I do and make the necessary strategic changes?"
- New concepts in industrial engineering for decisions on factory organization and layout, capacity and location, optimization techniques, and production planning and control will appear. All of our traditional industrial engineering techniques will need to be rethought in the light of economy of scope, joint cost economics, and the technology of computer-integrated manufacturing.
- The new manufacturing capabilities of variety, rapid responsiveness, and flexibility will become a basis for new marketing tactics. Marketing theories based upon assumptions inherent in traditional manufacturing technology need to be reconsidered. Concepts such as market segmentation, product positioning, and penetration vs. skim pricing may well change or even disappear in the light of factory-of-the-future capabilities.
- New styles of manufacturing management will be required. The manufacturing executive of the future will be more concerned with integration, innovation, and strategy and will spend less time dealing with the traditional tasks of people, materials, and flow control.
- Thinking at both the corporate-strategy and manufacturing-function levels will shift from manufacturing as an afterthought to manufacturing as a competitive weapon, and from a narrow focus on productivity to a broadly defined manufacturing-based approach to profitability and competitiveness.

In summary, the computer-integrated factory is based upon machine-readable data on product and process characteristics; operating specifications based on an ever more sophisticated understanding of material behavior and control theory; paperless management systems; and smart and flexible tools, material movers, and other processes that are integrated with production management and business systems through a communications network and a common data base. This leads to a close coupling between manufacturing engineering and marketing and levels of variety, flexibility, quality, and reliability not possible with traditional technology.

All of the above are necessary for the true factory of the future. Islands of automation and stand-alone computer-based information systems can and do exist and will contribute to improved productivity. However, the real benefits come when all of the above conditions are met--the whole is greater than the sum of its parts, and its value is a function of the strategy for its use.

The key messages are:

• The new factory technology, especially computer-integrated manufacturing, is fundamentally different in economics, design, and operations from the equipment, processes, and technology we grew up with in traditional factories. It is based on a higher level of scientific understanding of material and process behavior, has a higher level of predictability than ever before, and utilizes modern electronic technology and sophisticated software in every facet of its operation. It not only does old tasks faster or cheaper or more accurately; it can do them differently and it can perform tasks not possible in the traditional factory. Therefore, many of the opportunities, management styles, strategic options, and production management decisions will be counter-intuitive to experience based upon past successes.

• The impacts of this new manufacturing technology and capability will be pervasive throughout a given company. It will open up new styles of competition in the marketplace and will require major adaptation by research and engineering, distribution, and marketing as well as new organizational structures, different economic analysis and investment justification techniques, better trained people, continuous flow systems, new styles of manufacturing management and, most of all, a corporate-wide, top-down, strategic commitment to its introduction and utilization.

• The new production technology and operating style offer an opportunity for U.S. manufacturing to regain its leadership in the world market for manufactured products.

NOTES

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INTEGRATION OF THE MANUFACTURING SYSTEM

James E. Ashton

The emphasis in the Burnham and Goldhar paper was on the kinds of changes that will be required to take advantage of the factory of the future and that we are going to have to understand that factory and what kind of things we need to do to use it advantageously. I believe their observations are appropriate. My comments, however, concern what I believe is the biggest challenge facing American manufacturing management--the adoption of a managerial style and approach not only to understand and adapt to those changes but to adapt to the whole evolutionary process that is going to go on from now to some time in the distant future. We are indeed not going to get there through a revolution but, rather, through evolution requiring continuous change.

To illustrate my views, I will use my particular experience with the Fort Worth Division of General Dynamics. I spent about five years in manufacturing there; the last couple of years as Vice-President of Production. I was there from the time when the first assembly fixture for the first F-16 was loaded until approximately the delivery of the 200th plane. The Fort Worth Division of General Dynamics operates Air Force Plant 4, a facility with approximately 6 million square feet of usable floor space. The product, the F-16, has about 9,000 different parts made in-house, plus an even greater number of procured and installed items. The manufacturing process involves all sorts of machining, sheet metal fabrication, electrical and electronic work--almost every process you can think of--and then the subassembly, assembly and test, checkout and delivery. In summary, this experience involves a complex facility producing a sophisticated end product.

This is the same plant in which the F-111 was built. To provide a frame of reference concerning the achievements and changes we introduced, comparison between the present results (F-16) and the previous results (F-111) is provided in Figure 1.

A reasonably good way to compare two very different airplanes is in manhours per pound, and Figure 1 charts manhours-per-pound performance of the parts of the airplanes built within the Fort Worth plant. It is as close to an "apples-to-apples" comparison as I can reasonably make, and it indicates the results with actual values for the first 200 airplanes.

Figure 1 also provides another curve which takes the F-111 results and, since it was built in the same factory as the F-16, applies the cost-estimating relationships one would normally use to correct for the fact the F-16 is a smaller airplane. Generally, manhours per pound go down as the airplane gets larger, and cost estimators have empirical equations relating these parameters. If the F-111

FIGURE 1 Production performance: F-111 and F-16.

data is converted to what one would expect for the F-16, one gets something like the top curve in Figure 1. As indicated, at the 100th airplane (where, hopefully, the chatter in start-up and various design changes and test problems start to go away) the actual F-16 result of about four-and-a-half manhours per pound compares quite favorably with either F-111 actual values or the projection. We built the F-16 airplane for about half as many manhours as expected in the same basic facility as the previous airplane was built.

How did we do it? A lot of reasons are offered by people. A program called Tech-Mod started with the F-16 program and has received a lot of publicity. It was a program that has been very successful. Others point to the investment in new facilities, and indeed we invested in many new facilities. In the area of new technology, we introduced robots and other new processes. People point to those things and conclude: "Ah-ha! All we have to do is spend some money on R&D, and we spend some money on facilities, and look what wondrous things we accomplish."

Those things are indeed important, but let's put them in some perspective. In the process of getting to the 200th airplane, we had invested, in terms of capital facilities and rearrangements, no more than $50 million in a plant whose replacement cost, very conservatively, is at least $1 billion. It is a little hard to believe that $50 million, or a 5 percent change in the capitalization of a plant, is going to produce the sort of results that we achieved.

We also introduced much new technology. We changed many things, and these changes received extensive national publicity, things such as the first robot in an aircraft production environment. I believe that is the most pictured robot that has ever been made. It has been publicized in many magazines and it was very successful. However, at the 200th airplane, we had three robots replacing six people in a plant with 8,000 production workers.

We introduced photogrammetry and a very modern CNC-DNC system linking together some major new numerically controlled machines. They were very helpful and quite cost effective. We introduced computerized inspection. Each of these items was helpful, but they all were, in summary, not nearly enough to explain the curves of Figure 1.

We also changed the management information and control systems, work-in-process systems, inventory control systems, and ordering systems. We upgraded these from 1960 systems to late-1970 systems, and these improvements were very helpful. However, basically, not one of these things, or even the collection of these improvements in a narrow sense, could possibly explain the level of manhour differences we achieved on those learning curves.

One explanation for the favorable results is that we did a lousy job previously--but even then, why did we suddenly do a better job? The answer comes down to the fact that we changed something else that was probably the most important part of the process. We changed the management style and the belief in what we were doing away from what has become kind of a classic manufacturing management style. In this country, we have come to believe that change is bad in manufacturing, that change is disruptive. "If the damned engineers would quit changing the product, we would be better off. We bring in a new machine and it always disrupts things. Change is bad, and if I can just get to utopia when there is nothing changing, we are going to be very efficient." We have designed our management style and systems for that time when nothing changes and, unfortunately, that time will never be here. In fact, we do not want it to be here. The Japanese style (which was not necessarily consciously developed) is rather different and tends to be one receptive to the idea that they are going to keep changing things.

