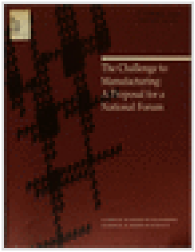

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The Challenge to Manufacturing: A Proposal for a National Forum

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Letter Report to William R. Graham and Erich Bloch

The following letter was addressed to William R. Graham, Science Advisor to the President, and Director of the Office of Science and Technology Policy, and to Erich Bloch, Director of the National Science Foundation, on June 7, 1988.

We have now completed our preliminary investigation of the desirability of creating a forum for the discussion of the broad problems that confront the manufacturing sector. A principal source of information regarding the need and desirability for this type of activity was derived from the workshop that was sponsored by the National Academy of Engineering and the National Academy of Sciences on March 25, 1988. We particularly want to thank you for your active participation in this workshop and for the very constructive contributions that you made to the discussions.

It seems safe to conclude from the workshop discussions and from conversations that we had with a number of chief executive officers of manufacturing companies that the manufacturing sector continues to experience severe competitive pressures. An effective response to these pressures will require a number of actions that involve various sectors of our society. In particular, industry itself must address the way in which it designs, manufactures, markets, and services its products. Government has a major role in establishing an economic, fiscal, regulatory, and legal environment that encourages industry to compete aggressively in the world marketplace. The university community has a role in educating the people who will work in and lead our manufacturing industries and in creating and communicating the new technology that will serve as an effective tool in improving the competitiveness of industry.

Although each of these sectors of society can proceed independently to accomplish its mission, it is obvious that there are a number of important issues that affect them all. It is also clear that the issues that occur at the interface between the various sectors are often the most troublesome since there is no standard mechanism that regularly brings the representatives of sectors together to address mutual problems and opportunities.

It was the general consensus of the workshop that the bringing together of people to discuss the broad issues that affect several sectors could probably be performed by a forum of the type that we have envisioned. It was the overwhelming view of the participants that this type of activity would succeed only if it had the endorsement and active participation of the senior policymakers of all the sectors that are involved. Thus, it was agreed that success is likely only if cabinet- or subcabinet-level officers of the government, chief executive and chief operating officers, or key vice-presidents of corporations, key representatives of labor, and presidents or chief academic officers of the universities are willing to devote the time necessary to meet and discuss these issues on a regular basis and facilitate actions based on these discussions.

It is our conclusion that this topic is worthy of further exploration. In view of the possible change in the senior-level administrators of the government in early 1989, we believe that it is best to delay further actions until the topic can be brought to the attention of the new administration. If the responsible policymakers in the new administration, along with the appropriate representatives of other sectors, are enthusiastic about this concept, the National Academy of Engineering and the National Academy of Sciences are prepared to proceed with the creation of a Manufacturing Forum. We believe, however, that the initiative for this effort properly rests with the government.

We attach to this letter a summary of the workshop discussions. We will publish, as soon as it is practicable, copies of the four papers that were prepared for the workshop, a draft of a charter that could form the basis of a future Manufacturing Forum, along with the summary of the workshop discussions. We hope that this document will be useful in the exploration of this matter with the next administration. Copies of the complete publication will be forwarded to you as soon as it is available. If the Academies can be of further assistance in this matter, please do not hesitate to contact us.

Frank Press
President
National Academy of Sciences

Robert M. White
President
National Academy of Engineering

The Challenge to Manufacturing: Summary of a Workshop

The easy exchange of goods and services in world markets, made possible by the availability of good communications and reasonably inexpensive transportation, has become an increasingly important and essential factor in the economies of many nations. Exports in 1986, as a fraction of gross domestic product, reached 27 percent for the Federal Republic of Germany, 13 percent for Japan, 25 percent for Canada, and 5 percent for the United States. World trade grew sevenfold between 1950 and 1986 at a time when real world gross domestic product was only quadrupling. A principal consequence of this transition to global markets has been the loss of assurance that local manufacturers had of their participation in their local market.

Foreign companies, some with the advantage of inexpensive labor, have found it easy to compete in the U.S. market. However, this experience has been neither the only nor the predominant course of domestic competition. Many firms have been supported by national policies that encourage exports. Most critical, however, is the fact that many nondomestic firms have learned how to offer products to American consumers at a price and level of quality that domestic producers find difficult to match. It is estimated that 70 percent of current U.S. manufacturing output currently faces direct foreign competition. This new competitive environment is challenging the existence of many U.S.-based companies and industries.

Whereas foreign competition was once viewed in terms of the more traditional labor and raw materials intensive "smokestack" industries, such as steel, glass, and automotive, it is now evident that it also extends to the "high-tech" knowledge-intensive industries. The positive trade balance in sectors previously dominated by the United States, for example, aircraft and complex electronic equipment, has been declining since 1985. As a sector, high-technology manufacturers experienced a negative balance of trade in 1986 for the first time in history.

In addition, although the relationships and interdependencies between manufacturing and other economic sectors, such as the service industries and agriculture, are becoming increasingly clear to many observers, there are some who do not yet recognize this important synergy. That manufacturing is a core part of the U.S. economic infrastructure and central to the nation's future economic well-being is a thesis that needs to be continually transmitted to national policymakers.

Although the situation described above is critical, it should not be assumed that manufacturing is disappearing from the scene. In fact, the contribution of the manufacturing sector to the gross national product appears to have remained nearly constant since the 1950s, with only modest fluctations about an average of 22 percent. This figure should not instill false optimism, however, as there is more reason to believe that statistical corrections would result in a lower figure rather than a higher one.

The challenge that exists is how to ensure that U.S. manufacturing sector remains vital and healthy. This is particularly necessary for those industries that have broad applicability and impact other industries, such as computers, semiconductors, telecommunications, software, and machine tools. Success in meeting the challenge of global competitiveness

This summary of a workshop held on 25 March 1988 was prepared by W. Dale Compton and Morris Tanenbaum.

will be a critical factor in determining the capability of the United States to remain a vital economic and political force in the world.

In attempting to affect and control the forces that influence our capability to compete in the world marketplace, we must recognize the distinct role that each of the major sectors of society play. Industrial managers must be committed to continuous improvement in product quality and productivity, as well as innovative function. The labor force must be well trained and committed to efficient production of a high-quality product or service. The government must be sensitive to the need for stability, predictability, and fairness in the economic, regulatory, and financial environments. The education system must be motivated and able to produce an adaptable and technically competent work force capable of meeting future challenges, not past ones. No one sector of society can, by itself, create a new competitive attitude and position for the United States. It will clearly require coordinated action by all segments—industry, labor, government, and the educational community.

Understanding the roles and responsibilities of each sector is an important first step in dealing with this complex set of issues. There can be no question that industry has the principal responsibility for designing, developing, and producing the products and services that are to be offered to world markets. It is the responsibility of industry to produce a spectrum of high-quality products and services that will appeal to a broad group of consumers at home and abroad. Industry must organize itself to recognize changes in current markets, to anticipate emerging new markets, to improve productivity, and to reduce significantly the time taken to bring a new product or service to market.

The environment within which industry operates to accomplish these tasks is and, we must continue to assume, will be influenced in a major way by the actions of both government and labor. This environment is determined by the fiscal, regulatory, and legal policies that are promulgated by the government. In addition, the natural aspirations of employees for a stable and satisfying work environment critically influence the way industry can respond to changing competitive circumstances.

The education system has a dual responsibility in the efforts to achieve competitiveness. It must provide a soundly educated work force that will recognize the need for a continuing educational experience throughout career spans, and the expansion of a research environment that will facilitate the origination and development of the advanced technologies and related processes that will ultimately be included in and used to produce the next generation of products and services that meet and influence market requirements.Achieving coordinated action among diverse segments of society is a complex process. There is no single body, either public or private, that has the responsibility for accomplishing this goal. There is no broad-based forum involving government, industry, labor, and education perspectives for the discussion of many of the topics in an environment that is knowledge seeking rather than combative. Although there are many data sources, there are very limited opportunities to consider that data from the viewpoint of the major stakeholders and disseminate their conclusions and perspectives to the policymakers.

Recognition of the absence of both this focus and a multisector forum that could discuss the issues that arise as each sector attempts to carry out its obligations led the Science Advisor to the President and the director of the National Science Foundation to request that the National Academy of Engineering and the National Academy of Sciences hold a workshop to explore whether an effective forum could be created that would encourage discussion of the many intersector issues that affect manufacturing.

The Academies organized such a workshop on March 25, 1988. Representatives of industry, labor, government, and universities participated in an active discussion of the various issues that contribute to the challenges confronting the manufacturing sector. This brief report summarizes the workshop discussions and the general conclusions that were developed. As an aid in focusing the discussions, four individuals with broad expertise in manufacturing were invited to offer their views of the problems, challenges, and opportunities for the manufacturing sector. They were each encouraged to emphasize the issues that exist at the interface of the domains of responsibility of the governmental, industrial, labor, and university sectors.

The consensus of the workshop was that the following topics would be particularly amenable to discussion and debate by a group composed of representatives of the four sectors.

STRATEGIC ISSUES

Strategic issues influence the capability of all sectors to support the competitive needs of the nation. These issues include the role and importance of manufacturing in a competitive world; the nature of the policies that influence the level of investment by industry in new plant and facilities; the overall policy of government concerning cooperative industry activities, including the development of joint manufacturing activities; the mechanisms by which small business is and can be provided technical support and encouragement for improving its competitiveness; the impact on the national technological infrastructure as both manufacturing and product design of key products and services are being sent offshore by American firms while foreign firms open facilities here; the interrelationship between manufacturing initiatives that are guided and applied by the Department of Defense and those of the commercial sector.

NEEDS AND ASPIRATIONS OF THE EXISTING WORK FORCE

The existing work force is being confronted with serious dislocations as jobs are eliminated in the traditional industries and replaced by jobs that require significantly different skills. Providing proper incentives, opportunities, and means for timely occupational retraining for these displaced workers is a major issue that must be addressed. The assimilation of unskilled, semiskilled, or inappropriately skilled workers into the labor force will be increasingly difficult in the years ahead. This problem will require the attention of all sectors of society.

THE WORK FORCE FOR THE TWENTY-FIRST CENTURY

The work force for the twenty-first century will require an unprecedented degree of adaptability to changing employment demands. Continuing education and a regular upgrading of skills will therefore be a requisite for stable employment. To meet the nation's increasing demand for engineers and scientists, the students must be drawn increasingly from the pool of women, minorities, and the disadvantaged, groups that historically have not participated in these occupations to a great degree; the manner in which this cultural change can best be facilitated needs to be explored. The need to upgrade the elementary and secondary education system in this nation to satisfy the diverse and increasingly complex demands of the future work force is critical to achieving and maintaining a competitive position for this nation; attention must be focused on improved vocational training applicable to the factory of the future.

TECHNOLOGY AS A TOOL IN ACHIEVING COMPETITIVENESS

Although technology alone cannot solve the competitiveness problem, there is ample evidence that technology can be an important tool in creating and delivering cost-effective products that will compete in world markets. Ensuring that the technical communities in industry, government, and the universities are properly integrated and that disincentives do not discourage the effective use of technology by industry is increasingly important. Technologies that relate to manufacturing, including materials, process control, semiconductors, and the software that is needed to control the manufacturing operation must be nurtured and disseminated to the industrial sector; at issue is the best means to ensure the optimum use of limited national resources to develop the critical core technologies deemed necessary to drive national leadership.

WORKSHOP CONCLUSION

The workshop participants concluded that a Manufacturing Forum, structured in a manner similar to the draft charter that is included as an appendix to this summary, could be an effective means of bringing together the representatives of the various sectors of the nation to address the types of problems outlined above. Although a majority of the participants endorsed the general concept of the Forum and indicated that their organizations would probably be willing to participate, this endorsement was strongly and explicitly conditioned on the presumption that the interest would be sufficient to ensure that the proper level of participation would be forthcoming. The participants in this workshop clearly believed that this process would be productive and successful only if high-level policymakers in each of the sectors participated actively. Without a commitment at this level of participation, the Forum cannot be expected to be productive and effective.

Draft Charter for a Manufacturing Forum

During the first half of the decade, this country experienced an unprecedented challenge from overseas manufacturers and exporters of goods. Foreign manufacturers, many with facilities in countries having low-cost labor and many with governments whose policies favored exports, created an economic environment that required a dramatic response by many U.S. companies. Oftentimes the domestic companies were faced with the requirement to restructure or go out of business.

The domestic manufacturing industries were particularly challenged by the confluence of a series of events, some of which should have been anticipated and controlled by them and some that were clearly outside their immediate control. Recognizing that future challenges to this industry can be effectively met only by a concerted effort on the part of industry, government, and universities, the National Academy of Engineering and the National Academy of Sciences have created a Manufacturing Forum.

The purpose of the Forum shall be to provide a means by which policymakers from government, industry, and universities can meet to discuss issues that influence the competitiveness of manufacturing industries. It shall be a device for improving communications. Key issues relating to such matters as technology development and utilization, incentives and disincentives for investment, strategic national plans as they relate to U.S. manufacturing industries, current and future trends in the labor force, and long-term educational needs and opportunities for the manufacturing sector will be discussed. The Forum shall not conduct studies, provide advice, or make recommendations on specific issues or policies.

MEMBERSHIP

Membership of the Forum shall be drawn from a wide spectrum of organizations having a direct involvement in matters relating to the manufacturing industry. Efforts will be made to obtain a commitment from the key operational person from each of the participating organizations. It is likely that membership will be drawn from the following organizations:

Government Agencies

Office of Science and Technology Policy, Executive Office of the President
Department of Commerce
Department of Defense
Department of Energy
Department of Justice
Department of Labor
National Aeronautics and Space Administration
National Science Foundation
Treasury Department

Industry

Suppliers of manufacturing equipment and tools, including both hardware and software

End users of manufacturing equipment and tools

Labor

Major labor unions

Universities

Major universities with significant research programs related to manufacturing

Universities and colleges with significant effort in retraining of personnel or in continuing education

Technical Institutes

In addition to the regular membership, the Forum shall avail itself of the advice and counsel of individuals who have particular knowledge and experience in the various matters that come before the Forum.

GOVERNANCE

The Forum shall meet as a committee of the whole.

The Forum shall typically meet in open session where diverse views among the participants can be freely expressed. Certain meetings of the Forum may be held in closed session, if the Forum members deem that this would enhance the free exchange of views.

The Forum shall be governed by a core group, not to exceed seven in number, of Forum members and will be known as the Forum Council. The Chairman of the Forum shall serve as the Chairman of the Council.

The Agenda of the Forum will be established by the Forum Council.

TENURE

The Forum shall operate for a period of two years. At the end of this period, a reassessment shall be made of its effectiveness. Continuation of the Forum shall require a strong endorsement of the value of it to the various participants.

Supporting Papers

The Paradox of American Manufacturing

Leo E. Hanifin

We are faced today with a paradox: We are a *nation at risk* and a *nation prospering*. The paradox is a glaring combination of a building crisis within conflicting signs of a strong economy. The foreign competition is eating our lunch, yet we can still sit down to a gourmet dinner. Thorough examination of both sides of the paradox is necessary before any real understanding of the state of manufacturing is possible.

There are many indicators that seem to demonstrate that our national economy is quite healthy. Unemployment is very low. Interest rates are low. Performance of many corporations was better than expected at the end of 1987. The plunge of the dollar has allowed us to begin to reverse the trade imbalance trend that has hobbled our economy over the last decade. Factories are operating at well over 80 percent of capacity. Many economic prognosticators have stated that we have withstood the most severe blow that the markets (stock and global) can deliver and come back strong. Perhaps all this arm waving about the impending doom, driven by the downfall of manufacturing, is just that—arm waving!

However, a closer look at other indicators of competitiveness show that the country may not be all that healthy. For many years, we have observed that the U.S. rate of productivity growth has lagged that of many other industrial nations. In each of these years, many dismissed this as a consequence of our tremendous lead in absolute productivity, the development of the emerging industrial nations and the rebuilding of those nations decimated in World War II. These rationalizations no longer hold; we have now been surpassed as the leader in absolute productivity.