We are not going to get to the factory of the future that Goldhar and Burnham described and then stop changing things. We are going to evolve and change and change and change.

The list below provides a qualitative comparison of management styles. The style on the left might characterize what was previously in place, and the style on the right is what we introduced. Also, the style on the left might be characterized as a management environment that is appropriate for a steady state, and the style on the right one that is appropriate when a high rate of change is expected and desired.

Manufacturing Management

Autocratic	vs.	Team Management
Short-term results	vs.	Long-term view
Management Science	vs.	Art of Management
By the numbers	vs.	Judgment
Fire fighting	vs.	Planning and control
Keep it working	vs.	Improve it

In terms of the first comparison, autocratic versus team effort, getting everybody together to work on what needs to be done is a lot more effective if things are going to be changing. On the other hand, in a steady-state situation, a "big whip" works quite well. Similarly, in a static environment, you can concentrate on short-term results; however, if you really want to keep changing things, every change is going to be at least a little bit disruptive, and you have to take the long-term view to capitalize on those results.

Those who believe in management science and doing it by the numbers will be driven to a lot of short-term things, worrying about what will happen for the next quarter. They will not make those subjective long-term changes. On the other hand, thinking of the management process in manufacturing as an art and using judgment to determine the things that will really improve the place (in spite of the short-term disruptions and problems) is conducive to innovation and to taking on new approaches (the unknown).

When a system is designed to be really great when nothing changes and then changes are introduced anyway, you end up fire fighting all the time. If you reward management for excellence in fire fighting, the cycle will be repeated continuously. If, instead, you believe the name of the game is to keep changing things and to do it under control, emphasize planning and control and avoiding the fire. Similarly, if instead of the emphasis on "keep it working" you emphasize improving it, then there is a good change you will keep changing things, and if you can change and change and change, eventually you will be a lot better than you were before, in spite of the continuous disruption you will have with each of the new changes introduced.

To introduce the kind of manufacturing technologies we have been discussing at this session, and to move toward that factory of the future, a management style that adapts to this whole evolutionary process is critical. If we do not adapt such a style, then we are not going to succeed. Somebody, be it the Japanese or other American plants, will outstrip us. We need to develop a philosophy and style consistent with the idea that change is absolutely necessary. It is, in fact, good, and it is going to go on forever.

AUTOMATION IN SEMICONDUCTOR MANUFACTURING

Robert P. Clagett

In my opinion the microprocessor, which comes from the semiconductor industry, has had the greatest influence on today's automation. As the power of the microprocessor has been increased to match that of computers of the past, and as its cost has become lower and lower, it has had a major influence on automation. This influence has come about in two ways. The first is in controlling an automatic process. Automatic processes used to be controlled either mechanically or with dedicated electrical apparatus. With the advent of smaller computers, large automation began to be controlled by computers, and today the microprocessor controls most new designs of automation. The reason is that the control can be done cheaply, accurately, and most importantly, flexibly. By reprogramming, the automation can be made to modify or even change the process. The best example we have is controlling a robot. It was not until microprocessors became powerful enough and cheap enough that the robot really became economical for wide application in industry.

The second way in which the microprocessor has influenced automation has been to use the information pertaining to the operation it controls, which can be remotely accessed by a larger processor overseeing a whole product line in which many automatic processes are linked together. Not only are automatic processes linked together in this fashion, but test equipment can also be microprocessor-controlled and therefore linked to the rest of the automatic system. And, of course, the transport systems now being designed into many automatic processes can also be controlled in the same way. The result is that a large amount of information can now flow from the individual process, from test stations, from the transport system, all controlled by a larger processor interconnected and exchanging information with the microprocessor at each automatic station.

I will now describe some of the ways automation, robotics, and information flow are applied to the semiconductor industry. It is interesting to note that we are now dependent on microprocessors to automatically manufacture very large scale integrated circuits--and of course the microprocessor is made of very large scale integrated circuits, which is why the cost has come down while the computing power has gone up. I will not be able to describe many of the 200-300 processes there are in making a semiconductor. I will concentrate on the process steps that change a very thin slice of polished silicon into the semiconductor sites on that slice or wafer. The steps prior to the creation of the slice involve growing a large silicon crystal, then cutting it into thin slices and polishing them prior to beginning chemical processes.

FIGURE 1 Stages in the process of manufacturing a functioning semiconductor.

FIGURE 2 Magnified photograph of an MOS-VLSI chip.

FIGURE 3 Plasma-etch operation using a human operator in processing wafers.

Figure 1 illustrates in very simplified form the process from silicon slice or wafer to complete device. Illustrated here is a metal oxide silicon, very large scale integrated (MOS-VLSI) device. At the upper left is the polished wafer, then the wafer that has had many layers of selectively grown materials applied at the sites where the integrated circuit is to be formed. This process involves photolithography, etching away the site that is exposed and applying layers of various doped materials to form the functioning semiconductor. The series of process steps that selectively place layers of precisely controlled materials is repeated many times until a functional semiconductor is created. And finally, there are metallized layers applied that will allow electrical contact with the outside world. The wafer is then cut into individual integrated circuits, shown greatly magnified on the left, and finally that very small chip is mounted and put into a complete package for use in an electronic circuit.

Figure 2 shows a single MOS-VLSI chip--a 64K RAM. We speak of semiconductors, and originally a single transistor--the semiconductor analog of a vacuum tube--was what we built. Today we speak of integrated circuits that are single chips on which thousands of individual components are created and interconnected. For example, even at this huge magnification the details of one of the 150,000 transistors on the chip cannot be seen.

I would like to just take a few of the steps in the process that creates the individual sites on the wafer to illustrate automation in the semiconductor industry. Figure 3 provides an example of what is happening. This shows a plasma-etch operation in which individual wafers are placed inside the chamber, and then a microprocessor controls the processes automatically, including creating the vacuum and doing the plasma-etch operation. The wafer is being handled by an operator with tweezers. In Figure 4 that same operation has been automated. In the background a robot arm picks up the wafers from the cassette of 25 wafers and moves them into the diffusion chamber. After the operation is complete, it

FIGURE 4 Fully automated plasma-etch operation.

FIGURE 5 Carrier for silicon wafers.

moves them back out and into the holder. As a matter of fact, the pickup uses the Bernulli principle so that it does not touch the wafer at all. Figure 5 shows one of those carriers. It carries about 25 of the wafers through all the processes. There is now available automatic equipment to remove wafers from the carrier into a process and back out again, completely automatically. As I have mentioned, automation applies to testing as well as process. Figure 6 shows a test setup in which the wafers are automatically unloaded, tested, and returned to a cassette. Figure 7 shows what might be considered a typical integrated circuit manufacturing facility. All work is done in an ultraclean environment, and many of the processes are automatic--but not interconnected.

The next step in automation is to develop transport systems to connect automatic processes. Figure 8 shows such an operation in which all the photolithographic steps are interconnected. In the center is a full and empty cassette of wafers. The wafers are automatically removed from the cassette, moved through several photolithographic operations, returned automatically through a transport system to the empty cassette, and then moved to the next operation.