We are even beginning to feel individually the impact of our competitive failings. Our standard of living, in terms of average wage, has dropped substantially. Many believe that higher paying industrial jobs are being replaced by lower paying service economy positions (Young, 1985). [Others believe that the employment gains are in higher paying jobs (Economic Report of the President, February 1988).] Regardless of the salary levels of new jobs, our workers in manufacturing are being paid less; as of the early 1980s, the average wage in most Japanese manufacturing industries surpassed the average in the same American manufacturing industries. (This comparison was based on an exchange rate of 140 yen to the dollar; the comparative buying power of U.S. workers has been further eroded by the dollar's devaluation (Scott, 1985).

So, if competitiveness is defined as the ability of a country's corporations to effectively deliver high-quality goods in the global marketplace without a reduction in the standard of living, we are not competing effectively.

Because of this paradox—the trend toward crisis within a prospering economy—it is very difficult to elevate the concern of the public and the policymakers for critical issues in manufacturing. However, the paradox has not gone completely unnoticed. John Young, in writing about the findings of the President's Commission on Productivity, suggested that "What this country needs is another Sputnik," or even better, "to have the Japanese launch a Toyota into space."

The paradox of conflicting signs creates a dangerous situation. Human nature encourages us to focus on either the positive or the negative signs and to employ only the information or data that support the chosen view. To do so would mean that we would either conclude that all is well and ignore the crisis or conclude that all is lost and ignore the opportunities. In fact, we must reconcile ourselves to the fact that the paradox is real and we face a situation that is both a problem and an opportunity. A closer look at some key indicators further reinforces this seeming contradiction. Five key indicators of our competitive position are growth, jobs, trade, income, and productivity.

Growth can be measured in terms of either absolute sales or market share. As an example, a five-year analysis of the semiconductor market (Figure 1) shows that the two largest American suppliers, Texas Instruments and Motorola, had substantial growth in sales over the last five years (63 percent and 100 percent, respectively). However, some foreign competitors grew by several hundred percent, dropping the American producers from the top two spots in market share to fourth and fifth.

As a broader measure of recent growth, sales continue to grow in the manufacturing sector, with factory orders consistently increasing for all but 3 of the past 18 months (Figure 2).

As another measure of its strength, manufacturing has maintained a consistent fraction (20 to 25 percent) of the U.S. GNP for the past 35 years. However, its impact on jobs has decreased dramatically during the same period. In fact, an analogy with agriculture is appropriate; while the employment in both have decreased dramatically, both remain critical elements of America's economic foundation.

Although unemployment is at record low levels, and manufacturing employment is quite strong, many criticize the income levels for our current jobs. "A 1986 report prepared by the Joint Economic Committee of Congress concluded that if only one parent worked in the average two-parent family of the 1980's, annual family income would decline, after adjustment for inflation, by one-fourth" (Morrison, et al., 1988).

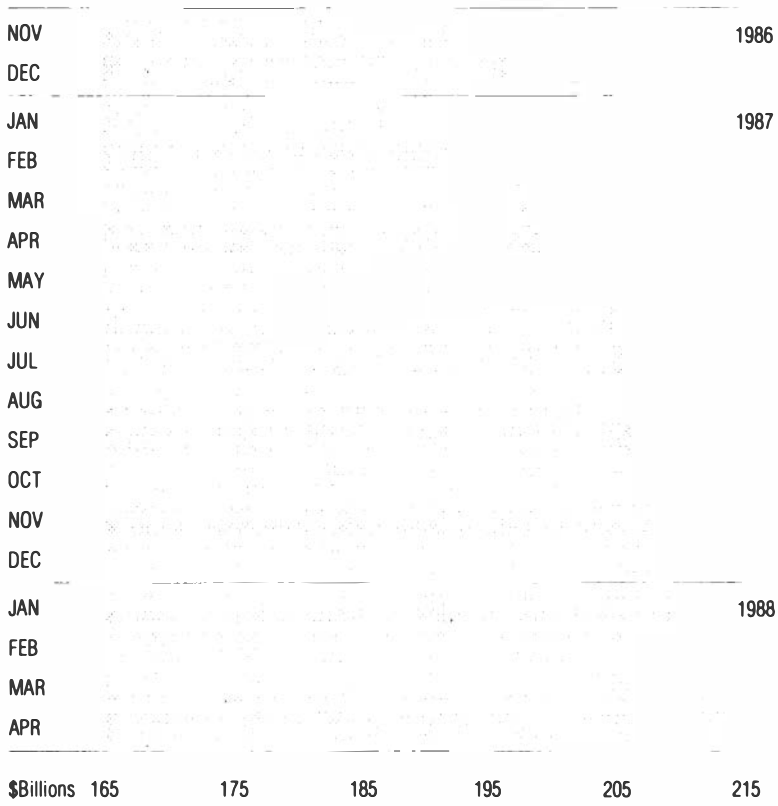
One of the most disturbing measures of the state of manufacturing is its contribution to the nation's trade deficit. It not only contributes the largest share of the deficit, but exhibits disturbing trends in terms of industrial

FIGURE 1
Worldwide semiconductor sales ($ millions).

1982			1987	
Texas Instuments	$1305		NEC	$3193
Motorola	$1219		Toshiba	$2939
NEC	$ 879		Hitachi	$2781
Hitachi	$ 879	100%	**Motorola**	$2450
Philips	$ 797	63%	**Texas Instuments**	$2125

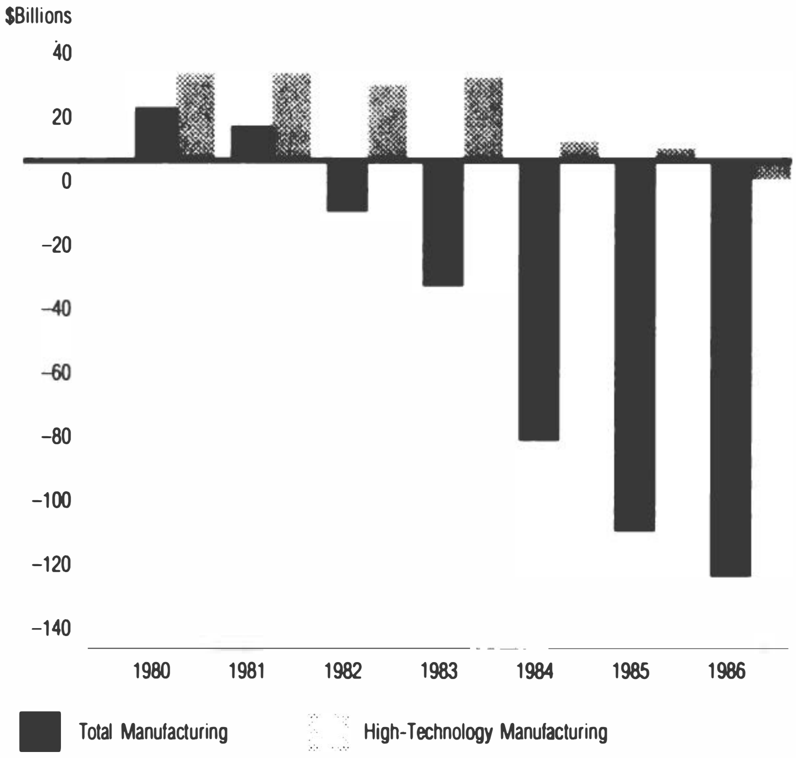
SOURCE: Dataquest, Inc

FIGURE 2
Factory orders.



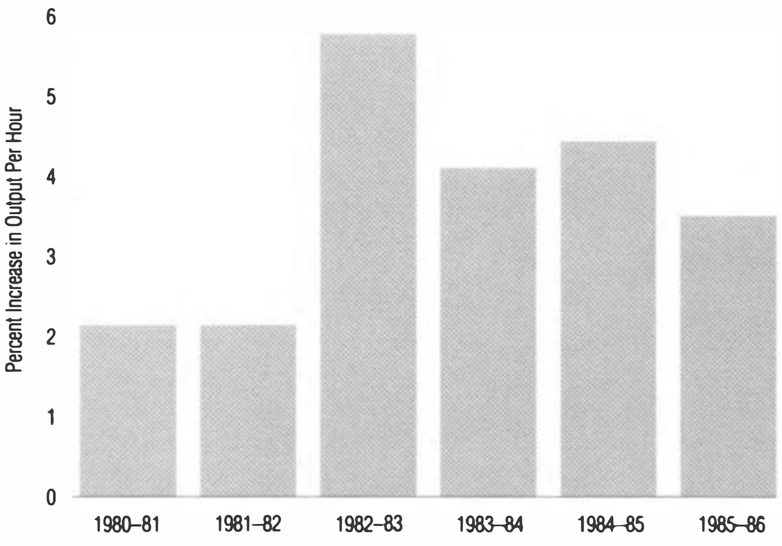
SOURCE: U.S. Department of Commerce

FIGURE 3
U.S. trade balance.



SOURCE U S Department of Commerce

FIGURE 4
U.S. manufacturing productivity growth.



SOURCE U S Bureau of Labor Statistics

mix. Figure 3 shows that over the past four years, high-technology industries have changed from the positive balance of the manufacturing sector's trade deficit to a contributor to that deficit.

Many of these mixed signals can be linked directly to the productivity of U.S. manufacturing companies. Although direct labor productivity is no longer the best measure of competitive strength, it does provide valuable insight. As with other measures of the health of the manufacturing sector, the recent productivity comparisons are inconclusive. During the 1970s, U.S. productivity growth was not competitive, languishing at about 1.4 percent. Recent years have been more encouraging, with average annual rates of 3.5 percent over the last decade, and with manufacturing productivity growth rates of more than 4 percent in the mid-1980s (Figure 4). These rates are still less than many industrialized nations. Nonetheless, recent advances in productivity may provide an element of opportunity.

A window of opportunity exists for the American manufacturing community, and for the nation. Recent improvements in trade, wages, sales, and employment all fuel our optimism, and provide necessary resources for further improvements in our competitive position. However, the recent improvements should not be taken as the first signs of an overall victory in the competitive struggle. Rather, they are transients that are more important in their provision of this window of opportunity. The core elements of our competitive weakness still remain. These include both the cultural and environmental structures that enable competition, and technological and managerial capabilities that provide competitive weapons. It is critical to the nation's future that we understand these issues and seize the opportunity while the resources necessary for change still exist.

Even without the existence of seemingly contradictory signals, manufacturing is, by its very nature, extraordinarily complex. The effectiveness of U.S. manufacturing companies is dependent upon a broad range of environmental, technical, and managerial resources and capabilities. These factors are derived from and influenced by the companies, their industries, and their nation.

THE ENVIRONMENT

There are a number of important trends that characterize U.S. manufacturing today and into the 1990s:

- Intense competition will continue, increasingly, from foreign firms.
- Product and process technologies will continue to evolve rapidly, providing not only differentiation of strategy but corporate strength in virtually every manufacturing industry; product and process life cycles will generally become shorter.
- Trade, capital and knowledge formation, and the economic structures will have a profound impact on the ability of corporations to compete internationally.

To be effective in this environment, each manufacturing enterprise must have several critical resources:

- Management able to understand the environmental issues, grasp the strategic implications of emerging technologies, and provide the leadership and flexibility to respond to both.
- A technically skilled and highly motivated work force able to support product and process technologies and work cooperatively with management.
- A technical staff with the knowledge and ability to work as a team on complex problems.
- The capital necessary to continually change product, process, and facilities in response to emerging technologies, demands of the marketplace, availability of resources, competitive forces, and evolving corporate strategy.

America has a great many resources that provide competitive advantages to our manufacturing firms. However, there are four environmental issues that significantly inhibit the performance of American manufacturing firms and, therefore, require some attention. They are the public image of industry and manufacturing, our primary and secondary educational systems, the American philosophy of work, and the financial environment.

Manufacturing's Image

Since World War II the image of industry and manufacturing in this country has steadily fallen. As affluence spread across the nation, the idea of working in a factory lost its appeal. No self-respecting mother advised her son or daughter to become the very best factory worker or manufacturing engineer that he or she could be. Dad (and maybe Mom, too) worked in the factory so that their sons and daughters could go to college and not have to work in a factory. Their children became doctors, lawyers, or accountants, and the nation's brightest and best stayed away from the factories.

During this period, the nation's concern turned from manufacturing or industrialization toward other issues, such as health and the environment, or space and defense. Industry was portrayed in the media as the "polluter of the biosphere," "the abuser of the worker," and the "purveyor of shoddy products." Popular writings, such as *The Silent Spring*, emphasized the need to attend to environmental issues, but no similar concern was expressed about competitive industrialization.

Although the loss of the priority and prestige of manufacturing was not unique to this country, it was certainly much more severe here than in other nations. In still other nations, the priority on industrialization remained high, leading to comparative advantages in public policy and the quality and scale of human resources dedicated to manufacturing improvements.

There are signs that the image of manufacturing is improving, but, in general, there is not an appropriate appreciation of the dignity, the challenge, the value, and the necessity of individual contributions and national competence in manufacturing.

Education Quality

To possess a strong manufacturing sector, the nation must have a technologically competent work force and engineering force. This is especially important if we are to exploit our technological advantages to balance other disadvantages, such as comparative labor rates or cost of capital. *A Nation at Risk*, the 1983 indictment of our educational system, confirmed what many had suspected. Our nation's primary and secondary educational systems have severe shortcomings and are in need of substantial reform. Beyond the general issues of excellence and quality of teaching, and the levels of expectations, there are several other serious shortcomings that directly affect the ability to create a competitive work force and an adequate pool of individuals pursuing careers in engineering and science. For example, as of 1983, calculus was available to 60 percent of all American high school students, yet only 6 percent completed a course in calculus. Thirty-five states required only one year of math and one year of science for a high school diploma (National Commission on Excellence in Education, 1983).

At the same time, other industrialized nations are teaching statistics to students in grade school, regardless of whether they are destined to become laborers or leaders. These shortcomings have not been alleviated in the last five years. Today, less than 10 percent of our high school students take physics. This means that 90 percent of our young men and women may lose the option of a technological education and career before they are old enough to appreciate its value. This loss is further compounded by the demographics of a "baby bust" that is shrinking the college-age pool and further amplifies the relative shortage of engineers and scientists.

The Worker and the Labor/Management Relationship

In America there is a whole set of social trends and phenomena that undermine the work ethic, the ability and willingness to work as part of a team, and a cooperative relationship between labor and management. Today there is a much greater emphasis on consumerism and spending rather than saving, on materialism rather than contribution to society. From the time our children can understand, television tells them that their primary purpose on earth is to consume. Is it any surprise that when a company asks them to contribute, to excel, to invest themselves in the well-being of the company, the response is a lukewarm, "What's in it for me?"

Manufacturing is a complex undertaking that often requires teams to bring together diverse sets of functions and skills. This is true whether efforts are focused on a single, complex device, such as a robot with vision or advanced controls and mechanisms, or on the whole factory with all its engineering and management challenges. Our society undermines an individual's willingness and ability to work as a team member through its emphasis on heroes and individual performance and recognition rather than teamwork. The glorification of the individual is epitomized by the single-handed conquests of such characters as Rambo. This, and the vestiges of the "me generation," all contribute to the individual's desire to be recognized as the "most valuable player," rather than as a supporting player on a winning team that has created something of value. Such a philosophy is an impediment to manufacturing management's creation of a participative spirit among the work force. It also impedes the ability of technological leaders to bring together diverse knowledge and human resources on a team so that they can apply advanced systems and technical concepts. It is clear that other countries have institutionalized teamwork to a much larger degree than we have.

Finally, adversarial labor/management relationships with the concomitant decrease in cooperative spirit is a significant handicap to American manufacturing companies. One manifestation of this adversarial relationship is the incremental restrictions on job classification and work rules negotiated over sequential contract settlements. These have severely hampered the ability of management to respond to competitive situations and to the evolution of advanced manufacturing processes. It is management's role to bring workers into every step of the operation and instill in them a vested interest in the well-being of the company. It is the responsibility of labor leadership to be open to new structures and rules that are fair and equitable and provide greater flexibility and avenues for their membership to contribute as responsible and committed team members. All these factors—work ethic, teamwork, and labor/management relations—must be transformed from the barriers they currently are into advantages if companies are to achieve manufacturing excellence.

Financial Environment: The Short View

In the 1985 report by the President's Commission on Productivity, it was stressed that "there is a definite correlation between the nation's level of investment and its growth and productivity." Compared with management in other countries, the managers of American manufacturing companies operate on a very short time line, which drives capital investment down. This is the result of two factors: the financial environment and the American school of management.

The financial environment in this country has a profound and negative impact on competitive investment by American manufacturing companies. The cost of capital in America is twice as high as in Japan. The high cost of capital and the intense scrutiny of public corporations require managers to invest only where there is clear evidence of short payout periods for capital investments and no danger of red ink (even for one quarter). This often results in sporadic investments that are narrowly focused, typically producing minor business improvements, rather than cohesive investments leading to some revolutionary alteration in the way the company does business or performs in the marketplace. However, even with the high cost of capital, such revolutionary improvements are, in many cases, still available to manufacturing companies. These include dramatic improvements in time-to-market for new products, quality levels, or responsiveness to customers' needs. Because these improvements are typically difficult to quantify, they are seldom used in traditional justifications for capital investments. It has been reported that a new theory now being explored would support investment on the basis of a combination of both financial measures and nonfinancial indicators such as those just mentioned (National Research Council, 1988).

The reluctance to make long-term investments is further reinforced by an executive work force that is vertically and laterally mobile and has short-term rewards and yardsticks. This, and the general attitude of risk avoidance in the executive suite, create disincentives to long-term objectives and revolutionary change. In particular, the possibility of investing in new technologies is often eliminated before it is given serious consideration.

TECHNOLOGY

It has often been said that technology is our greatest advantage in the manufacturing arena. Technical knowledge and its application to products and processes are indeed critical to our competitive success. To exploit technology, we must simultaneously accomplish several interrelated objectives:

- Ensure that our base of knowledge and generation of new knowledge are in the right areas to provide an advantage to the manufacturing enterprise and capitalize on emerging manufacturing concepts.
- Ensure the adequacy of the engineering work force in both scale and quality, especially in the critical technical and systems areas.
- Learn to better exploit our inventions and innovations through implementation in commercialized products and "floor-ready" processes.
- Integrate design and manufacturing functions to create more responsive companies through improved time-to-market, product customization, and simultaneous engineering.

Technical Knowledge

During the last several decades before the 1980s, there was little effort directed at manufacturing education and research at U.S. universities. That prompted the President's Commission on Productivity to judge that perhaps the nation's greatest weakness in technology is its failure to devote enough attention to manufacturing applications (Young, 1985). However, in recent years, there have been substantial increases in manufacturing research and education. The results from university labs in the United States and abroad and from industrial R&D centers, are providing new opportunities in manufacturing (Hanifin, 1987). The greatest potential for improvement in products, processes, and overall performance in manufacturing are derived from the following areas:

- *Materials:* New materials are emerging with remarkable mechanical and electrical properties. These materials include composites, ceramics, semiconductors, and superconductors. They not only offer dramatic opportunities for product development and performance, but also provide opportunities and challenges to manufacturing. In many cases, there can be no new product without a new process. As such, education and research in manufacturing and design of such materials are inseparable.

- *Computing:* The advent of new concepts in computer hardware and software, such as parallel processing, will provide exciting new capabilities for the factory floor. Control systems that embody extraordinarily complex phenomenological models of the process will be able to provide real-time adaptive capabilities at an affordable price.

- *Systems:* Many of the critical issues in manufacturing competitiveness lie in integration of all functions of the manufacturing enterprise. The challenges range from the development of small manufacturing cells to corporate-wide information and communications systems. Today's factories exist with distributed computers often with disjoint analysis systems and overlapping data bases. There is a need for better understanding of factory communication systems, data base structures and knowledge formats (including geometric representation), and control architectures.

- *Flexible Automation:* Flexible automation can enable corporate responsiveness. Flexible automation is a necessary, but not sufficient, element in the drive toward rapid product changeovers, shortened time-to-market, and just-in-time production. Appropriate schedules and interfaces between design and manufacturing are also required.

- *Statistical Process and Quality Control:* In the complex environment of manufacturing, the judicious use of statistical methods permits the definition of causes of variation and emphasizes the areas of greatest need and opportunity; they separate the signal from the noise. However, measurement of variation does not reduce variation; understanding the causes of variation is necessary to do so. Profound knowledge of the phenomenon in question is necessary to accomplish process improvements. Other techniques, such as the Taguchi method and Quality Function Deployment, seek to set priorities for quality features, reduce variability and sensitivity to variation, and further define relationships between design and product life cycle.

To effectively compete in many industries, we must focus on these five areas of technology, create new knowledge, and then disseminate and apply it. The next section, on research and development, will discuss the creation of new knowledge in the United States. The section on manufacturing education discusses the dissemination of knowledge, and the next two sections, Design/Manufacturing Integration and Invention vs. Exploitation, discuss the application of knowledge.

Research and Development

In general, the nation's R&D funding structures and philosophies are poorly suited to the support of technological developments important to competition in the civilian manufacturing sector. As stated in a recent report to the National Academy of Engineering (1988, p. 42):

> Federal participation in the development of technology downstream from basic research has generally been considered only when the case has been made that a crisis exists, as when the semiconductor or machine tool industry was in danger of irreparable damage from overseas competition.
>
> Federal response has frequently been to turn to the Department of Defense (DOD), rather than a civilian agency such as the Department of Commerce, to act as the federal focus for justification and funding, even though the civilian sector may be the intended principal beneficiary of the program.

The emphasis on defense-oriented R&D is reflected in the following statistics:

- Current research sponsored by all defense agencies, including the Defense Advanced Research Projects Agency and the National Aeronautics and Space Administration (NASA), is about $33 billion.

- Current basic research supported by civilian agencies is less than $3 billion (Presidential Commission on Industrial Competitiveness, 1983).

Principal competitors, such as the Federal Republic of Germany and Japan, spend about 2.5 percent of their GNP on nondefense R&D. In comparison, the United States spends 1.8 percent of its GNP on nondefense R&D (Council on Research and Technology, 1988).

In some cases, defense spending does directly address critical manufacturing issues. Sematech and the National Center for Manufacturing Sciences both focus on research agendas that are important to manufacturing. Also, these agendas were defined through dialogs involving broad constituencies of experts in the target areas. Conduits for the dissemination of resulting knowledge have also been planned in both cases.

In other cases, research objectives are defined by groups, often small groups, with mission orientations. The result is that too often new knowledge that can be used only on specific applications, and may have little transfer or use to the commercial manufacturing sector. For example, many of the DOD- and NASA-funded efforts in robotics deal with mobility and navigation, the areas deemed least important in a recent Robot Industries Association survey of American manufacturers (Hanifin and Ruggles, 1988). Such funding has drawn many American universities' robotic research programs into this area.

Civilian funding sources, especially the National Science Foundation (NSF) and the National Bureau of Standards (NBS), have dramatically increased their attention to manufacturing in recent years. However, the scale of their efforts still pales in comparison with defense efforts. Many of the NSF Engineering Research Centers concentrate on manufacturing research. NBS hopes to extend their knowledge conduit from their Advanced Manufacturing Research Facility (AMRF) to industry through a series of Technology Transfer Centers. The NSF will soon launch a new Strategic Manufacturing Research Initiative. However, this agenda, defined by about 100 experts from industry, academia, and government, will be supported by only $2 million dollars (Woo, 1988).

Nearly half the country's $125 billion R&D expenditures come from industry. Although most are spent internally, the support by industry for university research had risen to $375 million in 1986. This level of support is 5 percent of university research support, up from a low of 4 percent in the 1970s. (In 1960, industry support represented 8 percent.) Much of this increase reflects new forms of partnerships between universities and industry, sometimes with the encouragement and support of state and federal governments. The continued evolution and growth of such partnerships offer an attractive means of ensuring that resources are focused and programs operate in ways that result in both academic rigor and industrial relevance.

Manufacturing Education

Once the new knowledge described above exists, the next step is its transfer and incorporation into American manufacturing companies (unless it was created there). The objective clearly is to provide adequate numbers of engineers with the knowledge of advanced manufacturing technology and systems. This can be accomplished in two ways; either by educating new engineers who seek careers in manufacturing, or by delivering new technology and knowledge to the current engineering work force. For many reasons we need to do both.

Manufacturing Curriculum: Manufacturing, by its very nature, is an interdisciplinary area of application. An engineer working in manufacturing requires knowledge of a broad spectrum of technical disciplines, including electrical, materials, industrial and mechanical engineering, as well as systems and programming knowledge. There is also a need for an understanding of a variety of social and managerial areas. One approach to satisfying this interdisciplinary need is to develop a manufacturing engineering curriculum that touches upon all the areas important to manufacturing. This, however, is a disservice to the student, and his or her ultimate employer. Such an education is so broad and shallow that the student is trained in technologies rather than educated in the underlying disciplinary principles. Because they cannot understand the phenomena that underlie the new technologies, such shallowly educated people will become lost as technologies change. Also, they will not have the disciplinary depth to drive the evolution of new technologies.

A more appropriate approach is to educate engineers in a discipline and then teach them the application of their knowledge to manufacturing in two ways. First, focused manufacturing courses, such as robotic mechanisms or welding metallurgy, can be incorporated into the departmental curriculum. Second, engineering students must be taught to communicate across disciplinary boundaries and work effectively on interdisciplinary teams. This can be accomplished through capstone experiences in product and process design that require knowledge and participation in a number of disciplines. A growing number of universities are taking this approach, effectively teaching systems integration and teamwork through various manufacturing systems curricular sequences and interdisciplinary research center structures (Hanifin, 1988a).

Decrease in Numbers of American Technical Students: The demographics of a shrinking student population and reduced interest in a technological education provide critical challenges to the need for engineers in manufacturing. The growing need for greater numbers of engineers in manufacturing is emphasized in reports of national panels, such as *Education for the Manufacturing World of the Future* (National Academy of Engineering, 1985), and by the relative performance in this area by our principal competitors, especially Japan and the Federal Republic of Germany. In Japan, engineers constitute 40 percent of the workers in the shop, compared to 10 percent for the United States (Lewin, 1988). One way to respond to this need is to consider additional resources, such as foreign and foreign-born engineers. A recent study by the National Research Council (1988) indicates that we cannot accomplish our educational and research programs in American engineering schools without foreign-born individuals among faculty and graduate students. If we are to create a flow of new knowledge and engineers into manufacturing, we must consider these foreign-born students and engineers as a national resource in the tradition of the American melting pot. They are usually the brightest from their countries, and most would like to remain in this country.

Although the effective use of foreign students, engineers, and scientists can have a positive impact on our needs for technical skills, it does not answer the underlying question, "Why are so few of our young people willing and able to pursue technical educations, especially at advanced degree levels?" Once we answer this question, we may be able to attract and prepare more U.S. students for technical careers.

Lifelong Education: It would be impossible and unwise to try to replace our engineers in industry with new graduates. The experiential base in manufacturing is a critical corporate and national resource. However, if our engineers are to contribute throughout their professional lives, they must have the desire and the ability to educate themselves continually in new technologies. Even during their university education we must teach people how to learn continually and not just to prepare for exams. Further, we must make this continuing education available to them in the most stimulating, appropriate, and convenient form. One mechanism to accomplish this goal is satellite delivery of educational programs directly into the workplace. The National Technological University and a number of other individual universities are already using satellite delivery for continuing education in manufacturing.

Design/Manufacturing Integration

One critical issue in manufacturing today is the degree and effectiveness of the linkage between design and manufacturing. Over the years, corporations have developed a high degree of functional separation through the development of organizations assigned to specific domains of responsibility, such as product design, manufacturing engineering, and quality control. This separation has led to several detrimental effects on many corporations. First, many product design engineers have lost touch with manufacturing, resulting in product designs that place a priority on product function and performance without adequate attention to the product's manufacturability. Also, in most American companies, the definition of process occurs sequentially with the definition of product, being initiated only after the final product design is released. This creates a longer lead time for the transformation of design information into manufacturing and process definition and also inhibits the ability of manufacturing engineers to affect the design with respect to its manufacturability. Because the largest proportion of product cost is determined by design decisions, a sequential and disjoint process leads to high product cost, low quality, and slow time-to-market.

Many U.S. companies have accurately identified these critical issues and are employing several techniques to reverse the functional disintegration of design and manufacturing. These techniques include the following:

- *Design for Manufacturability:* A number of explicit techniques have evolved to increase the manufacturability of product designs. Some are focused on specific elements of the manufacturing cycle, such as assemblability. Others seek to increase the overall robustness of the product design, decreasing the sensitivity of product cost and quality to variations that might occur in its manufacture. Other companies have forced an early interaction between the definition of process and product through simultaneous or concurrent engineering efforts.

- *Concurrent Engineering:* Concurrent engineering is an extension of the interaction between product and process definition. A recent workshop on the subject defined it as "a systematic approach that creates a product design that considers all elements of the product life cycle from conception through disposal and simultaneously defines the product and process design" (Hanifin, 1988b). In a few dramatic cases, such as Ford and ITT, the use of concurrent engineering (especially, related quality techniques) has resulted in dramatic improvements in the quality, cost, and timeliness of products (Sullivan, 1986; 1987).

- *Computer-Aided Process Planning:* Another concept for reducing the time and difficulty of the transformations between product and process is the generation of computer aids for process planning. These include models of processes, allowing a variety of process and tooling definitions to be evaluated on a computer before commitment to a particular process plan or setting of process parameters. This includes phenomenological models of specific processes, such as injection molding or forming and may include corporate-specific machine capacities and capabilities. All of this drives process knowledge back to the design engineer, forcing an early evaluation of manufacturability as the principal objective. It also seeks to capture process and manufacturing knowledge from an aging work force of manufacturing engineers.

- *Feature-based Design:* Most CAD systems today create designs through a combination of points, lines, and surfaces. These elements, in and of themselves, have little meaning to a product or process engineer. Rather, product engineers are interested in design features that reflect product functionality. These features might include "webs" to carry loads, or "shoulders" for bearing surfaces. Manufacturing engineers also consider features, such as "pockets" that must be removed, or "holes" that must be drilled. If features are adequately defined in product form and function and processing operations, they can provide an increased level of knowledge within data structures and thereby enable a more effective design and integration of manufacturing.

Invention vs. Exploitation

It is a commonly held opinion that much of Japan's competitive success in manufacturing is based on its effective exploitation of the inventions of others, especially those of the United States. In fact, the Japanese have been more effective in implementing many of America's technological innovations on their factory floors than American engineers have been. Our relative preference for invention, as opposed to implementation, has its roots in our "NIH" (not-invented-here) syndrome. It has been aggravated by the movement of engineering schools away from a curriculum of engineering and toward a curriculum of engineering sciences.

The balance of invention and implementation can also be viewed in the strategic framework of the positions that countries and their companies assume within the product or technology cycle (Ergas, 1987). The United States has clearly executed a strategy that seeks to capture technological leadership by being the first to discover and use new knowledge. Japan, and others, "counterpunch" by using incremental improvements (especially in their processes) to minimize advantages of invention. Ergas argues that our comparative overemphasis on creativity does not create commensurately large gains in per capita income. Brooks and Guile (1987) observe that the ability of a nation to generate technological advances is insufficient by itself and may not even be essential for improving the national competitive position.

Regardless of the strategy used, it is clear that U.S. companies can gain a great deal through increased emphasis and ability to implement new technologies, especially on the manufacturing floor. It is ironic that the deemphasis was, in many cases, justified on a superficial strategy of "Yankee ingenuity." Real Yankee ingenuity was born of craftsmen who designed and built their products. Today, it has come to mean the design of products without concern for their manufacturability. Designing the next mouse trap has become more important than building it well.

Although this need is great, we must be careful that the pendulum does not swing too far. Any increase in emphasis on engineering practice and the implementation of technologies should be aimed at creating a balance with engineering sciences and invention rather than replacing or eliminating those. The strengths of American engineers in such areas as engineering analysis, creativity, and entrepreneurship are assets to manufacturing and must not be lost. If we are to compete effectively internationally, we must have both the flow of new ideas and technologies and the capability of exploiting them in our manufacturing companies.

This need for a balance of innovation and exploitation was also noted in a recent report of the National Academy of Engineering (1988, p. 27): "The effective exploitation of new technologies may be difficult, but it provides a major opportunity to excel in international commerce. It is incumbent on industry to join with other sectors of society in the effort to keep the United States in the forefront of the creation, development, and application of new science and technology. It is also imperative that government create an environment that facilitates the use of U.S.-created technologies by U.S.-based producers."