I have used these examples to illustrate how automation can be accomplished. Wafers can go through many operations in a similar fashion and can be tested at those stations, so that the test equipment can also be monitored by a shop processor looking over the whole operation. The cassettes can be moved in fact from one operation to the next automatically, as well as the wafers moved within each operation. Figure 9 illustrates how an entire shop can be automated. At the top is a shop flow computer that controls all the operations inside that shop. On the left side are individual terminals so that operators no longer have to use paper records but can access all information and processes through terminals. Each of the processes can be monitored by the shop flow computer; finally, test positions can also be monitored. That is the power that the microprocessor and automation can bring to such a shop. By tying all these systems together, not only can accurate control be achieved, but by monitoring the test equipment, any of the processes that begins to drift out of specification can be quickly and, in many cases, automatically brought back into specification. Operators and engineers

FIGURE 6 Silicon wafer automated testing operation.

FIGURE 7 Typical integrated circuit manufacturing facility.

FIGURE 8 Transport system connecting photolithographic operations on silicon wafers.

know at any time where any wafer is in the process and what is going on in that process and can much more accurately control the total process.

Many firms in the United States have accomplished automation with some of the processes. A few have gone further and have linked most of them together. My own firm is one of them. The application of these techniques is accelerating, so that I can say with some confidence that U.S. firms are neck-and-neck with the best in the world in automation for semiconductor manufacture.

FIGURE 9 VLSI information systems controlling production operations.

DISCUSSION OF "INTEGRATION OF THE MANUFACTURING SYSTEM"

Frank Daley

Because I am now a graduate of General Motors and to a limited extent free-lancing, please be aware that my remarks are those of an individual manufacturing engineer, and do not reflect in any way views other than my own. My comments are general, based on information about many companies from many sources. This is important because operating managers all over the United States are facing very difficult decisions about building bridges to the future.

Reaching for the integrated manufacturing system Goldhar and Burnham have described will take a long, strong arm. Surely, many of the elements can be demonstrated practically today, and the ability to combine pieces and develop the pyramid to its full capability is as much in our hands here in the United States as anywhere in the world.

The critical question is, how do we handle the timing? The timing of motivation and the timing of response will tell if the answers arrive in time to be useful. Can the benefits of the integrated manufacturing system accrue by getting it in place in time to stop the outflow of manufacturing from the United States?

A number of U.S. industrial companies have spent to their limits on retooling for new products or have come up against the wall because of costs or investment problems and have changed direction. The difficulty seems less intense in so-called high technology or new technology businesses in which the rapid and turbulent flow of new designs and the quantum jump of product improvements force continual investment and demand new processes just to stay in the market. Even in these fields, though, there is evidence that the turnover cycle is slowing and becoming more like some of our old standby producers in relying on a more conservative approach when possible.

Some colleagues argue that we as a nation are facing some decisions as to whether faltering mature industries are worth an intensive effort to do more than maintain present markets or whether we should accept a graceful decline. These people say that lower outlays by U.S. consumers may be a benefit of letting certain commodities be supplied by countries that have an advantage--in labor costs, for example--and that our efforts and investment should be applied to vigorous growth industries in which innovative high technology can establish a wider lead over potential competitors. I am glad I do not have to make those choices.

In areas in which we do want to be assured of leadership, we must think about reaching that goal in a manner that is faster than our traditional gradual expansion patterns have permitted. The incremental approach of creating islands of automation may build the confidence of managers to put down larger bets, but staying alive in the meanwhile will probably require some moves that seem contrary to what we really want.

It is difficult for me to see clearly what methods will be provided for decision makers to evaluate the costs and risks involved in a broad commitment to huge novel systems. Tradition would seem to say, "Wait until someone else tries such a system first," because in some cases the decision involves betting the company. Among other thoughts, in the product-development field a prototype is often created at considerable expense to do the vital job of convincing decision makers. In this case we may need a prototype large system to convince investors to reach out farther than can be achieved by the slow coalescence of the islands of automation. The people who are working on this part of the strategy seem hard to find.

Maybe the prototype mission needs to be recognized at appropriate places and levels in the engineering and management disciplines in manufacturing. The objective would be to generate a plan by which a large-scale integrated manufacturing system can be underwritten so risk can be spread acceptably in the event of trouble. Such a plan might include new concepts of reward systems that motivate working managers to give greater importance to long-term benefits, providing inducement to try significantly better ways of doing things, and breaking with the protective shield of traditional practices.

Walt Disney Enterprises has created a prototype of the future of our communities that will probably attract thousands. Is it possible to get a few ideas from that multimillion-dollar enterprise and attract top decision makers to take the big step to make U.S. industry again highly competitive in all areas?

One last note. In one of the examples of flexible machining systems given by Goldhar and Burnham, the reporter who was quoted comments that the system is capable of recycling off-specification parts a second time. A truly modern automatic system should produce nothing but good parts. Quality is a prominent capability of a properly integrated manufacturing system.

THE EXPERIENCE AT ROCKWELL INTERNATIONAL

Arnold M. Kriegler

According to George Schaffer's paper presented in session I, I am really the "director of organized chaos."

I would like to share with you an example drawn from our manufacturing experience that touches on some of the things we have heard about today, with emphasis on the rethinking of the manufacturing process that Joel Goldhar mentioned. Various people mentioned group technology, and this example shows some group technology application. It also addresses the dilemma that was posed by James B. Quinn: the apparent conflict between near-term results and long-term strategies. And there are some other things woven in here, but let me proceed with this example of a minor victory in this area.

Figure 1 shows a few of the thousands of different wave-guide mechanical assemblies that we produce for our microwave radio systems. We have already achieved the marketing ideal of making them different for every single customer. We are delivering about 15 to 20 customized major systems per day, with annual sales approaching a quarter of a billion dollars. These wave-guide assemblies are among those things that customize the end product.

The good news, as far as group technology is concerned, is that they are basically made up of similar parts that look somewhat like plumbing. They pipe microwave frequencies between 2 and 18 gigahertz, doing the same thing that wire does at other frequencies.

We had a fairly nonesoteric set of objectives that were driven by competition. We needed to reduce the cost of these assemblies by about 50 percent. We needed to reduce the lead time in order to accommodate this "marketing ideal." Our company emphasizes return on assets rather than return on sales, so inventory reduction was an objective. We set a goal for ourselves to have this project pay back in less than three years. Also, we wanted to set the stage for more computer-integrated manufacturing. This is a set of objectives that even the most flinty-eyed controller would probably agree with.

Our major strategy was to transform our batch metal-fabrication shop from its traditional organization of departments of like machines to the process-flow manufacturing setup that has been mentioned in previous papers. Our thought was that we could best accomplish that through group technology.

We took the approach that we would try to make use of existing machines and processes to the greatest extent possible. Figure 2 shows a floor plan of the traditionally organized batch shop in which like machines are grouped: The sheet metal brakes are all in one place, the spot welders are all in one place, the mills are all gathered together, the shears are all together. This traditional arrange-

FIGURE 1 Wave-guide mechanical assemblies for microwave radio systems.

ment gave rise to the random-arrival batch-flow situation that Joel Goldhar told us we had to change.

Figure 2 also depicts the organized chaos George Schaffer discussed. It shows the actual flow of one wave-guide assembly through the shop. It is, unfortunately, a real example of the random-arrival batch-flow, characterized by long delays and long queues, that causes the 95 percent nonproductive time that one of the earlier speakers mentioned.