The Japanese are clearly moving toward parity, and then leadership, in the creation of new knowledge. Two indications of their success are their publications and patents. Citations to Japanese articles in engineering and technology have doubled in the period from 1973 to 1986. According to a 1987 report by the National Academy of Engineering and the National Research Council Office of International Affairs, "The total number of research publications by Japanese engineers surpassed the output of French and West German researchers in the 1970s, and the USSR in the early 1980s." In the mid-1980s the number of Japanese technical publications will probably surpass the British and be second only to that of the United States.

The three top corporate recipients of patents in the United States in 1987 were Japanese companies. With its aggressive Technopolis Strategy, Japan's strength in innovation, linked to commercialization, is certain to increase further. This creates another element of our window of opportunity. If Japan succeeds in equaling or surpassing our capabilities in innovation of technology (i.e., creation of new knowledge) before we equal or surpass their ability to exploit new knowledge, the window may be closed forever.

MANAGEMENT IN THE MANUFACTURING ENTERPRISE

People, finances, and technology are three of the four critical systems in any manufacturing company; the fourth element is management. Management must provide the leadership and strategy if the other elements are to have the optimal impact on the company.

Leadership

Articles in the popular press often refer to the need for U.S. manufacturing companies to "retain a competitive position" or "become competitive." If a coach or general manager of any professional sports franchise in America issued a statement that his goal was to "become competitive," it would be his last statement for that team. In sports competition, winning the championship is the only acceptable goal. Similarly, our manufacturing companies should aim at becoming world champions not just competitors.

To attain the goal of being best, the United States needs managers who are leaders as well. Managers in manufacturing companies must expect nothing short of excellence. They themselves can never provide an effort that is "good enough" or expect the company to be "just as good as the competition." Those attitudes must be eradicated from the top down.

Manufacturing Strategy

Manufacturing, with its array of new technologies and systems, provides an enormous opportunity to create strategic advantages. However, most American manufacturing companies have not developed a manufacturing strategy that fits with the corporate business strategy and drives a selection of technological, human, or systems investments.

Skinner (1974) has said, "A factory cannot perform well on every yardstick. There are a number of common standards for measuring manufacturing performance. . . . These measures of manufacturing performance necessitate trade-offs—certain tasks must be compromised to meet others. They cannot all be accomplished equally well. . . ." This implies the establishment of a manufacturing system based on strategy. Conversely, it is also appropriate that corporations develop strategy based on their current and anticipated manufacturing strength. Regardless of the direction of cause and effect, it is critical that there be a strategic fit between manufacturing strategy and the manufacturing system. Further, the manufacturing strategy must fit the corporate business strategy.

There are a number of factors that inhibit the development of strategy and fit. First, most corporate executives have little understanding of technology in general and of manufacturing in particular. This shortcoming has been the result of the long-accepted concept that good management can be applied to any industry and that knowledge of a particular product and process is not critical. That concept has led to the ascendancy of individuals with management, marketing, or financial backgrounds. At the same time, the manufacturing management has been disenfranchised from participation in the setting of corporate directions. Instead of seeking a strategic fit, many companies invested in technologies that are either quick-fix solutions dreamed up by top-level management, or biased technological choices promoted by articulate technologists who favor their own knowledge base (and understood how to use the accounting system).

Fortunately, these issues of "fit" and the "short view" have been noted by many industrial leaders, and a growing number of companies are responding effectively. One response is to provide the technical leaders of manufacturing engineering and the operations managers with a clear understanding of corporate business strategy. They must have not only the opportunity but also a direct charge to participate actively in the definition of corporate strategy. Corporate executives must, for their part, be considered "members of the technical staff." It is only then that corporations can expect to have both the strategies and the investments to create business advantages through manufacturing.

For example, a company may wish to compete by rapid introduction of new products in an industry characterized by rapidly changing technology. They may also decide that corporate strategy will allow product customization to meet specific customers' needs. The manufacturing strategy to fit that particular corporate strategy requires highly integrated design and manufacturing systems to reduce the time-to-market. The corporate strategy of responsiveness would require a high level of manufacturing flexibility. Investments dictated might include design systems with a high level of attention to design-for-manufacturability, fast, accurate, and possibly automated generation of process definitions and, even the hard and soft tooling requirements. Such technological investments as direct numerical-control machine tools, robotics for flexible assembly and material handling, computer-aided design and engineering, and computer-aided process planning might be made. Also required are investments in human capital in such areas as training in design for manufacturability, and maintenance and operator training for computer-driven automation.

Even after the fit between investment and strategy is accomplished, the strategy must be clearly enunciated and understood by manufacturing management. Otherwise, machines and systems purchased and installed for one reason might be used for something completely different. For example, in the case just described, a flexible manufacturing system might be used to reduce cycle time and work-in-process in the factory. However, the manufacturing floor supervisor, thinking that these machines are expensive, might attempt to maximize machine utilization by having extensive queues of work-in-process before each machine, thereby subverting the very reason for the capital investment.

Once the concept of fit is understood, executives in manufacturing companies can dare to lead, secure in the creation of strategic vision and the selection of investments to support that vision.

THE RESPONSE

The issues relating to the environment, the technologies, and the management of manufacturing are indeed ominous. They are woven together in an intricate pattern with many strengths and weaknesses that vary by industry and company. However, if we view the whole cloth, the paradox remains: The challenge to our future is real; the strong economy is real.

Clearly, we need to awake to the challenge. When we look closely at the complexity of the situation, even the Sputnik analogy fails. No single event will affect all industries and people. Manufacturing excellence must exist in thousands of American companies, not just in one massive program such as NASA. The response required is a national one from our companies, our government, and our people. Fortunately, the resources for that response exist today:

- Although their commitment to their companies has been shaken, the workers can do the job. Given the opportunity and the incentive to contribute, they will.
- The technical position of the United States and the U.S. companies is still strong.
- If the issues are presented properly, legislative and corporate leaders will grasp the critical issues and lead in appropriate directions.
- When it is clear that teamwork is required, Americans can still form teams that are more effective than any in the world.
- The financial strength is there, and the devaluation of the dollar should assist corporate profits, which combined with low interest rates will allow capital investment in manufacturing technologies and systems.
- Universities are willing and able to create the necessary scale and quality of manufacturing education and research programs.
- In fact, in every issue and challenge described in this paper, there are good examples of American organizations and individuals who have recognized the critical issues and effectively responded to the challenges or grasped the opportunities. It is incumbent on all of us to identify these cases, study and document the responses, and replicate their effectiveness across the country.

Although we have the required resources to respond, we do not yet have the resolve. The challenges are distributed throughout manufacturing America, and, indeed, nonmanufacturing sectors as well. In our society, companies compete, countries do not. It is necessary, but not sufficient, that the issues be understood by a few leaders within the nation. The issues need to be understood and acted on by large and small companies, by accountants and manufacturing engineers, and by product engineers, boards of directors, and school boards. The response requires action by every manufacturing company and by government and academia to provide a fertile competitive environment.

We need to recognize the current situation for what it is: an opportunity to rally in the midst of a battle we are slowly but steadily losing. If we grasp this opportunity, we can, in the next decade, reestablish the United States as the world standard of excellence in manufacturing. Further, if we can regain that leadership through a combination of competition and cooperation, we can lead the world to a period of unparalleled prosperity. The world markets, and individual market shares, can both grow, creating a larger share for all, rather than endure the debilitating competition in which a few gain a larger share of an unchanging market.

If we do not grasp this opportunity, we will surely lose the foundation that manufacturing provides our economy. Without that, and the other segments dependent on the manufacturing base (such as services), the economy will deteriorate, causing the United States to lose its position as the leader of the Western Democratic World. Such an outcome for the United States and the world is untenable.

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National Manufacturing Policy: An Industry Perspective

Laurence C. Seifert and Alfred D. Zeisler

The United States needs a national policy for accelerating and sustaining productivity improvements to regain global manufacturing competitiveness. This paper establishes a basis for formulating such policy initiatives and supporting government actions.

The need for national initiatives has been widely discussed. Many programs aim at improving the productivity and performance of U.S. manufacturing firms—including Department of Defense projects, National Science Foundation research grants to universities, and attempts to shape U.S. trade policy.

Government policy makers appear to desire a proactive national manufacturing policy, but they lack a theory for selecting and integrating components of a meaningful policy. Such a "theory," offered in this paper, would provide a foundation for effective initiatives.

OPPORTUNITIES IN A CHANGING ENVIRONMENT

U.S. manufacturing is now widely perceived as having lost its world leadership position. There is evidence of rebound, albeit insufficient to ensure recapturing that leadership. By working together, government, industry, labor, and academia can correct this situation.

The basis for competitiveness rests with two principles:

- *End-to-end business performance*, from component and product design to customer support, must be of superior *quality*.
- Competing in global markets mandates equal access to all markets for all competitors; e.g., "level playing field."

The first principle is dealt with in this paper; the second is an issue for trade policy, and is currently being considered by the Congress.

The broad perspective suggests that the following aspects of manufacturing need attention:

- *Development of process technology*, the D of R&D. Current levels of process research, publicly or privately supported, may be adequate but we have not demonstrated the ability to use our technology advantage to achieve results comparable to those of foreign competitors.
- *Skills mobility* among the existing work force. As a nation, we worry about effects of technology and foreign competition on our work force, yet there is a shortage of skilled workers. Constraints on work force mobility must be adjusted to accommodate competitive realities and put the right people in jobs that need doing. Our mindset must change from protecting the status quo of our work force to reshaping it.
- Shortage of *software skills*. We must address both quantity and quality shortfalls.
- Vulnerability in certain *underlying technologies*. Materials and semiconductors, especially, are a vital underpinning for a wide range of industries.
- Lagging deployment of *process control* technology and systems, for both production and design processes. Proven benefits are not being realized. If we are to compete with other nations who maintain a lower standard of living, and therefore enjoy lower labor costs, we must use out technology to extend our process capabilities to lower overall costs.
- *Economic system disincentives* to investment in manufacturing, as perceived by industry.

More technical research, in and of itself, will not address these problems. Government support of the manufacturing sector has traditionally focused on research programs and our fine university system. In these, we have maintained global leadership. These strengths are necessary, but not sufficient to achieve our broader goal. Moreover, despite our technical research, foreign competitors have largely caught up in technology innovation. Even where they have not, rapid diffusion of new technology has neutralized the traditional U.S. advantage. We must not delude ourselves with a technical Maginot line in our battle for manufacturing leadership.

THE TARGET: PRODUCTIVITY GAINS

The United States can no longer expect to compete globally based upon technology alone. Instead we must achieve *continuous cost improvement* in both the operations and infrastructure of manufacturing. Annual productivity gains approaching 10 percent would put this country's manufacturing base on a course to intercept the productivity gains of the world's best in less than a decade (see Figure 1). Productivity gains at this level are possible—achieved in Japan between 1960 and 1973, and recently in several U.S. firms.

Over the years 1979–1986, U.S. manufacturing productivity improved approximately 3.5 percent per year while that of Japan increased 5.6 percent, and Federal Republic of Germany 2.7 percent. Beginning in 1986, the United States may have initiated a sustainable rate of productivity increase that is greater than that of other nations. This country has always stretched to meet important, difficult goals. A 10 percent annual productivity increase is a worthy objective for U.S. manufacturing. However, each industry, and within it each firm, must be free to evolve its own model, set its own objectives, and select tools to meet the objectives.

An Era of Change: Key Trends in Manufacturing

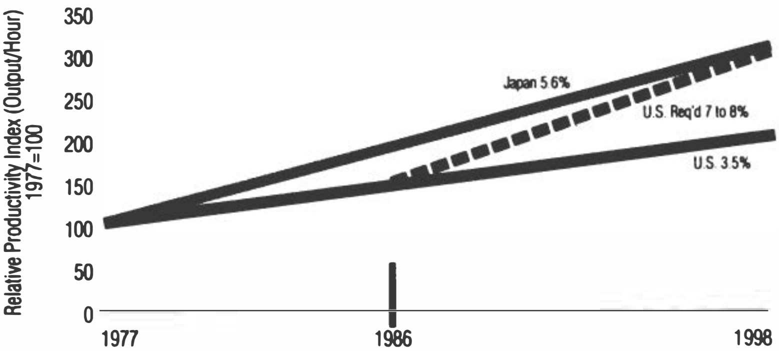
We believe, based on discussion with others, that industry is in general agreement about changes affecting it during the latter decades of the twentieth century. These changes translate into challenges—or opportunities. The following are critical factors for success during the coming period. Creative approaches in these areas are needed to support a 10 percent per year national productivity initiative:

- Traditional job categories often lack relevance to information-intensive contemporary manufacturing. Industry must have incentives and freedom to seek out talent for new jobs among workers in traditional classifications and move those workers into training or new jobs—for example, blue-collar workers into the ranks of software workers.
- The welfare of our natural environment has won the widespread support of manufacturing industry. But environmental policy requires stable ground rules, lest confusion hinder investment and deflect resources unnecessarily.
- Process control has taken on paramount importance to all aspects of manufacturing. The tools of control (sensors, computers, software) must continue to improve and be integrated into systems—in the United States, by domestic firms, whenever possible. Process development costs must also be acknowledged, in many cases, as beyond the resources of individual firms. This accelerates the trend toward industrial alliances, including cross-border alliances.

FIGURE 1

Manufacturing productivity growth.

	U.S.		Japan
	Mfg.	Non-Farm Business	Mfg.
1979-1986	3.5%	1.1%	5.6%
1985	5.1%		7.3%
1986	3.7%		2.8%



SOURCE: Based on data extrapolated from Hatsopoulous and Brooks "Capital Formation in the U.S. and Japan" and *MLR*, Dec. 1987, Vol 110, No. 12 (for productivity figures)

- Lack of educational preparedness and retraining opportunities retard our efforts to boost productivity. Many studies argue for new emphasis on manufacturing processes in engineering schools, anticipating shifts in training requirements, and tightening relations between colleges and industry.
- U.S. industry has not aggressively and promptly deployed available new processes that are flexible and support rapid changes in product output. Better deployment of new process capabilities is required where rapid changes in production rates and product models are called for, and to support the growing trend toward customization of products and systems for individual users.
- We need more process technology experts. The pool of expertise must be balanced between citizens of the United States and noncitizens, who may be unable to serve in the defense sector of U.S. manufacturing.

TABLE 1
Manufacturing Shipments

	Dec. 87 ($B)	Δ 86 (%)
Food (S.I.C. 20*)	28.3	+ 5.4
Transportation Equiptment (37**)	27.0	− 4.4
Electrical Machinery (36**)	20.7	+10.7
Nonelectrical Machinery (35**)	20.5	+ 6.2
Chemicals (28**)	18.2	+10.5
Petroleum (29)	10.7	+10.8
Fabricated Metals (34)	10.4	+ 1.2
Primary Metals (33)	10.2	+37.2
Paper (26)	10.2	+15.1
Printing (27)	9.6	+ 5.5
Rubber and Plastics (30)	6.2	+11.3
Instuments (38)	5.6	+ 3.5
Lumber (24)	4.9	+10.8
Apparel (23)	4.9	+ 5.5
Stone, Clay, Glass (32)	4.6	+10.2
Textiles (22)	4.3	− 1.0
Furniture (25)	2.9	+10.8
Miscellaneous (39)	2.5	+10.8
Tobacco (21)	2.2	+ 3.5
Leather(31)	0.8	+ 5.4
Total Manufacturing	$204.5	+ 7.1

* Standard Industrial Classification/Figures are unadjusted for seasonal variation
Source: U.S. Department of Commerce
**Focus of preliminary analysis

SOURCE: Industry Week, 3/7/88

DEFINITION OF MANUFACTURING

Manufacturing industries in the United States are categorized by the U.S. Department of Commerce in the Standard Industrial Classification (SIC) Codes 20-39. This broad array of industries ships approximately $200 billion worth of goods per month and employs about 19 million people (see Table 1). In this discussion, manufacturing industries and companies, not factories, are the focus.

A traditional categorization views manufacturing as a stand-alone function, supported by other organizations such as product design, sales, distribution, and so on. Manufacturing accounts for about 20 percent of national employment, about 23 percent of total output, 60 percent of exports and 75 percent of imports. Manufacturing generates about 20 percent of the GNP.

Manufacturing Redefined

Manufacturing today must be regarded in a perspective sometimes called the "product-realization process" (the term used in AT&T). In this now widely understood view, the customer is at the heart of all the activities that result in a product, or service (see Figure 2). Manufacturing is no longer a stand-alone function but is instead seen as one element in an end-to-end process—from marketing or technological innovation, through product design and manufacture, to delivery and after-market service.

Systems engineering disciplines are used in the manufacturing process to bring major benefits in efficiency and shorter concept-to-customer intervals without significant financial investments. Critical to product realization are revised internal measurement systems that are customer based and customer responsive. A successful process is determined in the marketplace, not simply by meeting internal criteria.

Besides the product realization perspective, other factors also redefine manufacturing in the late twentieth century. Manufacturing industry now experiences growing dependence on real-time information transfer, software, unique materials, integrated circuits (including photonics), worker knowledge, and sophisticated process technology. Aggressively addressing these areas now will enable United States manufacturing to step decisively ahead. The application of manufacturing technology by itself will provide less competitive differentiation than at present. (We must nevertheless take better advantage of available new technologies than we now do.)

A new relationship between producers and suppliers is evolving to support higher levels of quality and customer responsiveness. Plants are being opened close to suppliers and customers in order to reap the economies of just-in-time procedures. In international markets in-country value-added regulations will continue to impact supplier decisions. The traditional supplier/customer model is changing to a partnership arrangement.

Manufacturing of all types will depend increasingly on the intellectual capabilities and skills of its workers. The "information trades"—specialists who can integrate information processing in a company or industry, and replicate those processes in global operations—are of growing importance. The information tools—for resource planning, accounting, just-in-time—will be less industry-specific and more generic, as the customer base becomes more global. Critically important will be the ability to facilitate technology transfer between individuals, companies, and geographic locations. A depository of information and an easily accessible system to permit acquiring the information will be of immeasurable value.

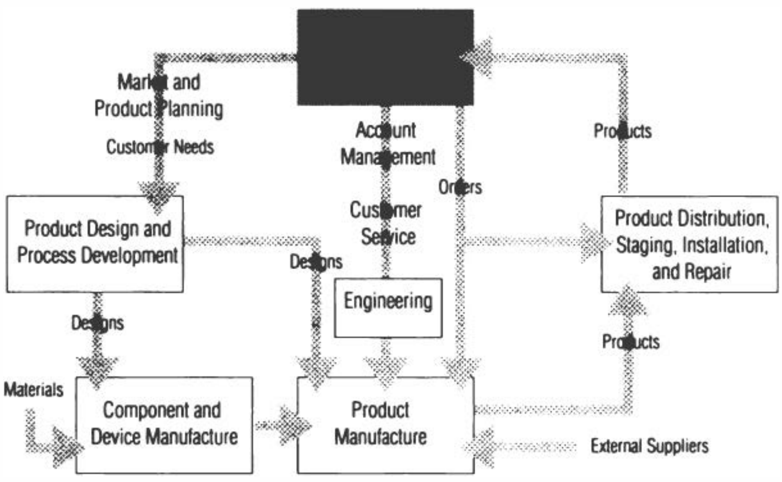
As assembly and fabrication costs improve, white-collar infrastructure costs and productivity must improve. All processes within a manufacturing company must receive rigorous scrutiny and undergo the discipline of quality and productivity initiatives.

Keeping Our Eyes on the Ball

It is possible to rationalize away the challenges faced by U.S. manufacturing. Recent positive trade and productivity figures may give an appearance that we have turned a corner—that perhaps there is no need to forge national initiatives. Missing in this conclusion, however, are a series of facts, including the following:

• Aggregate statistics are deceiving. A major shift out of declining industries has taken place. This has seemed to boost productivity

FIGURE 2
AT&T product realization system.



rates, but does not take account of the possible detrimental impact on long-term national interests.

• U.S. influence on the evolution of the world's industrial style (i.e., the equipment used, design configurations, standards and management) has diminished steadily. As a result, our ability to sell plant and industrial tools to other nations is lessened.

• Technological leadership is now generally distributed among companies and among nations. What leadership there is is more transient than ever. Thus, all industry is at higher risk now than in the past. For example, leadership in transportation equipment may depend on composite material leadership; leadership in communications equipment depends on photonics leadership; future power supply leadership may depend on leadership in superconductivity.

• Apparent gains in manufacturing productivity must be viewed in light of shifting currency levels, which lead to increases in volume and capacity utilization that may be transitory. Maintaining high utilization rates is not assured without progress in production fundamentals. Only this will allow the United States to compete internationally with a broad range of products and over fluctuating exchange rates.

- Employment in the growing service sector is rising, but this sector is intimately tied to manufacturing industries, not independent of them. The service sector exhibits less productivity growth than manufacturing and is ripe for further competitive inroads. Any reduction in our manufacturing base would have a broader impact on employment than in the past.
- Manufacturing capital investment is often delayed by fluctuations in, and uncertainty about, the tax treatment of such investments.

Comparative R&D Investment Today

R&D expenditures in the United States have risen in recent years, but from a manufacturing perspective the expenditure on process development, as opposed to research, is insufficient. A reapportionment of resources is called for.

The share of industry's investment in R&D expended for "development" fluctuates between 65 percent and 75 percent of a $65 billion total, that is, about $40 billion per year. Yet there appears to be insufficient spin-off to generate world class processes. This may in part account for the U.S. lag in innovation and time-to-market.

Japan today leads this country in R&D investment in several industrial segments (food, textiles, metals, rubber), and is closing the gap in others. The R&D intensity of manufacturing firms has risen faster in Japan than in the United States, although there is some evidence that domestic increases are occurring. Company-financed R&D in manufacturing was 1.3 percent of sales in Japan in 1970 and 2.7 percent in 1980. In the United States the figures were 2.2 percent and 2.8 percent respectively. Japan's rate of increase in R&D exceeds our own.

It would appear that what we do spend on R&D is not buying what we need. For example, large sums have been spent on robotics, but the results are questionable. Major investments in computers have also returned less than promised productivity. U.S. innovation is being openly questioned. Evidence suggests that the Japanese are often able to develop and introduce commercial products more quickly and less expensively than American firms.

Why does a nation using less automation than our own appear so productive? It is noteworthy that R&D in Japan is undertaken at the suggestion of customers and production workers twice as often as it is in the United States. This might indicate that R&D expenditures directly responsive to customer desires and supportive of the needs of production have immediate economic benefit.

In the United States, the Department of Defense is one entity with a demonstrated ability to move from research to development, with a commitment to improving and implementing new manufacturing processes, quality controls, and management techniques. Expansion of programs here could well serve the longer-term commercial interests of the United States.

CRITICAL TECHNOLOGIES FOR NATIONAL COMPETITIVENESS

There are four critical technologies that are, or will be, a basis for future U.S. competitiveness—materials, semiconductors, software, and process control equipment.

Materials

The world of advanced materials is changing drastically. In some cases, the United States has lost its international competitive edge. We increasingly depend on overseas suppliers of advanced or technologically critical engineered materials.

The new materials acquire their special value from integration into complex systems. For example, as an ingot, aluminum is worth about $1 per pound; shaped, it is worth about $5 per pound; but applied as a microconductor, its value rises to about $5 million per pound on silicon chips. The materials field suffers from a chicken-egg syndrome. It is too expensive for a supplier to develop a material for an application without a commitment by a user. But users do not commit without knowing what the material can do. Many U.S. firms are having difficulty justifying development costs and risks, and the United States is losing its domestic supplier base. From an industry viewpoint, what is needed is:

- A refocusing of education to balance the use of resources in research and applications.
- Development of related processes for high-quality, effective bonding, forming, and drilling.

- Stable administrative procedures to deal with questions of environmental hazards associated with material processing.
- Development of a methodology to support costly material process scale-up.

To ease the industry efforts under way, there are several roles government can play. These include:

- Focus on the issue of technology transfer in materials and related process technologies.
- Support advanced materials engineering in academia.
- Provide expanded support for materials consortia composed of industry and universities.
- Ensure a level playing field for both import and export of materials.
- Expedite release of classified information on materials, consistent with security needs.

Semiconductors

For the semiconductor industry a most critical issue is the inability of individual firms to fund adequately the broad range of supporting technologies. Among the efforts considered most important are:

- The development of alternative lithographic technologies that will allow the manufacturer to choose the most cost effective integrated circuit (IC) patterning technique.
- The development of fully automated flexible processing lines that provide rapid device and product turn-around times.
- The availability of packages that will bear multiple chips, and the supporting package technology, within five years.
- Accelerated improvement in test capabilities, including computer-generated test programs, networking of test systems worldwide, and broad application of built-in self-testing capabilities.

The semiconductor industry will continue to be a global industry. Influencing the locations of design and fabrication of semiconductors will be the cost of labor, the distance to technological leadership and educational institutions, and ease of access to controlled markets for select products.

Nationally based support of IC wafer fabrication, assembly, and test will accelerate the dispersion of IC manufacturing throughout Europe and Asia. Asian governments, such as in China and India, are willing to subsidize much of the capital required for a strong position in IC manufacture. Another influence on the location of tomorrow's design centers is the large proportion of trained university graduates relative to available jobs in the Asian countries, coupled with the relatively low investment for establishing IC design capability there.

To make way for the United States to regain a preeminent position in design and fabrication of semiconductors, several policy changes and legislative actions, in addition to corporate initiatives, are suggested:

- Continue to encourage joint partnership through favorable antitrust and tax legislation and R&D incentives.
- Provide appropriate incentives to facilitate the availability of capital necessary for investment in plant and people.
- Through combined government-industry-academic efforts, increase emphasis on education in IC design and manufacturing, and related software.
- Stimulate high school students to major in the sciences and engineering in college.
- Develop a government program to support industry education programs to augment university training in critical technical fields.

Software

As the software content of products and process expands, the need for software grows faster than industry's current ability to create it. Yet rapid creation and support of software are essential to meet such objectives as responsive product customization.

The development time for finished software is often unpredictable, and its cost often higher

TABLE 2
Potential Impact Matrix

	Process Development	Work Force Mobility	Software Skills	Base Technologies Development
PROGRAM GRANTS				
Universities	L	M	H	L
National Laboratories	M	L	H	M
Consortia	H	L	H	H
Private Industry	H	H	M	H
Primary/Secondary Education	n/a	L	H	n/a
INDIVIDUAL GRANTS				
Faculty	L	L	M	L
Fellowships	L	L	H	M
Student Loans	L	H	H	L
Capitation	L	H	H	L
DEVELOPMENT PROJECTS				
Military	H	M	H	H
Special Consortia	H	M	H	H
Industry	H	H	H	H
INCENTIVES				
R&D Tax Credit	H	L	H	H
Capital Investment Tax Credit	H	L	M	H
Cooperative Venture Relief	H	M	H	H

H=High M=Medium L=Low

than projected. For companies with a long history of using software, the costs can be highest of all, because they not only face the cost of software development for new activities, but must also support the maintenance of large volumes of software currently residing in working systems.

Software itself is complex and requires highly trained people to create it. There is a shortage of such skilled people. Opportunities to work around the shortage include: "open-systems" computing architectures; more modular construction of programs; improved diagnostic systems; greater functionality on ICs; and greater use of intelligent systems, thereby decreasing error carry-through. These are now being called CASE (computer-aided software engineering) capabilities.

The training of software developers today falls largely to industry itself. Better partnerships between industrial and academic communities would help increase the exposure of young programmers to industry requirements.

Process Control

The key to quality products is the ability to monitor and control all aspects of processes being used—in other words, process predictability. State-of-the-art process control is built around a combination of special-purpose hardware, high-precision sensing and effecting mechanisms, statistical quality control algorithms, software, mini and micro computers and multichannel information transfer networks, all assembled into an integrated system. The future of process control technology will be based on real-time computing as technology in the physical sciences brings this field along.

Enhanced process control grows more important as processing moves into suprahuman modes (tasks not executable by people).

An uninterrupted supply of world class process control equipment may require national initiatives in the form of incentives, use of the resources in our national laboratories, and support of consortia.

RECOMMENDATIONS

A U.S. public policy that supports essential technology building blocks would be useful. Specific recommendations are as follows:

1. *Stimulate process development and deployment* by fostering an atmosphere in which a significant proportion of available government and industry R&D expenditures is utilized for this effort. Parallel efforts can be taken to bring this to pass; first rebalance R&D funding to focus on this goal; second, support a program to facilitate related process technology transfer on a national level (consortia formation and capital investment incentives would help meet this need); third, provide financial support to help government and academic research personnel become familiar with industry's manufacturing facilities and needs.

2. *Enhance work force mobility* through innovative education and reeducation programs.

Government could support vocational retraining to prepare workers for change; provide financial incentives to industry and individuals for continued education; reimburse industry for broad national training programs; and improve basic primary and secondary education, emphasizing science and math.

3. *Support software R&D* by promoting software skills in schools and among the existing work force; providing resources to enable expansion of CASE projects; and increasing funding for software R&D in universities.

4. *Support materials and semiconductors R&D* by supporting industrial consortia; facilitating rapid release of related Department of Defense information consistent with national security; encouraging Ph.D. study by U.S. citizens; and providing incentives for industry research.

Who Should Act?

Public policy in the United States is decentralized and its tools are many. These include a range of program grants, individual grants, supported projects, and incentive programs. The tools are applied through institutions such as universities, schools, national laboratories, private industry, the military, industry groups, and the tax system.

Table 2 displays this information as a matrix with a range of policy tools and institutional tools on one axis and four areas of manufacturing in need of policy attention on the other. Each intersection marked with an H is a locus for programs that could have high impact in support of manufacturing competitiveness. In work force mobility, for example, effective programs might be mounted by private industry with grants and development projects, and through government student loans and grants to schools.

The range of tools is broader than shown here, and the areas for application of the tools undoubtedly more numerous. Further, the impact assessments indicated are subjective. But this matrix is a start on identifying national initiatives that show promise for U.S. manufacturing competitiveness.

Final determination of the elements of a national policy should be based on more quantitative evaluations of potential impacts of specific programs. Further deliberation by a national resource such as the National Research Council Manufacturing Studies Board could refine and augment plans for initiatives and develop a better assessment of the advantages of each.

CONCLUSIONS

Initial deliberations suggest that a national manufacturing initiative aimed at sustaining 10 percent productivity improvement per year, along with an international trade initiative aimed at a level playing field, would be useful. A manufacturing initiative must address the real performance needs of industry. Public programs that stimulate manufacturing process development and deployment, enhance work force mobility, strengthen our software R&D skills base, and support essential underlying materials and semiconductor technologies would be the elements of a manufacturing initiative. As this work is based on discussion with a limited set of U.S. industries, additional study is recommended.

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Reorganizing Production to Restore Competitiveness

Stephen S. Cohen and John Zysman
with Sabina Deitrick

Fundamental changes in the international economy are reordering the hierarchy of wealth and power among nations, and the United States is not navigating this transition very well.

Two sets of basic forces are driving the transition. The first set consists of fundamental changes in both the extent and the nature of international competition confronting American producers of almost everything from semiconductors, to autos, to financial services. A generation ago foreign competition was a marginal phenomenon in the U.S. market; today upwards of 70 percent of everything we make is subject to direct (or imminent) foreign competition. We face not just a sudden increase in the extent of competition but a significant change in its nature. The change is not just from the Atlantic to the Pacific as the common shorthand has it. Rather it concerns America's response to the challenge of the Developmental State—a new set of arrangements among government, society, and industry designed to change the structure of a nation's comparative advantage in international trade. It was first, and most effectively, developed in Japan, but is now being imitated, with varying degrees of success, in country after country.

The second set of forces consists of fundamental changes in the organization of production, extending from the shop floor through corporate, institutional and societal arrangements for production. Its emblematics are flexible production as opposed to standard, mass production; total quality as opposed to a trade off between quality and cost, and "just in time," and accelerated product cycles. This "soft" or organizational change is reinforced in its impacts by a simultaneous change in the technology of production, consisting essentially of the advent of microprocessor-based technologies in the production of everything, from watches to computers to insurance policies. All these forces interact and magnify one another. The intensified competition drives the changes in production, which in turn create yet newer competitive pressures. Old advantages erode, new ones compound. And it all moves very quickly. Not long ago it took more than 25 years for industries to move from world leaders to basket cases; now the transformation is being accomplished in five.