Our strategy was to capture an appropriate mix of the machines involved in the manufacture of this family of wave-guide parts and bring them into a manufacturing cell dedicated to the wave-guide family of parts (see Figure 3). In this small area, now, we will do about 25 percent of this shop's annual volume.

Figure 4 shows the area after we brought the deburring and degreasing functions, the cut-off saws, the staging and stocking area, silver soldering, mechanical assembly, and the machining processes all together into a group-technology cell designed to build this family of parts. The area was our prototype cell, an example that would serve to reduce a supervisor's fear of change.

After making this fundamental change, this rethinking of a very traditional manufacturing process, we have had the following results:

- Reduced cost 30 percent (vs. 50 percent)
- Reduced lead time 70 percent (vs. 50 percent)
- Reduced inventory $500,000
- Maintained quality

FIGURE 2 Traditionally organized shop with random-arrival batch-flow intermixed with other production.

- Payback in 1 year (vs. 3 years)
- Created climate for progressive change to CIM
- Second and third cells coming easier

Interestingly, the bulk of the savings has been the indirect part of the cost. Direct labor savings are on the order of 10 percent, since we have just started to address the automation of some of the processes.

But the indirect costs have been a very pleasant and major improvement. We have disposed of dispatching functions and material handling functions. Since the out basket of one operation is the in basket for the next operation, we do not need dispatchers and we do not need material handlers. We have even cut out internal inspection as things go from step to step and have convinced the people who make the parts that they are responsible for quality. There seems to have been no loss of quality; in fact, I can probably make a case for improved quality.

We have beat our lead-time objective. We have cut the average throughput time for these parts from seven weeks to less than two weeks. That has resulted in an inventory reduction of $500,000, which is about two-thirds of the work-in-process associated with these parts. And our responsiveness in being able to provide these customized parts to final assembly is correspondingly improved.

We have maintained quality, as I said. We achieved our pay-back on this project in less than a year. We had a three-year objective and surprised ourselves when it really worked out to be "payback-as-you-go." Since we received benefits from the indirect savings so quickly, we are confident that near-term financial

FIGURE 3 Existing machines and processes were moved and reorganized into a manufacturing cell dedicated to the wave-guide family of parts.

FIGURE 4 Group-technology cell with process-like flow of family of parts.

objectives and long-range strategies are not necessarily mutually exclusive.

One of the most important things we believe we have created is a climate for change that minimizes the problem William Beeby discussed--psychological failure. My veteran shop management folks now are less afraid of trying to do things in radically different way. As testimony to that, the second and third cells are coming much more easily. In the next two or three months we will complete our sheet metal cell, and we have a machining cell in design. These next two projects are coming along much more easily than this prototype cell did.

INTEGRATION OF THE MANUFACTURING SYSTEM: EXPERIENCES

M. Eugene Merchant

One of my major responsibilities is to observe and evaluate research, development, and implementation of advanced manufacturing technology throughout the world. In so doing, I find it quite evident, as reflected in the paper by Goldhar and Burnham, that by far the most powerful and revolutionary manufacturing technology being researched, developed, and implemented today is computer-integrated manufacturing (CIM). This technology has the capability to integrate all of the various elements of the total system of manufacturing--from the design of the product through the entire production process to the final shipment of finished products, fully assembled, inspected, and ready for use (see Figure 1). Furthermore, it has the capability not only to integrate all of these elements into a total system but also to optimize and to automate both the operations within these elements and the total system--and to do that on-line and flexibly.

Although this technology is still, generally speaking, in its infancy, it has already demonstrated far greater potential for increasing manufacturing productivity and quality and for reducing manufacturing costs (i.e., creating real, tangible wealth most cost-effectively) than any other technology that has appeared on the scene since the onset of the Industrial Revolution. As such it is generally being recognized worldwide as beginning to create a second Industrial Revolution.

An indication of this potential can be gleaned from performance experience already obtained with computer-integrated systems of machine tools and related production equipment. These systems, commonly known as flexible manufacturing systems (FMS), are to some extent microcosms of a portion of the future total system of computer-integrated manufacturing. To illustrate the potential power and cost-effectiveness of this technology, I will discuss two examples.

The first is the system that is installed at Messerschmidt-Bölkow-Blohm in Augsburg, West Germany, producing titanium parts for the Tornado fighter plane. Figure 2 shows the components of this system. There are some 28 numerically controlled (NC) machine tools, such as those seen in the center of the figure, operating under coordinated computer control within the system. Supporting these are two other main subsystems. The first is an automated workpiece transfer system bringing workpieces to and from the machine tools by means of computer-controlled carts, such as those shown in the lower right-hand corner of the figure. The second of these is a fully automated tool transport and tool-changing system. This brings tools to each machine via an overhead transport system, seen in the upper part of the figure. It then automatically transfers these tools to a continuous elevator tool storage, seen at the left of the figure, which in turn interfaces

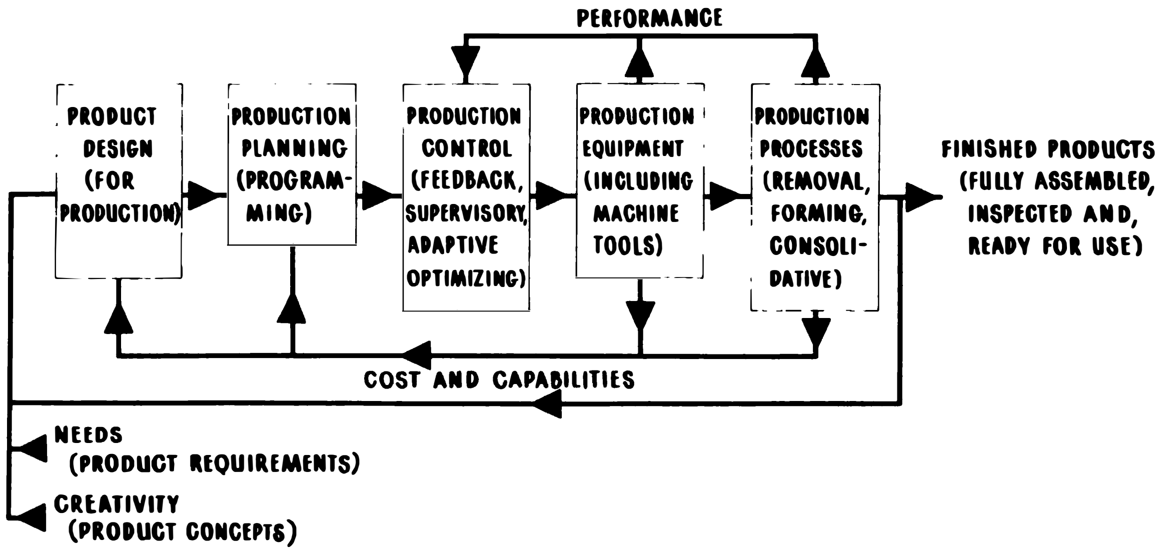

FIGURE 1 Computer-integrated manufacturing (CIM) elements.

with the automatic tool-changing mechanism of the machine tool. All three subsystems--the machine tools, the work transfer system, and the tool transfer system--are coordinated, controlled, and automated by a hierarchical distributed computer system.