In this paper, we maintain that weaknesses in manufacturing capabilities have been at the heart of America's eroding competitiveness. It has not been the unique cause, nor is it the single remedy. Macroeconomic difficulties—feeble savings rates, and a severely overvalued dollar—played major roles in turning a manageable problem into a national emergency. But although macroeconomic solutions are necessary to any sustained improvement, without a focus on major improvements in the production process, America will not be able to reassert its economic primacy. The wealth and power of the United States depend, as never before, on a major reorganization of production.

Although the exchange rate has been brought back down, and some "good numbers" are beginning to appear, we have not solved our problem. Instead, what we have done, at great cost, is to open the possibility of addressing those problems. That window will

This paper draws heavily on Stephen S. Cohen and John Zysman, *Manufacturing Matters: The Myth of the Post-industrial Economy* (New York: Basic Books, 1987) and Stephen S. Cohen and John Zysman, "Manufacturing Innovation and American Industrial Competitiveness," *Science*, 4 March 1988.

not stay open very long. Other countries have forfeited the advantages of a devaluation. We must not assume that a similar unhappy fate cannot happen to us.

American wealth and power rested on the preeminence of American manufacturing. America produced goods, in vast quantities, that other nations simply could not produce competitively. That was the basis of our fabulously high wages, whole number multiples of those paid by our best competitors. Our manufacturing preeminence in turn was rooted in a particular organization of production: mass production. Innovated in the late nineteenth century and perfected in the first half of this century, American mass production was the most successful production organization the world had ever seen. It won the war; it won the peace. It was the envy of the world. And after the war everyone else, the Japanese, the French, and the Germans set out to copy it and catch up with their future. What actually happened was not so much faithful copies, but something quite different. New forms emerged from efforts to follow America's need in radically different environments. These innovations in production have substantially changed the terms of competition and introduced new models that accelerate cycle time, heighten product differentiation, and oppose economies of scope and flexibility to traditional economies of scale.

THE SHIFTING COMPETITIVE ADVANTAGE IN MANUFACTURING

The most obvious sign of U.S. weakness is the trade deficit, which climbed to a record $173.7 billion in 1987, while our major high-wage, advanced-technology competitors (Japan and the Federal Republic of Germany) ran massive surpluses. Despite substantial improvements in recent months, the trade deficit has not reversed nor has it even dropped as sharply as expected, given the extent and the duration of the dollar's decline. Further devaluations are not the answer. There is, of course, some exchange rate that will balance not just our trade account but also our commercial account (which includes the interest we now must pay to foreigners on our massive debts to them). But a steadily declining dollar translates as a steadily impoverishing and weakening America. It is not the policy objective; it is the price of inappropriate response.

In 1971 the United States ran its first merchandise trade deficit in this century. The Nixon administration responded to this unprecedented event by removing fixed exchange rates and devaluing the dollar. Macroeconomic policy worked; exports grew against imports. By the late 1970s, however, the trade account turned negative again, while the dollar remained low against the major competitors' currencies. Clearly, something more fundamental than exchange rate misalignment was affecting America's competitive performance.

Many often point to the strengths of American high-technology industries as offsetting deficits in other industries. But high technology cannot answer our trade problems; high-technology goods are not something separate from manufacturing—high technology is a part of manufacturing. The Germans have successfully adopted new technologies to traditional manufacturing production, and, with their high wage economy, are a world leader in "traditional" manufacturing industries such as machine tools, chemicals, and automobiles. A Japanese steel plant does not look "low tech" with its sophisticated control systems. High-tech intermediate goods such as semiconductors depend on downstream markets for sales, both high-tech computer sales and traditional industrial and consumer electronics markets. As has already happened in the United States, without domestic production in a final market such as consumer electronics, semiconductor makers lose access and then even the ability to manufacture devices for that market located abroad.

Furthermore, and critically, America's competitive advantage in high technology has decreased, not increased, from the late 1970s, as both industrialized and developing countries continue to close the technology gap (Carvounis, 1987, p.18). The U.S. trade balance in high tech dwindled from a surplus of $25.5 billion in 1980 to the first deficit in 1986. In high tech the United States runs a deficit with Japan and the Asian "Four Dragons"—Singapore, Taiwan, Korea, and Hong Kong—while maintaining a surplus against Western Europe as a group and Canada. Also important to consider are sectoral subgroupings: in high tech, aircraft exports often conceal trade deficits in other critical industries, such as semiconductors and computer peripherals, and the equipment to make them.

While the U.S. deficit continues in the face of a lower dollar, our competitors maintain trade surpluses with rising currencies. Japan, in particular, has succeeded in increasing its exports and expanding in overseas markets, even with a doubling in the value of the yen in relation to the dollar over the past two years. From this point of view the Federal Republic of Germany has also been doing quite well.

Japanese producers are succeeding in a situation in which U.S. firms failed. In contrast to the American experience a few years earlier, to compensate for the rapidly rising yen, Japanese firms increased, rather than decreased, their investment in manufacturing systems to boost productivity gains. Furthermore, the Japanese were able to carve out market shares earlier when the value of the dollar was high relative to the yen, and now, to protect those markets, have introduced new products and cut profits to maintain those shares. To be sure, many Japanese firms have lost money in some segments and relocated some production offshore, some to cheap labor sites, more to high-cost sites such as the United States to leap over anticipated import barriers. But these cheap-labor moves should not be mistaken as revealing the Japanese long-term response. Japanese firms are not following the example of American producers, who fought cost battles by seeking to cut labor costs, especially direct labor, rather than seeking to change production itself. The Japanese have shown that they can produce and be innovative in a high wage location, much as American producers did 30 years ago, and that their competitive advantage rests on manufacturing innovation. For America the solution to balancing trade accounts while maintaining our wealth and power lies not just in exchange rates and macroeconomic policies, but in something more fundamental to the working of the economy and production.

We argue here that in recent years, other nations have introduced innovations to the production process that have enabled them to produce more competitively than the United States. These innovations began as small adaptations of traditional production methods, tailoring best practice to the constraints, strengths, and social institutions in those nations. They do not encompass radically new tools or automated lines as much as a reorganization of ideas, people, and production methods.

These organizational innovations have proceeded gradually, but their impact has threatened American firms sharply in just the past decade or so. Only with dramatic losses of market share in certain industries—beginning in industries such as consumer electronics and continuing through steel, shipbuilding, automobiles, and machine tools to such high-technology sectors as semiconductors—have producers in the United States begun to consider the nature and the import of these changes.

How have these changes come about, and why has the United States been so slow to respond? Even for a brief answer, we must step back to an earlier period, when firms in the United States built their manufacturing capabilities on a set of institutions that developed during a different era of capitalism. Beginning in the early nineteenth century with the introduction of interchangeable parts for guns at the Springfield Armory, American firms forged a system of mass production that reorganized capital and labor and swept away artisan and craft work in many industries. By the time of Henry Ford's moving assembly line for the Model T, the modern mass production system had begun to take hold in a wide range of industries. Coupled with the rise of scientific management, modern mass production generated greater specialization of production and further subdivided labor within the plant (Chandler, 1977, Parts III and IV). The new system revolved around the management of people, referred to as Taylorism, and control of markets and production strategies, Fordism. The system focused on volume production of standardized products for a relatively homogeneous market. Volume allowed the specialization of tasks, both for machines and for people. The steady increase in specialization and the growth of new functions within the firm such as distribution and marketing eventually resulted in a brilliantly successful new form of enterprise, the hierarchical, divisionalized corporation.

The modern American company emerged after World War II powerful and positioned to dominate the world economy. The system defined the lines along which technological advance would proceed, and technological advance steadily improved the system's performance. Despite new technologies and new industries developing during the past 40 years, the basics remained entrenched.

Why did the system congeal? First, of course, because it not only worked but worked better than anything that came before or anything elsewhere. It was simply the best production system in the world. It defeated Fascism abroad; it won social peace at home. It was the model for every nation in the world. And it was improving steadily. That is a powerful first reason. There were several secondary reasons for its stubborn stability. A great many dominant industries such as automobiles and steel had become stable oligopolies with mature, sluggishly increasing demand and high barriers to entry. These structures diverted competition from basic change in production or technology into marginal changes in product, price, and style. Also, complex social structures are robust. The production structure had developed elaborate systems of labor relations and comparably complex systems of management training, organization methods, and reward. Massive forces ranging from unions through business schools (a product of this period) had invented themselves and structured themselves around the basic design of that production system. Changing it would mean changing them. The mass production paradigm was not going to change without the shock of innovations from abroad. That shock took a long generation to come; when it hit, it hit hard.

CHANGING THE MASS PRODUCTION PARADIGM

Two innovations in particular made the difference. The first consists of a new and active role for the state in systematically developing industry and in seeking to directly change the structure of the nation's comparative advantage. As mentioned above, Japan is the premier example but not the only case. (For the role of institutions and economic development in Japan see Johnson, 1982.) Here, the government instituted a set of policies to promote investment over consumption, target strategic industrial sectors through state-steered financing, and, crucially, protect domestic producers from foreign competition.

The second form of innovation is the focus of our attention. Its effect is to turn the manufacturing process itself into a source of advantage. The emblematics of the production innovations are carried by code words such as "flexibility," "just in time," and "total quality." These both suggest and obscure concrete changes in the way goods are designed and produced. In the best firms these innovations extended well beyond the shop floor to the nature of the product, beginning with a design concern for manufacturability and extending to a corporate decision process in which anticipated economies of scope could justify investments in new technologies that are difficult to justify through more traditional criteria but figure in the firm's strategic positioning against its competitors. In this light, just in time reduces the costs of carrying expensive inventories at every stage of production; these cost savings can be quite significant, and they are calculable by traditional methods. But the decisive advantage of just in time is not to be found by the methods taught in U.S. business school and practiced in American corporations, that is, through quantification of reductions in inventory carrying costs. Just in time means, fundamentally, a new relationship with suppliers, something quite different from the traditional Detroit whipsaw, and the most significant benefits realized take the form of continuing improvements in quality and accelerations of product cycle time. Reduced cycle time creates not marginal pricing advantages, but decisive strategic advantage. Japanese automakers have substantially benefited from their huge advantage in cycle time over their American competitors.

In industry after industry and product after product the Japanese used manufacturing advantage to gain market share, market share to further enhance manufacturing advantage, eventually dominating industries that only shortly before seemed impregnable. After all, in 1962 Detroit produced more automobiles in one week that Japan produced in a whole year; today Japan produces more automobiles than the United States.

Initially American firms attributed the Japanese advantage to low-cost labor. The response was to seek even cheaper labor—offshore. As a competitive strategy, relocating production offshore proved to be the wrong solution to the wrong problem derived from the wrong analysis. It assumed that the competitive problem was direct labor costs and attacked at that point. But labor costs were only one element—and a rapidly shrinking one—of the Japanese advantage. Indeed in many of the industries that ran offshore for cheap labor, direct labor was only about 20 percent of cost, at most, and often a good deal less. As many producers were to realize soon, but nonetheless, too late, the Japanese advantage hinged more on production organization than on low-wage labor. The American consumer electronics industry was an important leader in this downward direction, moving production offshore, lobbying successfully for special legislation to protect its reimports, and blinding themselves to the reality of their competitive problem until a dominant industry was effectively wiped out. For as American firms shifted production to low-wage sites in Asia and Latin America, they accelerated their own downward spiral. First the cheap labor solution permitted them to ignore the need to rethink their production organization. It bought time, not for a long-term competitive response, but for the Japanese competitive advantage to cumulate beyond reversal. This strategic debacle affected not only the consumer electronics industry but a broad set of other industries such as semiconductors, which would have been a very different case of industrial history had the Japanese not wrested dominance in consumer electronics, and used it as the key to the mastery of volume production in semiconductors. Moving production offshore further reduced the manufacturing infrastructure of the United States not only by relocating jobs overseas, but by helping to develop systems of suppliers, subcontractors, and technology transfer to the overseas locations.

In our best competitor countries, especially in Japan, rapid industrial growth afforded firms the opportunity to invest in new machines and new production methods. But the introduction of a new machine does not necessarily guarantee productivity gains. Installing new machines is the second part of the story; reorganization of production must come first if the machines are to live up to their potential. In many U.S. companies, the machines were installed, often at colossal expense, but the painful organizational questions were sidestepped. General Motors spent "more on automation than the gross national product of many countries," (Stephen G. Payne, quoted in Business Week, 6 June 1988, p.100) but the benefits have yet to be realized. In contrast, GM's joint venture with Toyota, the New United Motor Manufacturing, Inc.(NUMMI) plant in Fremont, California, is one of GM's most productive plants; the plant's success stems from its changed labor relations and reorganization of production on the line, rather than the implementation of the most automated equipment (see Turner, 1988).

FLEXIBILITY IN MANUFACTURING

Mass production is inherently static. More important the managerial methods and calculations to which it gave rise and which are so deeply embedded in American business schools and corporate practice are also static. Production dynamics are not. When mass production competed with artisanal and batch production, its static approach did not matter; its revolutionary power obscured the problem; the efficiency advantage was overwhelming. Today, however, greater uncertainty in markets and technology rewards flexibility in manufacturing rather than static approaches. American management is clinging to its static, quantitative methodologies and the standard, mass production approach.

A study by Jaikumar (1988) demonstrates this contention more concretely. Comparing both Japanese and U.S. flexible manufacturing systems (FMS), the author found that for making comparable products, the Japanese and American firms used almost the same number of tools—six in Japan, seven in the

United States. From those tools, however, the Japanese made an average of 93 parts, compared with 10 in the U.S., while the average volume per part in the U.S. was 1,727 against only 258 in Japan. The American firms essentially applied the new flexible tools to their old inflexible style of manufacturing, while the Japanese used the tools to develop and produce a flexible range of products. The author concluded that the use of FMS in the United States showed a basic lack of flexibility in use (Jaikumar, 1986, p. 69). The American firms used the new tools to improve economies of scale—lowering the cost of production through increasing output. The Japanese firms increased production and efficiency through economies of scope—increasing production in a range of goods.

Some, even many, American firms, and industries, are attempting to produce more flexibly. The era of static, mass production has not ended, but a shift to more flexible production has helped the competitiveness of some firms. Companies such as Allen Bradley and Black and Decker have embarked on new production strategies to reduce costs and improve designs. There are examples in other companies ranging from Hewlett-Packard, to Cincinnati Milicron, to IBM, to Timken Roller-bearings, and even, uncharacteristically, to particular product lines at General Electrics such as circuit breakers. In the semiconductor and computer industries, several firms are working out new kinds of relations with their components suppliers and with equipment makers. In the semiconductor industry, for example, Cypress Semiconductor, a small firm specializing in fast, high-performance semiconductor devices, produces 74 products in 80 different packages down one line in an integrated production facility designed for flexibility and rapid turnaround. The Sematech agreement aims to promote manufacturing and production technology in a joint arrangement among semiconductor and equipment firms. Examples abound, and every day there are more. But contrary examples also abound; it is still too early to know whether these examples trace an important trend or catalog heroic but isolated cases.

Flexibility, then, is a key to competing in today's markets. Innovations such as programmable automation allow a machine to perform a range of tasks through software changes. This flexibility allows for economies of scope in the production process—producing a set of goods on a common line—something Seiko does in producing three new watches per day. Economies of scope are to flexible production what economies of scale are to rigid mass production. Often, however, economies of scope and economies of scale move together, with large-scale plants allowing both volume production and product variety. In the semiconductor industry, the cost of building a production line has risen at least two to three times in 10 years, while at the same time, more and more devices are user-specific products and not standardized. Firms cannot afford to invest solely for economies of scale, since products may change rapidly and they may never produce a large enough volume to realize their investment; they need to build plants that can accommodate changing chip designs, requiring a flexible approach to manufacturing.

We should distinguish between two different notions of production flexibility. Static flexibility refers to the ability to adjust operations at any moment to a rise or fall in market demand. Firms make adjustments within a fixed product or established production structure, with labor being the most flexible way firms can adjust their output within a static framework. For American firms this implies layoffs; Japanese firms use a wage system—lump sum bonus payments —to adapt. Dynamic flexibility, by contrast, allows firms to increase productivity by improving the production process and change products quickly. The advantage for firms is to get to the market quicker and stay ahead of the competition.