The results obtained with this technology are as follows: The machines in the system are cutting metal 75-80 percent of the time, instead of the usual 15-30 percent obtained with machines that are not part of such a system. The lead time for the Tornado is 18 months compared to 30 months for an equivalent plane produced conventionally. The system, when compared with identical NC machine tools producing the same parts that are not part of such a system, has reduced the required number of skilled machinists by 44 percent, the required floor space by 39 percent, the part-flow time in the factory by 25 percent, and the required capital investment by 9 percent.

In addition, nonquantified benefits are experienced with this system. Quality has been increased, manifesting itself in the form of higher reproducibility, lower rework costs, and lower scrap rates. This in turn has resulted in lower quality assurance costs. Also, adherence to production schedules is much improved, and the usual flood of paper has been considerably decreased. Furthermore, working conditions are improved owing to the decreased risk of accidents and the relief from heavy physical labor and monotonous work.

The second example is that of an essentially unmanned FMS installed at Niigata Engineering Company's Internal Combustion Engine Plant in Niigata, Japan. Its cost was about $2.5 million. It is machining 30 different types of diesel engine cylinder heads in lot sizes ranging from 6 to 30 parts. A robot mounts the simpler parts on pallets automatically. The system runs 21 hours per day producing parts; it runs completely unattended at night.

The savings with this system are as follows: Only 6 machines are required to produce the parts, compared to the 31 (including 6 NC) required conventionally (an 81 percent reduction); the number of operators has been reduced from 31 to 4

Automatic tool transport system

Automatic tool transfer

(adjustment)

transport system

FIGURE 2 Five-axis multiple-spindle CNC milling machine in bridge design with automated peripheral equipment installed at Messerschmidt-Bölkow-Blohm in Augsburg, West Germany.

(an 87 percent reduction); and the lead time for these parts has been reduced from 16 days to 4.

Both of these examples are drawn from countries other than the United States, and that fact pinpoints a problem. Although the major portion of the technology implemented there originated in the United States, American manufacturing industry, sadly, has not moved as rapidly as industry in some other countries to implement the results of that native basic knowledge and innovative manufacturing technology.

This situation does not exist because the technology is not available from American suppliers, but rather because, in large part, American industry has lost its understanding of the importance of manufacturing to its competitiveness and survival. That fact, and the factors responsible for it, have been aptly described by James Quinn in his keynote address.

There are those who say that there is no future in manufacturing for American industry--that, instead, the future is in high technology. Most regretably, such thinking is completely blind to the fact that today manufacturing is high technology. If you are associated with manufacturing and high technology is not a fact, or on the way to becoming so, in your company, then indeed, for your company, there is likely to be no future.

SESSION 3

SUMMARY AND CALL TO ACTION

Session 3 participants. Left to right (standing) Jordan J. Baruch, George S. Ansell, H. Guyford Stever, Peter Scott, (seated) Allen Newell, Session Chairman Erich Bloch, and John K. Castle.

SUMMARY OF PREVIOUS PRESENTATIONS

H. Guyford Stever

Let me begin by telling story. In 1975 on the occasion of the 250th anniversary of the Soviet Academy of Science, I was in Moscow as their guest. While attending a session that was being presented in Russian, which I could not follow, I was delighted to be tapped on the shoulder and invited out to talk with Georgi Arbatov. He is the head of the North American Institute, an immense organization that keeps the leaders of the Soviet Union completely informed on everything that is going on in North America, mostly in the United States. (By the way, I am absolutely sure that the talks this afternoon are already in their hands and being digested right now.)

In any case I sat down opposite his desk, and he fixed me with his eyes and said, "Dr. Stever, America is the greatest ad hoc nation that every was." Well, I thought, I still do not know what the subject of the conversation is, but I thought first of ad hoc committees. They are the ones that the chairman can dismiss at will, and I was wondering which chairman was going to dismiss us. In any case, I finally discovered he really meant that before we ever did anything significant we had to have a tremendous crisis, a blow that hit us over the head with immense force, and even then we could only begin a slow process of building a consensus, while confusion reigned.

One of our speakers discussed such consensus building, and that is exactly what has been going on for about a decade on the subject of our forum today. From my point of view, and I have been involved in that process for the full decade, these discussions today have been a good summary of that consensus building, with understandable data, with clear analyses of the problems, and with creative suggestions of the paths to take toward the solution of some of our manufacturing problems.

Our first two speakers brought together a statement of the problem of the past, where we stand today, where the future is, and what our hopes are. From now on I think we can concentrate on what we do about our problems, rather than trying to go deeper into analyzing them.

The best thing about their presentations was that both were optimistic: one, a professor, analytical, very knowledgeable, very well connected with industry and all that is going on in the world; the other an industrial manager deeply immersed in trying to fight his way out.

There are no single villains (we started off trying to find one, by the way, a few years back). Our keynote speakers pointed out the many advantages we have. They pointed out that the most important future fields of manufactures are precisely those fields in which we are strongest, in which computers and software and microprocessors get together, in manufacturing technology. We are very strong in future industries such as genetic engineering.

They listed the mistakes of the past. They said that capital became too expensive, and they asked who was to blame; that there was a short-term outlook, and they asked who was to blame; that there was a neglect of R&D, and especially of manufacturing technology and manufacturing, and they asked who was to blame. They pointed out that our strategic thinkers did not recognize the nature of the changes in international competition that overtook us in the last two decades. In fact, in the begining we did not even recognize we were in international competition.

They suggested courses of action: Support innovation, capital investment, and saving and make capital less expensive; and revive engineering education and our whole process of research in manufacturing technology.

What they left us with is the belief that we now understand the problem very well, and, following them, we should be cautiously optimistic that we have a good chance of success in a comeback. But there is still a lot to do.

Both the first and second panels on manufacturing proved the point that was made by our first two speakers--that we have and have had throughout the manufacturing crisis many successful companies, leadership companies. We were shown many examples of things that are going well. They made an important general point about parts production, assembly, and testing--that the future is going to require a much greater emphasis on securing data and handling information in the manufacturing process. We should change manufacturing from an art to a science in which we control processes accurately.

The second manufacturing session argued that the systems approach was the key to the future. The speakers pointed out that we have examples of real success in many different industries--aircraft, semiconductors, telecommunications (the examples of successes in machine tools were primarily from overseas). The panel's broad outlook covered a variety of problems for management, capital investment, scientific discovery and technical innovation, education, public policy and, last, labor policy and laborers.

I feel now that I understand the problems we face. I am optimistic that we can do what we need to do, and I am looking forward hearing from six people with the detailed solutions.

PANEL DISCUSSION: CALL TO ACTION FOR THE 1980s

Erich Bloch (Chairman), George S. Ansell,
Jordan J. Baurch, Irving Bluestone, John K. Castle,
Allen Newell, and Peter Scott

Mr. Bloch The panel for this afternoon was picked with great care. Irving Bluestone, Professor of Labor Studies, will reflect on the labor aspect of the changes that we have been discussing. Jordan Baruch, President of Jordan Baruch Associates, former Assistant Secretary of Commerce for Productivity, Technology, and Innovation, will look at the problem from a public policy viewpoint. George Ansell, Dean of Engineering, Rensselaer Polytechic Institute, will represent the university viewpoint. Allen Newell, Professor of Computer Science at Carnegie- Mellon University, a pioneer in computer science and artificial intelligence, will give a technial futurist's viewpoint. John Castle, President and Chief Operating Officer, Donaldson, Lufkin, and Jenrette, will look at manufacturing from a financial and capital investment vantage. Peter Scott, Executive Vice President of United Technologies Corporation, will represent the management view.