Some discuss these changes in terms of a historical shift in production. Although most production has always been done in batches, the prevalence of mass production has prompted the placement of technical issues in historical context. Henry Ford's assembly line became Fordism—a type of mass production, and simultaneously, a social organization of production. Subsequent developments reverting to batch production have been labeled post-Fordist, or using general purpose tools to produce a variety of products. Some contend that this technological shift will reorganize the structure of firms in an economy to favor smaller firms competing in market niches over large firms in mass markets (Piore and Sabel, 1984; Sabel, 1982). There is, however, nothing in the notion of dynamic flexibility that negates scale economies, especially the advantages of size in marketing, financial staying power, and the capacity to invest in expensive machinery. A new romanticism focusing on small firms is not necessarily prudent. We must remember that Matsushita and Seiko are leaders in both flexibility and scale. Of course nothing is certain. But in today's environment, firms rooted in a social organization of production of the past are finding it increasingly difficult to compete.

TOWARD A NEW KIND OF INDUSTRIAL ECONOMY

We have argued that the world economy is in the throes of a basic transition, propelled by basic changes in the extent and nature of international competition and by revolutionary changes in both the organization and technology of production. These changes are profoundly affecting the U.S. economy and revealing weakness in an organization of production that propelled the country into world dominance but now threatens to leave it lagging. We see a fundamental weakening of America's productive capacity, a weakening in its ability to regenerate and innovate and subsequently in its competitive position.

Traditional explanations may appeal to some, but we are not solaced by them. Some of these have become the basis for policy decisions, despite a lack of evidence or even the presence of contradictory clues. For instance, the United States cannot expect to continue to lead in technological developments if it no longer produces the products that embody those technologies. Many industries already serve as examples in which we first lost our competitive position and then lost our technological lead. We used to produce steel and export steel engineering services; we now import both. In consumer electronics, relocating production offshore meant that American producers lost out on the next generation of products, notably the videocassette recorders and compact disc players. In both cases, we lost the "rent" on innovation that enables a firm to increase sales volume in a new product and invest in R&D for the next-generation product.

Moreover, the United States is not experiencing a transition from an industrial to a postindustrial, service economy, as some may argue. This is explanation by false analogy, comparing a shift up and out of industry and into services to an earlier shifting out of agriculture and up into industry. The earlier shift never occurred. We did not abandon agriculture or relocate it offshore; we automated it. We shifted labor off the farm and added massive infusions of capital, technology, and education as we steadily increased output and productivity. Industry now requires the same investments in capital, labor, education, and technology. We argue that millions of high-paid service jobs are complements to industry, not substitutes, and if we lose industry, we will lose, not increase those service jobs. To revert to the agricultural analogy, but in a more accurate form, the crop duster is not an agricultural worker; he is a service worker. Move the farm offshore and you also move the crop duster, the winery, the large animal vet, and the harvesters. These jobs, though classified as service jobs, are in reality "tightly linked" to agriculture. They are complements to agriculture. It is quite the same in industry, but on a vastly larger scale. The economy is becoming less gritty. More and more people work in something closer to offices than to dirty, noisy factories. But there is no such thing as a postindustrial economy. The solace such a myth affords us is false. We are in a transition not from an industrial to a postindustrial economy but toward a new kind of industrial economy.

That the economy is changing in fundamental ways is clear; what is less clear is what our responses should and will be. We cannot simply copy our best competitors, establish an American Ministry of International Trade and Industry, and merge Citibank, AT&T, and

General Motors into an American Keiretsu. We can, however, learn from them and adapt. We must realize, however, that our choices are sharply constrained: Future options rest on past decisions, and our opportunities are limited. First, we must not accept the notion that to compete internationally firms must cut wages. Our best competitors—Federal Republic of Germany, Sweden, Japan—pay wages equal to or higher than ours. The trick is to promote productivity increases, to sustain high and rising wages. Second, a retreat to blanket protectionism is short-lived at best and does not encourage reorganization among less-than-competitive firms. Third, to generate broad support for a national commitment to growth and innovation, we need policies that reduce inequalities rather than foster them.

The opportunities afforded us are likewise constraining. Today, information and technology flow easily across borders; advantages lie not just in developing that knowledge, but in diffusing it throughout the economy and exploiting it through product and production innovation. Both labor and management can help realize these possibilities. If we cannot keep pace with our new competitors, we could find ourselves in a long cumulative economic decline that ultimately threatens the wealth and power of the nation.

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A Nation at Risk: Our Eroding Skill Base in Manufacturing Systems

Joe H. Mize and Terrence G. Beaumariage

The United States has experienced many crises and has thus far been able to respond successfully to the accompanying challenges. Today, the United States is facing a crisis that is fundamentally different from those in the past, and there is no assurance that we will be successful in responding to the current challenges.

The crisis facing the United States today (and at least for the remainder of the twentieth century) is that it has lost its position of dominance in global competition for the sale of manufactured goods. The evidence is clear. Listed in Table 1 are several industries that were once dominated by U.S. companies but are now dominated by non-U.S. firms. Many of the product groups listed in Table 1 are not manufactured in the United States at all. Many of those carrying American names are actually manufactured abroad and sold under the U.S. label or through a U.S. distributor.

U.S. firms in several other critical industries are also experiencing an alarming loss of market share. The problems of the U.S. automobile industry have received widespread publicity. Other industries that are being threatened include aircraft, computers, gas turbine engines, a wide variety of electronics, and precision instrumentation.

For several decades following World War II, U.S. companies were able to compete on the basis of superior quality, lower cost (because of much higher labor productivity), and a significant lead in research and development. Figure 1 illustrates the relative strength of the United States and other industrial nations over much of the twentieth century. For several decades following World War II, the U.S. had very little competition.

Concerns began to surface during the 1970s, when a few observers became aware that many nations were rapidly closing the gap between themselves and the United States in terms of such important measures as labor productivity and per capita gross national product (GNP). A frequent response to such concerns was that we should not worry, because as the other nations closed the gaps, their rate of closure would decrease. They would find, as we did, that incremental gains are much more difficult as the absolute values of these measures increased. Furthermore, as these other nations become more affluent, their motivation to continue improving would lessen, as ours did once we had achieved widespread affluence.

Unfortunately for the United States, the other countries were unaware of these "natural laws of economic behavior," and in their ignorance continued striving for improved performance. The story is now clear. In 1986 Canada surpassed the United States in labor productivity, with three other countries now on the verge of doing the same. In 1987 Japan surpassed the United States in per capita gross national product.

TABLE 1
Some U.S. Industries That Have Lost Market Dominance

Bicycles	Semiconductors
Binoculars	Sewing machines
Cameras	Ships
Castings	Shoes
Clocks/watches	Steel
Machine tools	Tape recorders
Motorcycles	Telescopes
Radios	Televisions
Robots	Textiles

Figure 2 shows the approximate relative performance of the United States, Great Britain, and Japan over the past 130 years in terms of per capita gross domestic product. Over the period 1870 to 1913, the annual average GNP. growth rate of the U.S. exceeded that of Great Britain by only one percentage point, yet that difference was enough to move the U.S. past the leading industrial power of the nineteenth century (Landau, 1988).

Since 1979 the annual average GNP growth rate of the United States has been about 2.2 percent where as that of Japan's has been about 3.8 percent. Although this difference may seem small, over an extended period of time it has a dramatic impact, as shown in Figure 2. In 1987, the output of goods and services for each member of Japan's population was $19,642 compared with $18,403 for the United States.

WHAT "SOLUTION" ARE WE SEEKING?

Clearly, the United States is faced with a crisis regarding economic competitiveness. There is no single, simple solution. There is nosingle source or institution to which we can turn for answers.

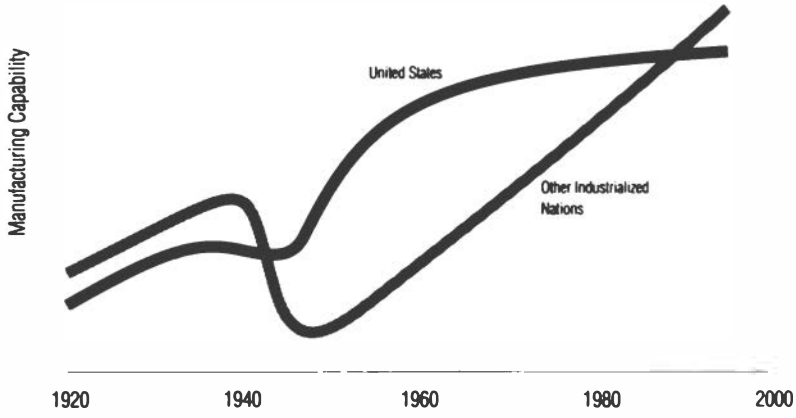
Exactly what "solution," or "answer," are we hoping to find? Does any clear-thinking person really believe that the United States canregain its position of overwhelming dominance in the world economy?

We must be realistic. The forces shaping economic trends have shifted in irreversible ways. The United States will never again enjoy the unchallenged position of economic dominance that it occupied for some 30 years following World War II.

The solution, or answer, we are seeking, therefore, is not how to regain dominance but *how to avoid falling from the ranks of the leading economic powers*.

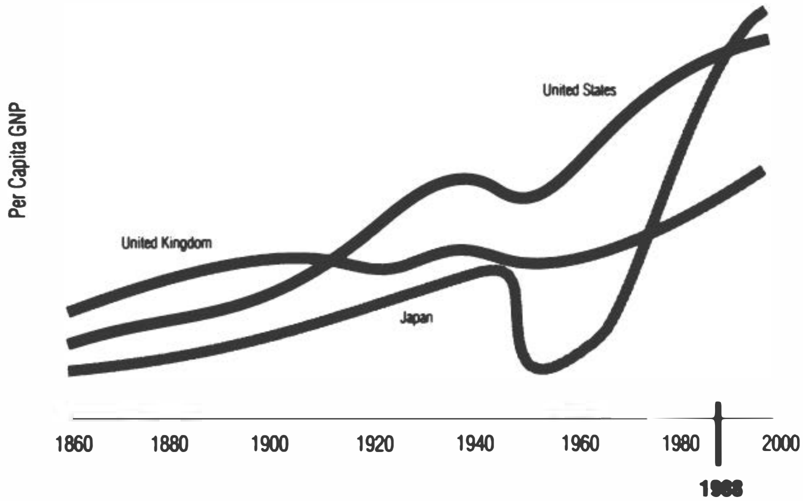
We should not be disturbed by the prospect of being one of several leaders. Indeed, we should be somewhat relieved that other nations are becoming economically strong enough to assist us in providing economic and defense assistance to developing nations. *What we should be disturbed about are the persistent signs that we may be losing our ability to remain competitive in an increasingly discriminating world marketplace.*

FIGURE 1
Manufacturing capability of the U.S. vs. other industrialized nations.



SOURCE: James J. Solberg, Purdue University

FIGURE 2
Approximate relative performance of three global competitors.



ARE WE UP TO THE CHALLENGE?

What will be required for the United States to reverse its decline relative to the leading industrial nations? Lester Thurow (1985) has said, "In many way what is needed is the moral equivalent of defeat" to cause us to take the difficult steps that will be needed across all segments of U.S. society if we are to correct our deficiencies and remain among the economic leaders of the world.

The United States has always responded well to crises. In fact, it can be argued that this national characteristic is both our greatest strength and our greatest weakness.

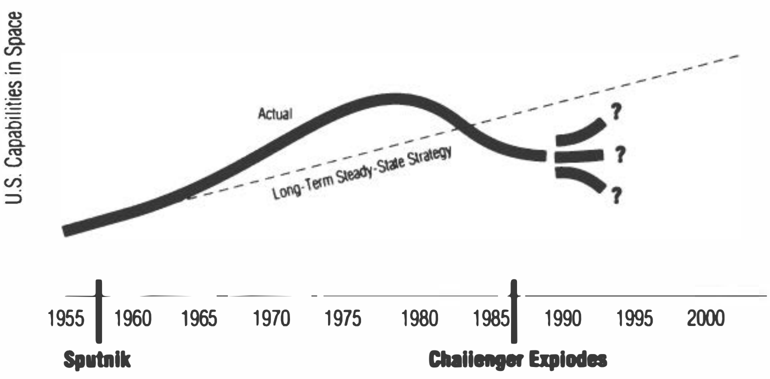
We are basically a nation of problem solvers. We would be wise to shift our emphasis to problem prevention. We tend to allow problems to grow to crisis proportion before we respond, and then we too often overreact for a short period of time and fail to sustain the gains that were made.

Consider the U.S. space program. This program was underfunded until we were shocked when the USSR launched Sputnik in 1957. We then marshalled our resources and spurted far ahead of the Russians for a few years. The Apollo Program successfully took Americans to the moon and back by 1969, only 12 years after Sputnik. The U.S. lead in space seemed insurmountable. Hundreds of thousands of highly skilled engineers, scientists, technicians, and technical managers formed a technical force the likes of which the world had never seen (and may never see again). Today, two decades later, we have difficulty conducting routine launches.

This situation is portrayed in Figure 3, along with a dashed line that shows where we might be today if we had pursued a long-term, steady-state strategy regarding our space program. Again, we seem to prefer crises to stable programs.

The reward structures within individual companies also reflect the crisis mentality. Problem solvers are rewarded as heros, while problem preventers have difficulty selling their conceptual ideas to management. Consequently, our large discrete-part manufacturing plants are still run by armies of expediters who storm through the factory with "hot lists," playing havoc with the shop schedules that had been carefully constructed by the problem preventers. Guess who receives the highest rewards?

FIGURE 3
U.S. capabilities in space: Actual performance vs. alternative strategy.



WE DO NOT NEED ANOTHER CRASH PROGRAM

Too many of the "solutions" being proposed to the United States competitiveness problem are simply additional products of our collective national mentality favoring crash programs, or quick fixes. Crash programs are necessary to respond to events such as wars, natural disasters, and disease epidemics. They are invariably counterproductive for long-term, fundamental activities. After the euphoria is gone, they simply cannot be sustained over long periods of time.

On rare occasions, the United States has shown that it is capable of conceiving and sustaining long-term initiatives. A specific example is the land-grant university system initiated around 1860. The Agricultural Extension Service has been well funded for more than a century. The results have been nothing short of astounding. In fact, the entire system of higher education in the United States is the envy of the world.

Another example of a successful long-term initiative is the National Science Foundation (NSF). Scientific and engineering research has been funded on a sustained high level for several decades. Many other countries have attempted to model their science mechanisms after the NSF, but none has achieved the same degree of success.

FRAMING THE ISSUES

There are many dimensions to the set of issues that must be addressed in order for the United States to retain its competitive position in world markets. It is advantageous for the present discussion to classify the issues into two groups; those over which individual firms have full discretion and control, and those that are outside the control of individual firms. Table 2 lists several major issues in each category.

Many of the issues external to individual firms are discussed in the accompanying briefing papers by the other three authors. For the remainder of this paper, we will restrict our attention to some of the more critical *internal issues* which we believe must be addressed. Again, by "internal issues," we mean those things that each U.S. manufacturing company must address on its own, and over which it has essentially full control.

FUNDAMENTALS OF COMPETITIVENESS

All the factors of competitiveness listed under external issues in Table 2 will affect all U.S. firms equally at any particular time. All firms have access to the same work force, face the same tax structure, and have the same access to fundamental scientific breakthroughs. Given a particular set of external conditions and factors, the competitiveness of an individual company is determined by how it addresses the internal competitiveness factors listed in Table 2.

A company's competitiveness is determined by how well it meets the needs of the market relative to other companies competing in the same market. There are only four fundamental ways a company can improve its competitive position in a given market:

- Lower the cost of the product.
- Improve the quality or functionality of the product.
- Improve customer service, e.g., schedule performance.
- Differentiate the product line.