Let me start the discussion with something that was mentioned during the day but did not receive enough consideration: it is the shift in employment from the industrial sector to the service sector. We have seen a shift like that before when agricultural employment dropped significantly and industrial employment picked up the slack. Are we going to see that same thing happening again? The displacement occurring in one sector: Can it be neutralized by the employment opportunities in the new services and information sector?

Mr. Bluestone First of all, it is self-evident, and I believe that by and large labor has accepted this, that technological advance is essential to improving our competitive status, enlarging the productive wealth which we can produce as a nation, and providing the opportunity to enhance the economic well being of our citizenry. Advancing technology, however, poses problems for labor and management in which each has, or should have, a keen interest. This is especially true in light of recent projections that by the year 2000 only about 5 percent of the work force will be employed in the manufacturing sector (President Cynert, Carnegie-Mellon University).

One of the problems has been and continues to be, especially with traditional and orthodox management, that by and large management fails to recognize that the most important resource anyone can bring to the workplace is his or her own intelligence and innate capability, his creativity as a human being.

We know that in the workplace, and this relates to white-collar as well as blue-color workers, management executives historically have taken the position that they make the decisions, they give the orders, and they want the employees to follow those orders. Even line supervisors and middle managers complain that little by little there has been an erosion of their authority to make decisions as the decision-making process becomes increasingly centralized. As we enter into new fields of technology advance, it is an absolute necessity for management to change from its traditional role and to recognize that a new system or organizational and work structure is needed that will incorporate the opportunity to accord all employees at all levels of the organization the right to be involved in the decision-making process.

Last year, I understand, a study was undertaken to determine how much managers actually know about workshop and worksite problems, and the research indicated that a manager knows approximately 4 percent of the problems that are actually occurring on the shop floor, a superintendant about 79 percent, a line supervisor about 97 percent, and the workers 100 percent.

Engineers in this regard have an essential role to play as well. Unfortunately, the engineer too often has been divorced from the workplace in the sense that he fails to consult with the operator, the person who knows most about what is wrong and perhaps can make suggestions as to how to correct it. Engineers should relate more closely to the workplace, whether it is an office or a manufacturing facility; they should work more closely with the operators themselves, who have intense and direct knowledge of what is going on and how to make corrections.

This utilization of the human being as a creative person, as someone who has knowledge and experience, as someone who wants to develop a sense of enhanced self-worth, self-respect and self-development, is increasingly a subject in the negotiations undertaken between management and unions and is generally referred to as "improving the quality of worklife." This concept represents a sharp departure from the eight-decade-long concept, the traditional imposition of the principle of scientific management, with which engineers are so familiar. It is a departure from that tradition in which the employees are merely order takers, and it moves instead toward involvement of the employees in the decision-making process.

There are two fundamental issues from a labor point of view that must be considered and on which action must be taken. One is to introduce vast training and development programs for those whose jobs are being deskilled, for those whose operations will require enhanced skills. Unless this is done, the workers themselves will be demanding the opportunity to learn the new jobs and to learn the new skills. The second is not to overlook while you are inventing new ways, new means of creating greater efficiency, there is also the problem of redundancy, and those who are adversely affected will be insisting upon a system whereby the advance of technology occurs at a rate that will ensure lay-off avoidance. Employment security becomes an essential element in decisions to adopt new technologies. The major corporations of Japan, of course, recognized this some years ago, and it has made a vast difference in the attitude the employees themselves take toward the workplace.

These are the issues that require very active consideration and participation by management--the training, development, and employment security issues.

<u>Mr. Bloch</u> Thank you, Irving. You didn't really answer my question. I would want to come back to that later. But your comments triggered another question: Peter Scott, how come management fails to recognize the innate capability of our employees and knows little about what is going on on the shop floor?

<u>Mr. Scott</u> I wish I knew the answer to that, but I don't. I certainly concur with what Dr. Bluestone just covered. However, I would like to pick up on one

comment that he made (which I happen to agree with), the solution to which will be one of the major problems facing us over the next couple of decades. That was his comment that he believes labor is beginning to accept the effects of automation and what it is going to do to the workforce.

Mr. Bluestone Pardon me. Has accepted.

Mr. Scott I probably would agree that they have begun to accept it, but I think the overriding problem is they don't know what to do about it. The job security you speak of is the issue in their minds. Whether or not they have accepted it or are beginning to accept it is not the point that I am making. The point is that they don't know where to look to solve the problem: to government or to industry? We have talked all day about the changes in everything, the rapid technology infusion into manufacturing. Those people understand that these changes must come, but what is not clear to them is how they will fit into the new structure.

Lip service relating to retraining for a technology that is so foreign to the individual that he cannot cope with it--that is the real problem. I recently looked at a long-term unemployment forecast by a major U.S. corporation that is very credible in this area, which projected that our current rate of 10.1 or 10.2 percent would still be between 7 and 8 percent by 1990. Obviously, if you look at the long-term unemployment forecast and couple it to this whole issue of retraining, the problem, I think, is bigger than what we think it is.

Mr. Bloch Mr. Ansell, you probably want to talk about the retraining problem.

Mr. Ansell I would like to go to the retraining question and the initial question raised--that is whether, in the shift in employment from the manufacturing sector, productivity gains will occur through labor acceptance, as Professor Bluestone said. Will the service sector indeed absorb that displacement and will retraining be effective?

I think that is a very dangerous assumption, although it is paid lip service, and the reason for the danger is that the very improvements and changes in automation, which are largely information-based, have had more effect in the service sector to date than they have had in the manufacturing sector. The easiest way is to look at the discussions of the integrated department store, bank, insurance company, or brokerage firm, which is truly managed to handle product-in, product-out, sales, inventory control, etc., in a totally integrated process with large-scale reduction in workforce. Most of what we are talking about in integrated manufacturing systems will occur more quickly in the service sector. We are faced with labor displacement in both sectors due to analogous productivity enhancement.

This aspect of the productivity shifts in both the manufacturing and the service industry is much more complex in the United States than in any other country. Each of the other countries in which productivity shifts are occurring in the manufacturing sector shows a concurrent gain in business expansion and growth, while in the United States we are just talking about replacement of equivalent markets. That issue is fundamental to all of the issues discussed today.

Mr. Bloch Are you pessimistic about our ability to absorb?

Mr. Ansell Not at all. I am pessimistic about the ability to absorb, but it is unnecessary. We have talked ourselves into a societal structure that has stagnated at a 40-hour workweek and a 45-year working life. That stagnation started sometime between the end of the Second World War and the current time, following a long history of change. As Professor Quinn has shown, both the workweek and the working life were experiencing a gradual but steady reduction from the start of the Industrial Revolution. It may be the most important change to affect society. We must start recognizing that one of the benefits of automation, both in the manufacturing and service industries, is the reduced demand on the working life of the individual. It is a bonanza rather than a hindrance. We have treated it so far as a disaster.

Mr. Bloch Mr. Baruch, you wanted to comment on this.

Mr. Baruch I would like to comment on your first question--the absorption by the service sector--by pointing out two fallacies inherent in the question. You pointed out the decline of the number of people, as did Mr. Quinn this morning, in the agricultural sector of our economy. In large measure that is an artifact of a bad measurement system. The fact is that the measurement system does not include all the people in the manufacturing sector who are designing and building reapers, threshers, plows, and Caterpillar tractors, and other machines. It does not include the people in the manufacturing sector who are making pesticides, who are making fertilizers, and who are making super feeds for our livestock; and it does not include those people in the service sector who are creating the knowledge on which all this is based.