TABLE 2
Issues Affecting Global Competitiveness of U.S. Firms

Issues Internal to Individual Firms	Issues External to Individual Firms
• Commitment to excellence	• Quality of education in work force
• Responsiveness to market dynamics	• Production vs. consumption incentives
• Product development/design	• Tax structures
• Climate for Innovation	• Basic research infrastructure
• Process development/design	• Equal access to world markets
• Capital investment	• Industry-wide technology transfer mechanisms
• Strategic management	• Regulatory climate
• Operational management	• Broad, sweeping social changes
• Personnel development/training	• Fundamental scientific breakthroughs
• Reward problem preventers	
• Return on assets, long-run	

These four factors are the superordinate key result areas for any manufacturer. There are several subordinate key result areas, such as productivity and return on assets. Each of the internal factors listed in Table 2 can be associated with one or more of these four generic key result areas.

It follows, then, that the U.S. industries listed in Table 1 that have lost market share performed relatively poorly on the four generic key result areas of cost, quality, service, and differentiation. Our major concern at the present time is to determine how current U.S. firms can maintain or improve their competitive position through continually striving to improve their performance on the four generic key result areas.

Life would be simpler and easier if a company could concentrate on one or two items to improve its performance. Unfortunately, the real world of manufacturing is very complex.

A company's competitive position is improved whenever a worker discovers a way of reducing set-up time by three minutes; when an industrial engineer rearranges the work flow to increase manufacturing velocity by 7 percent; when a design engineer reduces a subassembly from 17 discrete components to 12; when a purchasing agent concludes an agreement with a vendor to place orders electronically; when the quality control department certifies the manufacturing process of a vendor to eliminate incoming inspection; when a new computer system is installed, permitting a significant increase in data accuracy; when a robotic paint-spray cell is installed to achieve uniform coating of paint. The list is essentially endless.

It is clear that the "competitiveness battle" will be won (or lost) by individual companies doing (or not doing) a wide variety of things required for continuing, never-ending improvement.

Far too many U.S. managers are desperately groping for "the secret" of manufacturing competitiveness. There seems to be a collective national mind-set that slogans, gimmicks, and fads will prove to be "the answer" to all our problems.

The only "secret" is that *there are no secrets*. Improved performance on cost, quality, service, and differentiation is the cumulative result of long-term relentless efforts to improve performance continually in all areas. To be successful in such efforts, a company must understand and practice the fundamentals of systems improvement. Athletic teams win national championships by flawlessly executing the fundamentals time after time. National championships are never won with trick plays, slogans, or gimmicks.

Similarly, the "secret" of Japan's success is not that it has implemented robots more widely than in comparable U.S. firms, but that it has a better understanding of the fundamentals of manufacturing competitiveness and the discipline to achieve flawless execution those fundamentals repeatedly.

Even among those U.S. firms who are aggressively modernizing their companies, there are many managers who are under the impression that they are engaged in a one-time, discrete initiative, with a recognizable completion state (and date).

It will not be that way. Factory and company modernization must be recognized as a continuous, ongoing process, with between 20 and 30 percent (depending on the industry) of all processes and systems being replaced annually. While a company is implementing major changes, its forward planning group should already have a fairly concrete idea of even more advanced systems that will replace those being installed today.

CAUSES OF WEAKNESS IN U.S. MANUFACTURING FIRMS

To regain and retain global competitiveness, U.S. manufacturing firms must learn to do certain things better than they are now doing them. Although the list of needed improvements is quite lengthy, we will focus on what we believe are among the more critical ones.

- Better product design
  - More functional
  - Higher quality
  - More reliable (fewer parts)
  - Less expensive
  - Designed for manufacturability
    - Automated handling/transport
    - Automated loading/unloading
    - Automated inspection test
    - Automated packaging
  - More modular, for alternative configurations
  - More use of design retrieval
  - Requires aggressive, sustained effort in product R&D
- More responsive to market
  - Faster to market
    - New products
    - Upgraded products
  - Design for international markets
  - Service after the sale
  - Obsession with customer satisfaction
- Better process design (entirely new conceptual paradigms for performing process design/redesign)
  - Process design in parallel with product design (parallel engineering)
  - Better use of advanced process technologies
  - Processes designed for programmable reconfiguration
  - Concept of generic manufacturing systems (within broad process categories)
  - Faster development to production time; first article, acceptable quality requires aggressive, sustained effort in process R&D

- Better strategic management

  Ability to visualize the future
  - Markets
  - Megatrends (environmental forces)
  - Global factors

  Ability to target opportunities, aggressively define, create, and capture appropriate markets

  Ability to capitalize on and influence emerging technologies
  - Materials
  - Processes
  - Devices (e.g., mechatronics)
  - Basic sciences

  Ability to capitalize on and influence emerging conceptual developments
  - Information management processes
  - Statistical treatment of data for controlling/managing processes, departments, functions, vendors, and people
  - Organizational dynamics
  - Motivational concepts
  - Individual/group behavior
  - Knowledge-based processes
  - Object-oriented programming and modeling

  Ability to conceptualize and continuously reinterpret long-term transition paths for their entire corporations (corporate warrooms)

  Ability to comprehend entire corporation as a dynamic system, with many interacting functional components, the total performance of which must be optimized over the long term

- Better Operational Management

  Linking strategic planning to operational action

  Ensuring consistency and congruence between strategic business goals and operational programs.

  Configuration management applied to the design and operation of the operational management system
  - Data integrity
  - System discipline
  - Accurate, updated system documentation
  - Observance of boundaries (limits) in loose/tight management policies

  Reward structures congruent with desired system performance

  "Control room" approach to production management (digital readouts; cause-effect mapping)

  Managing continual change/modernization

  Possible shift from hierarchical to network organization, with accompanying modifications to accountability/responsibility/authority relationships

THE NEED FOR A SYSTEMS ENGINEERING PERSPECTIVE

If the Japanese have a "secret" regarding their approach to manufacturing competitiveness, it is their ability to perceive their company as a dynamic system. They understand how all the functional components of their companies interact to influence the firm's performance on cost, quality, service, and differentiation. Furthermore, they know how to engage in "organizational experimentation," in which they change system parameters (such as the size of their engineering design staff) in an ongoing attempt to optimize the total performance of the firm over the long term.

The Japanese do not like to take risks. When a Japanese manager makes an investment decision, he is not simply "rolling the dice" hoping that his firm's performance will improve. Most likely, the decision was thoroughly tested and evaluated through the use of quantitative and qualitative models of his firm.

The term "systems engineering" is used to characterize the rational approach to organizational performance improvement described above. The concepts and methodologies of systems engineering originated in the United States, primarily in connection with defense and space programs. It was the Japanese who saw the applicability of these concepts to the design and operation of industrial firms.

It has been observed that if Boeing designed airplanes as U.S. firms design companies, the airplanes would never get off the ground. If airline pilots attempted to fly their routes as U.S. firms operate and manage their companies, they would rarely have a successful flight and would almost never arrive on time.

FUNDAMENTAL NEEDS FOR IMPROVED COMPETITIVENESS

If U.S. manufacturing firms are to improve their performance, there are some prerequisite, fundamental needs that should be addressed.

- Need for a new paradigm for manufacturing system analysis, design and operation

  Systems engineering approach
  - Inputs
  - Transfer functions
  - Outputs
  - Feedback control loops

  Designing system for accommodating external and internal perturbations
  - Responsiveness
  - Flexibility
  - Fault tolerance
  - Robustness

- Need for new, improved methodologies for *analyzing, designing, and operating* advanced manufacturing systems

  Better methodologies for functional analysis

  Better methodologies for *analyzing*, and characterizing current system
  - Identifying cost drivers
  - Measures of performance
  - Comprehensive, integrated, forward-looking total cost models

  Better methodologies for *designing* new, improved manufacturing systems
  - Need design principles and guidelines
  - Need computer-aided tools for aiding manufacturing system design engineers in conceptualizing new designs, performing "finite element analysis" equivalent, and even animating the factory design

  Better methodologies for *operating* manufacturing systems
  - On-line, real-time simulation model to facilitate "what-if" decision making
  - Knowledge-based decision support tools

- Need for a science base for manufacturing system design on which to construct the new, improved methodologies

  Manufacturing system theory

  Theory of integrated systems

  Theory of system rationalization

- Need for a greatly increased capability in U.S. universities to produce engineers prepared to contribute to companies' efforts to improve their manufacturing capabilities

- Need for much better mechanisms to network the capabilities of manufacturing specialists, so that large multiplying effects can be realized for rapid dissemination and implementation of emerging concepts in advanced manufacturing systems

- Need for much broader understanding among U.S. manufacturing managers that it is just as important and critical to invest in new, improved process design as it is in new, improved product design; and that they should attempt to recruit and develop the same top level of manufacturing engineers as they do product-design engineers

SUMMARY

During the decade of the 1970s, U.S. managers and policymakers convinced themselves that we were experiencing temporary forces in the international market place, and we refused to acknowledge that we were losing competitiveness. The 1980s convinced us that, indeed, the competitiveness of U.S. firms is weakening, and we desperately sought the "secrets" used by the Japanese. Thousands of U.S. managers participated in industrial tours to Japan.

Americans are not very good listeners, we do not prepare well for these trips, we do not really know what to look for, and we often misinterpret what we see or what we are told. We wildly embraced "participative management," "total quality," "just in time," *kanban*, etc., viewing them as quick fixes that can simply be plugged into our company structures in the United States.

Without having a clear, rational understanding of how our companies function as complex systems of interacting components, it is not surprising that a very large majority of initial efforts to implement "Japanese management techniques" ended in dismal failure.

There is no easy path or shortcut to achieving world-class manufacturing competitiveness. We all have much to do in the decades ahead.

There is a major role for each of the three sectors of industry, government, and education. These roles are described in the following section.

RECOMMENDATIONS

The three major sectors that can impact U.S. competitiveness are industry, government, and education. Figure 4 illustrates the interdependent nature of initiatives in each of the three sectors.

Each of the sectors can and should embark on independent initiatives. For example, it is the responsibility of the federal government to ensure that U.S. firms are competing on a relatively "level playing field" in international trade. It is the responsibility of higher education to provide the proper international perspective in curricula requirements. It is the responsibility of each industrial firm to ensure that the fundamentals of world-class manufacturing are executed flawlessly on an ongoing basis.

Joint responsibilities between sectors are reflected in the intersections shown in Figure 4. Many of the potential initiatives for restoring U.S. competitiveness will be those that reflect a joint dependency among two or more of the sectors.

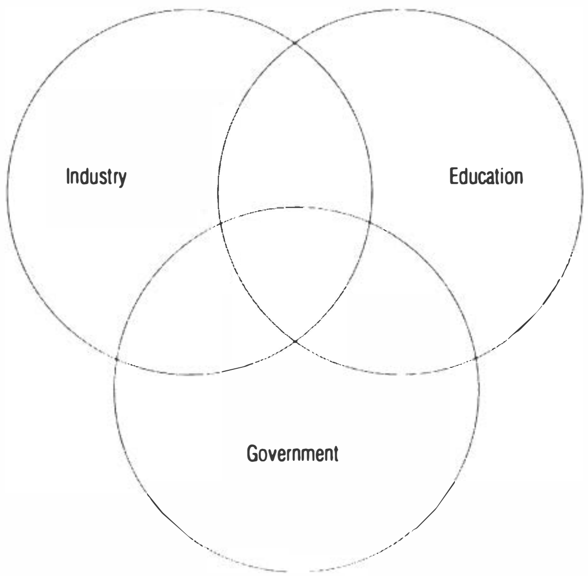
Education-Government Initiatives

Basic research related to greater understanding of the fundamental principles of manufacturing systems engineering should be greatly expanded.

Applied research related to the development of improved manufacturing system design methodologies also needs to be greatly expanded and accelerated. The applicability of systems engineering tools such as feedback control theory needs to be explored through a focused, well-orchestrated research initiative.

To address the shortage of engineering faculty members in manufacturing systems engineering, a long-term, multifaceted program should be designed, implemented, monitored, and modified as needed. This program could encourage promising graduate students to pursue advanced study in manufacturing systems through government-funded supplementary grants. Current faculty members could be "retreaded" through intensive summer programs at selected universities, with

FIGURE 4
Interdependencies of initiatives of three major sectors regarding restoration of U.S. competitiveness.



industrial interaction a required feature of the program. Practicing engineers having masters degrees could be encouraged to pursue doctoral programs through government-funded supplementary grants. The grants could require two years of university teaching for each year of the grant.

Industry-Education Initiatives

Industry should greatly increase it participation in engineering education. The two most obvious mechanisms currently existing are the American Society for Engineering Education (ASEE) and the Accrediting Board for Engineers and Architects (ABET).

Another mechanism that has worked exceptionally well where it has been used in industrial advisory boards for colleges of engineering and for individual engineering departments.

Greater emphasis needs to be placed on summer or year-long industrial internships for engineering faculty, and on summer or yearlong educational sabbaticals for practicing engineers.

Increased use of industrial equipment and laboratories by university faculty members and graduate students should be encouraged.

In specific industries, research consortia, such as Electronics Research Corporation and Sematech, should be encouraged to provide needed funding for focused programs of R&D conducted at several participating universities and research laboratories.

Exchange programs (of faculty and engineers) between universities and industry should be encouraged for the mutual benefit of both parties. Similarly, greater use of qualified adjunct professors and adjunct researchers from industry should be encouraged.

Industry should be encouraged to be more willing to provide coded data regarding their experiences in manufacturing initiatives, as a basis for meaningful case studies. In this regard, companies should be encouraged to be more willing to disclose their failures, so that others may benefit from their experiences.

Greater "teaming" of specific university faculty members with specific industry engineers should be encouraged through appropriate mechanisms. For example, many technical journals now give additional weight to articles authored by such teams. Likewise, university reward structures should be encouraged to recognize the inherent value of technical papers that contain practical elements.

Industry-Government Initiatives

Increased use of high-level industry/government task forces to explore means for increasing the competitiveness of U.S. firms is needed.

There needs to be consciously conceived initiatives to develop a better understanding of the effects of government actions on U.S. competitiveness.

Greater interaction and cooperation between industry and the federal laboratories should be encouraged. Better mechanisms should be developed to demonstrate and convey to industry the potential benefits of using the inventory of fundamental knowledge residing in our federal laboratories.

Consideration should be given to expanding programs that conduct long-term R&D initiatives by combined teams of researchers from several companies. Such programs would necessarily be restricted to those research initiatives having high potential payoffs but whose high costs and risks are greater than individual companies are able to consider. There is a need to explore innovative funding mechanisms that would earmark some of the profits realized on successful programs to be used in funding subsequent programs. Such a bootstrapping mechanism would alleviate the need to depend on general revenues to support these expensive initiatives.

Industry-Education-Government Initiatives

Perhaps the most fruitful initiatives for improving U.S. competitiveness will be those in which all three sectors—industry, education, and government—participate. Many such initiatives are already under way, and should be monitored, modified, expanded, or disbanded as appropriate. Some of the existing industry-education-government initiatives are:

- Engineering research center programs at the National Science Foundation
- Industry/university cooperative research center program at NSF
- Energy analysis and diagnostic center, Department of Energy
- Cooperative initiatives among federal laboratories, universities, and industry

An initiative that is just being launched originated in the National Bureau of Standards and is intended to encourage technology transfer to manufacturing firms.

It is recommended that consideration be given to a carefully conceived initiative to develop a better understanding of how "America, Incorporated" acts as a system in the context of a complex world economy.

Some version of "industrial experiment stations" and "industrial extension services" should be conceived and implemented on a trial basis. There are a few successful state-level systems (such as the one at Georgia

Institute of Technology) that could be used as prototypes and as examples to learn from. It is realized that such a program implemented on a national scale would be extremely expensive. Only the overwhelming success of such a model in agriculture gives impetus to the concept of even considering such an undertaking.

A more modest initiative is one that would provide opportunities for industrial internships for faculty members on a regular, recurring basis. This could be combined with an industry-education-government initiative to capture the talents of many retiring (but still young) practicing engineers for service in manufacturing curricula.

An earlier section in this paper is entitled "We do not need a crash program." Some of the recommendations cited above may sound like "crash programs." They are not meant that way.

The strong belief that we Americans must move away from our crisis mentality is reiterated. We should decide what is needed for long-term competitiveness and then have the discipline and resolve to pursue long-term initiatives that focus on fundamental needs.

Trick plays will not help us regain our competitiveness. Dedication to continuing improvement in the way we design and operate our manufacturing firms is our most promising strategy to pursue. Our future as an industrial power depends on how well we execute the basics time after time, year in and year out.

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