We have similarly bad measurements in the manufacturing sector. We show this tremendous growth in the service sector in part because we are transferring, by our new automation and by other things, people from the manufacturing sector to the service sector who are doing the same thing they were doing before. For instance, take a software writer. What could be more service sector that that? He puts out a product that sells for a fortune, and it has raw materials worth practically nothing, nothing but brains. He clearly belongs to the service sector--or is he in the manufacturing business? Try to run one of those computer-integrated manufacturing systems without him. Of course he is in the manufacturing business. So, let us not get hung up on service, agriculture, and manufacturing sectors. We have a bad measurement problem.

The second fallacy inherent in the question is to recognize that part of the reason we are in trouble in manufacturing is because we have not recognized that manufacturing is part of the service sector. Ted Levitt once pointed out that a man does not buy a quarter-inch drill; he buys the expectation of a quarter-inch hole. Unless they are collectors, people do not buy IBM computers; they buy the expectation of computation. The only thing that makes a product worth selling (and Edwin Mansfield has shown this in beautiful econometric terms) is the service that it provides to its buyer in relation to its cost. And unless we recognize that our products are embodiments of service, we will keep on talking about designing for manufacturability, designing products that will sell, based on some set of characteristics, instead of recognizing that manufacturing--the manufacturing design process, product design, and product development--are all part of the service sector designed to take some raw materials, some smarts, and turn out services that just happened to be embodied in products.

There were two fallacies. One is that the measurement is bad, and the other is that to separate manufacturing from the service sector is a disservice to the people involved because it beclouds their judgement.

Mr. Castle I want to comment on the issue of how we can create the jobs and improve productivity to keep American manufacturing industry healthy, rather than to talk about the specific definitions. I agree with the comments that were made on the distortions between the service and manufacturing sectors.

In terms of creating jobs and having relatively full employment in an environment where we change how we manufacture, it is clear that technology is the driving force in improving our productivity. Therefore, the competitiveness of American industry, as well as new technology and the creation of new industries, has been an important factor in creating new jobs. As the financial expert on the panel, I think that venture capital is one very important form of creating and funding new technology and creating new jobs.

I know the U.S. General Accounting Office has done a number of studies to demonstrate that many venture-capital companies have created substantial numbers of new jobs for the amount of money invested. Therefore, I am of a view that we used the right kind of national policies. Earlier today, Mr. Quinn indicated that when the capital gains tax went up, the amount of investing in new companies went down. This illustrates that we should be very concerned about having a lower capital gains tax rate to make it attractive for people to put money in speculative businesses.

There is room for even additional increases in the tax credits that go for incremental R&D efforts. Within our society we have created a number of interesting and exciting ways of funding new types of technology, including the R&D partnerships that are taking the country by storm. In this form of venture, investors get near-term write-off, and a capital gain, hopefully, in the long term.

There are other mechanisms for the institutionalization of the venture-capital process that has been going on over the last decade. I believe it is important that we get money funneled into those activities and areas that give us a competitive edge and create new employment opportunities for people. That should be our focus. Professor Quinn said that the number of acquisitions has gone down in recent years. While this might be true, the fact is that the dollar amounts have gone up, so that you have billions of dollars going into certain types of acquisitions; the same amount of money deployed in perhaps creative entrepreneurial kinds of ventures and vehicles might create a lot more jobs and make our economy much more viable.

Mr. Bluestone I wanted to raise, and perhaps supplement, what was just said concerning financing. When I went to school I was brought up on the notion that the free enterprise system grew strong because people were willing to take risks, and the older I get the more I feel that the most conservative element in our society is risk capital. What has been happening is indeed that vast sums of money, hundreds and hundreds of billions of dollars, which should be sent into risk capital for the purpose of creating wealth and creating jobs, is moving into mergers and acquisitions; the most ridiculous one that took place was between Bendix and Martin Marietta recently.

When Mr. Daley said that the barriers to what we have been talking about all day rest at top-level management, I think he is right. Those barriers exist because, first, debt/equity ratios exert a constant pressure on management to maximize dividends and profits in the short run. This pressure to maintain dividends, this pressure to maintain a high credit rating, causes companies to distribute dividends even when they lose money. This is ridiculous; the need is to invest that money in order to become more efficient and more productive.

Mr. Castle I think one of the reasons capital has become so conservative is the very high interest rates that we have had in the United States. If within the last year you could invest your money on a tax-free basis at 13 or 14 percent, there was no reason to put your money into anything that was terribly risky.

Now, the high interest rates are caused by many factors, but they are probably heavily related to the large federal government deficit. In fact, if the prime rate went to 3 or 4 percent, you would find this money becoming substantially more venturesome and eager to stimulate new activities. But the high rates of the recent past have been stifling, and it is a lot easier to say, "Well, I will buy the 14 percent municipal bond rather than take any chances."

Mr. Bluestone But the largest number of mergers and acquisitions, based upon what we saw earlier today, came when interest rates were low!

Mr. Bloch What Mr. Bluestone implied is that the value and reward system that U.S. management has been operating on prevents it from doing the right things from a technological and management viewpoint. If true--and it is true--that is a problem that needs our attention.

Let me get to another question and ask the panel to comment: What is the most important action the various sectors of society must take to help us make the transition into this new world of manufacturing? How would you answer Mr. Scott, from a management viewpoint?

Mr. Scott The best way I could address that question would be to go back to two particular points in Professor Quinn's opening keynote speech that struck home to me. He said that from 1960 to 1977 the U.S. position in world trade was reduced from 25 percent to 17 percent. That was a reduction of 30 percent in 17 years. Heaven help us if it continues at that rate over the next 17 years. The second thing he said was that we should adopt a positive vision of the future.

Those things are obviously opposed if one looks at what has happened and what the trend is. It becomes very difficult to adopt a positive view and positive vision of the future. To do so requires what everybody talked about today--change. That is the answer to the problem. The change that we talked about is going to have to come about, and yet, we must be sensitive to all the things we were just talking about.

Many of you probably are familiar with the writings of the famous Belgian writer, Maurice Metterling. He said: "Every progressive spirit is opposed by a thousand people self-appointed to guard the past." That is the problem we have.

Mr. Bloch Mr. Bluestone, what should labor do?

Mr. Bluestone In the past 10 years, in part at the insistence of labor and in part at the insistence of management, there has been a growing effort for management and labor to move copperatively with regard to those issues that are of mutual and common concern. Part of that movement has, as I noted earlier, been directed toward affording all employees an opportunity to participate in making decisions.

In other words, the hierarchical structure begins to change; it gets loosened up; it becomes more flat; and, in effect, there is a willingness, a desire, a request that people use their brain power, whereas previously they were told simply to obey orders and not to think. In that regard labor has an important role to play: bringing more democratic values into the workplace which, in the final analysis, result in benefits to management in the form of improved efficiency, to the workers in improved job statisfaction, and to the consumer in a better-quality product.

Mr. Bloch Mr. Newell, what should research and technology provide?

Mr. Newell I will answer that in one moment, but I have to start by finding ways to disagree with Mr. Goldhar. When asked what ought to happen, I was going to say manufacturing must become a science. On the other hand, Mr. Goldhar said manufacturing is a science. The problem is, he is wrong. He hopes it is a science, and I am not trying to disparage the number of people, especially those in engineering disciplines, who have already accomplished some of the concepts disclosed today. If one, however, believes that manufacturing is in the same position as chemistry or physics or even mechanical engineering, that simply is not true. There is no body of PhDs generating theories of manufacturing and devoting their lives to understanding the nature of manufacturing. It is clear, by the way, from everything that was said today, that manufacturing is going to get intimately involved with the information processes used in manufacturing. There are at the moment few people devoted to understanding those kinds of systems. Mr. Goldhar was a little premature.

We will give him a little rhetorical excuse for being that way. In fact, one thing we must do is to see if we can find a way to create in the scientific world, on the campuses, the notion of manufacturing as a fit topic for scientific study.

There is a very interesting lesson, by the way, in operations research. I am not trying to tread on anyone's toes, but if right after the World II War one would have proposed that something like inventory control was a proper problem that an academic should actually be interested in, that would have been unthinkable. However, one of the most intriguing transformations that occurred on the intellectual scene in the United States after World War II was the transformation of a whole bunch of processes that no self-respecting academic would ever have looked at into fascinating areas to which operations research and management science people devote their lives. That same kind of transformation, I think, has to take place if one wants to proceed with the rationalization and the understanding of manufacturing.

Mr. Bloch Mr. Ansell, what should the education sector do?

Mr. Ansell As a Dean of Engineering, I do not think manufacturing need be a science, but it must at least be an engineering discipline, and that is not meant as a facetious remark. It is unlikely manufacturing will ever be a science. That has no relevance except that to make things one needs to draw on bases in the applied sciences and the engineering arts. But the issue of whether it is a discipline or not is a very serious one in terms of an engineering area.

Manufacturing has not been a serious engineering discipline in the past. As a result, we are not looking at a field that obviously needs a generation of skilled people to develop and put new technology in place for innovation and people to manage these new manufacturing systems. It is not clear that these people exist, nor is it clear that the best and brightest of our students are really attracted to manufacturing careers. This must change.

Fortunately, there is an awareness of the problem both in the educational institutions and in industry, and attempts are being made in both sectors to try to change this situation. It is not clear where the endpoints of these changes will occur, but it is clear that there must be the development of an engineering discipline in manufacturing which at least has viability within an engineering educational institution and other university structures.

What is difficult about this field is the need to integrate and synthesize some very classic generic disciplines that now exist in other engineering fields: artificial intelligence, controls, automation, robotics, materials, process areas. The synthesis and integration of these disciplines and their application to the manufacturing process does not exist as a coherent field within engineering schools. Young people have to be in an environment in which they can learn from faculty who themselves contribute at the leading edge of a discipline. At the present time we have not created a system in educational institutions that assures the continued contribution and development of faculty at the leading edge of manufacturing.

Some interesting shifts have occurred at several institutions that are trying to put in place efforts large enough to be viable. The system of rewards in universities must adapt to that requirement, so as to encourage and develop long-term careers in this field. The real issue in the engineering institutions is to try to develop such manufacturing systems in cooperation with both government and industry, and I think the question of the cooperation with government and industry is one of continuous stimulation, one in which there is a reality to the process as well as the cogent development of that discipline.

That is the experiment we are now engaged in, and it is interesting that several major corporations are leading in the pressure to improve that situation in the universities.

Mr. Bloch Mr. Castle, what should your sector do besides not looking at quarterly reports only?

Mr. Castle That is an unfair point. You see, it is all those pension funds that want to have a good quarterly performance, and those pension fund trustees are usually corporate managers. It is a terrible cycle, but we must provide an environment, an ambience, that makes it attractive to invest in more high-risk technological areas. A lot of that has to come from public policy, through tax changes, through moving away from a government deficit that creates very high interest rates that make it more attractive to put money in a high fixed-income security than into something that has more risk associated with it. I am personally very optimistic about all the attention this problem has received. After years and years in which the senior management of major corporations had to focus on marketing problems, now they can concern themselves with the kind of manufacturing that is going to lead to the technical innovation that we need.

Mr. Bloch Mr. Baruch, what does the public sector do, what should government do?

Mr. Baruch I am not going to talk about what government should do because I am tired of trying to get government to do anything.

In the area of what public policy should be, I am going to talk about the public I know best, the engineering profession. We are in trouble. Every one of us has seen the cover of today's program, which shows the marvels of modern scientific manufacturing--cathode ray tubes, drawings, robots, drills, automatic paint spraying--and I have not heard one of you scream in outrage that the hex-nut on the cover has eight sides and that the robot is grabbing it by the points rather than by the flats.

We are forgetting that we are engineers. The fact that we meet in this building implies that engineering is a branch of science, namely applied science, and that is nonsense. Engineering is a profession that applies science. Gilfillen summed it up when he said that the invention of the steam engine did more for the science of thermodynamics than the science of thermodynamics did for the steam engine.

When my son wrote his resumé as a young engineer, I told him, "You have to end it with one sentence that will tell an employer what he really ought to know about you." He came back with a defiant look in his eye and threw it down on the table and said, "How is that?" His sentence at the end said, "I make things work." It is too bad we have a bunch of engineers in our society who have forgotten that the role of engineering is to make things work. Instead, we complain about managers and how they behave. Yes, they are largely technologically illiterate. When I was at the Harvard Business School and got elected to the Academy of

Engineering, I was all excited. I went out into the hall and told my colleagues about it. They all congratulated me and then asked me what it was.

Yes, we have mergers. We have finance people running our companies. When all you have is a hammer, everything looks like a nail.

Let us recognize that the only industries that are going to survive in the future in this country are the knowledge-based industries. Our initial leadership was based on cheap rents, later on cheap labor, and later on cheap capital. We will never see those things again, nor will we ever again see cheap energy. The only cheap thing we have left is smarts.

If the only industries that are going to survive are those that are knowledge-based, and if engineers are the ones who are skilled in applying knowledge to problems, then the engineers will have to learn to be part of the management group, not pointing at others but pointing to themselves as management. The striking part of Japanese industry, when you look at its automation, is the fact that more than 50 percent of its managers come from engineering and the hard sciences, not from finance and marketing.

I would like to challenge the National Academy of Engineering rather than the government. I would challenge it to exercise a certain degree of leadership to bring to the engineering curriculum the knowledge of how industrial processes work. Why teach students about the natural laws of gravity, the natural laws of friction, and the natural laws of stress and strain, but not about the natural laws of economics, technology diffusion, organizational management, and supply and demand?

We are going simply to have to take over the management of industry in the country, and, to me, that is the best public policy one can charge the engineering profession with.

<u>Mr. Bloch</u> That was almost the last word, but not quite. There is not a single action that will fix the problems we discussed today. There are many actions by all sectors of our society that need to taken to solve the deep issues we are facing as a profession, as an industry, and as a country.

Courtland Perkins opened the program this morning. He has the privilege and the right to close it.

<u>Mr. Perkins</u> I think that this has been an exceptionally fine technical session. It follows last year's on genetic engineering, which was also exceptional, and it proved the point that it takes an awful lot of work to put one of these sessions on successfully.

The steering group has worked long and diligently to put this program together, and we all thank them for a job well done.

We also ought to thank Kerstin Pollack, who is the administrator on the NAE staff. We have been blessed by a very fine staff in the Academy of Engineering.

As for our members and guests in attendance, we have been delighted to have you here and we hope you can attend next year's annual meeting.