FUNDAMENTAL RESEARCH in MANUFACTURING for NATIONAL COMPETITIVENESS

A Plan with Concrete Recommendations
for Long-Range Economic Growth

A Workshop Report submitted to the
NATIONAL SCIENCE FOUNDATION

VOLUME I

MARCH 1992

FUNDAMENTAL RESEARCH in MANUFACTURING for NATIONAL COMPETITIVENESS

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Key Points

- The National Science Foundation (NSF) should play a central role in spurring U.S. global competitiveness and economic growth.
- U.S. manufacturers have not kept up with the product and manufacturing innovations that have made other nations highly competitive.
- American universities are producing many ideas for new products and for technological improvements that are not being utilized by industry.
- NSF funding of manufacturing research (1.2% of the total 1991 budget) is too low to have an impact on U.S. competitiveness.
- NSF should support the transfer of technology from universities to industry.
- The manufacturing infrastructure at American universities must be rebuilt.
- New manufacturing education programs are needed.

PREFACE

In November 1991, an NSF-sponsored workshop on *Fundamental Manufacturing Research for National Competitiveness* brought together in Ann Arbor more than 60 representatives of industry, government, and academia to discuss how university research in manufacturing can help American industry regain its competitive edge. This is Volume I of a two-volume report on the workshop. Included are the discussions, conclusions, and recommendations of the participants. The material is presented in four major sections:

I. Problem Assessment

II. Workshop Structure

III. Conclusions

IV. Recommendations

We believe that if the recommendations generated by the workshop are adopted, the U.S. will return to world leadership in advanced manufacturing techniques, which will lead directly to economic growth and job expansion.

ACKNOWLEDGMENTS

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Executive Summary

Introduction

In 1978, the U.S. machine tool industry was number one in the world with a larger share of the global market than any other nation. Today it is in fourth position with only 7% of the market [1]. Similar trends have occurred in other manufacturing-related industries including automobiles and steel.

On November 20-21, 1991, a National Science Foundation-sponsored workshop on *Fundamental Research in Manufacturing for National Competitiveness* brought together in Ann Arbor more than 60 representatives of industry, government, and academia to discuss how university research in manufacturing can help American industry regain its competitive edge. Recognizing that American universities are some of the best in the world at producing basic knowledge, the goal of the workshop was to identify and address the problems that sometimes inhibit the transfer of that knowledge into useful technology.

This report on the workshop aims to provide the National Science Foundation with information and advice from the scientific community so that national-policy decisions in basic research in manufacturing can be made with wisdom and timeliness.

The Workshop

Workshop participants, among whom were prominent administrators and established researchers, focused their discussions on the research and development pipeline in manufacturing science. This pipeline consists of three parties:

1. Government agencies, which provide research funding (e.g., NSF, DOC, DOD).
2. Universities, which receive funding and produce knowledge and students.
3. Industry, which receives students and knowledge (to supplement its own sources of knowledge).

To find out why the pipeline has not always been successful in producing useful technology for industry, conference participants split into working groups to discuss three links within the pipeline:

1. Coordination of funding within government agencies.
2. Coordination between universities and industry in the direct transfer of knowledge.
3. Education of students in manufacturing.

The working groups reached a number of conclusions:

1. Government, industry, and academia are doing excellent work individually, but the system as a whole does not function well because of weak interfaces or linkages
   a. between universities and industry;
   b. among the top-level decision makers at federal agencies;
   c. among researchers at different universities.
2. Increased funding of manufacturing programs by NSF could be a catalyst to revive the manufacturing industries.
3. The infrastructure of manufacturing research and education in universities is old and should be rebuilt.

4. National competitiveness requires a better balance between the applied engineering interests of the professional master's degree and the research orientation of the Ph.D.
5. There are superior intellectual resources at our universities that are underutilized and could contribute more to the nation's competitiveness.

Recommendations

As first steps in addressing the above concerns, the workshop participants propose the following:

- Enhance technology transfer to industry.

1. When sponsoring research in manufacturing, NSF should consider the inclusion of a technology transfer plan and the active participation of industry in the research proposal.

2. The funding of the Division of Design and Manufacturing (DDM) at NSF should be increased by $4 million to sponsor involvement of small businesses as subcontractors in university research to facilitate technology transfer (up to 15% of the grant).

3. To encourage small businesses to cooperate with universities, universities should waive the indirect cost of Phase-I SBIR subcontracts offered by industrial partners.

4. DDM funding should be increased by $3 million to encourage hardware construction or prototyping for manufacturing-theory validation.

- Enhance coordination of funding within government agencies.

5. NSF should team up with other federal agencies (e. g., NIST, DARPA) to coordinate the implementation of programs that complement its basic research role in manufacturing engineering.

6. A national steering committee should be formed to identify the weakest links in our manufacturing technology and to formulate a long-range plan toward the strengthening of those links.

- Build interfaces between researchers from different universities.

7. DDM funding should be increased by $5 million to establish a program of consolidated research on a focused manufacturing topic, which would combine the talents of the best researchers on this topic from several universities. The topic should be related to a product or process development or improvement needed by industry.

- Rebuild the university infrastructure.

8. DDM funding for new equipment should be increased by $4 million to rebuild the infrastructure in manufacturing research and education at our universities.

- Broaden manufacturing research programs.

9. DDM funding should be increased by $4 million to augment its programs in control of manufacturing processes.

- Broaden education programs in manufacturing science.

10. DDM funding should be increased by $6 million to support domestic master's degree students directly, through institutionally awarded traineeships in design or manufacturing.

11. DDM funding should be increased by $4 million to support new initiatives at regular universities and undergraduate institutions to enhance manufacturing-teaching methodologies.

- Reorganize NSF to better utilize intellectual resources in manufacturing.

12. NSF should establish a study team to investigate the effectiveness of establishing a *DIRECTORATE FOR MANUFACTURING SCIENCES*, which will include the present Division of Design and Manufacturing combined with a part of the present Division of Information, Robotics, and Intelligent Systems, augmented by intellectual resources from the business administration and social science disciplines. It will be characterized by its interdisciplinary approach (engineering, computer science, business, and social sciences) and by its close ties with industry.

Summary

The recommendations in this report arise from an intense discussion of the problem of global competitiveness by some of our nation's best-informed leaders in industry, government, and academia. To implement these recommendations, the Division of Design and Manufacturing (DDM) at NSF will need additional funding of $30 million per year. (Even with this increase, the DDM budget will be less than 3% of the total NSF budget.) This limited increase would provide a very significant signal of a new direction to the manufacturing research community. We believe that these recommendations, if implemented, will help our nation's manufacturing-related industries begin a return to competitiveness in the world marketplace.

I. Problem Assessment

An Economy in Trouble

- In the past 15 years, American machine tool manufacturers have lost 53% of their market, going from being the number one producers in the world to number four. Some types of equipment have lost 80% to 90% of their market share, primarily to the Japanese. Machine tools were a $5.7 billion industry 12 years ago in the U.S., today the figure is $3.8 billion [2].

- Japan holds 26% of the U.S. car market and is the leading producer of cars in the world. The number of Japanese automobiles sold in the United States is a fraction of the total Japanese production. Japan exports its automobiles in other parts of the world such as Asia, the Middle East, and Africa, and has a lion's share of the overall world market [3].

- "In Thailand, near Bangkok, there is a plant to make TV tubes. The spotless plant, which will make one million cathode ray tubes this year, uses technology developed in the United States, where 26 companies once made televisions. Next year, the factory will begin exporting tubes to America, where only two U.S.-owned TV manufacturers remain, Zenith and Philips" [4].

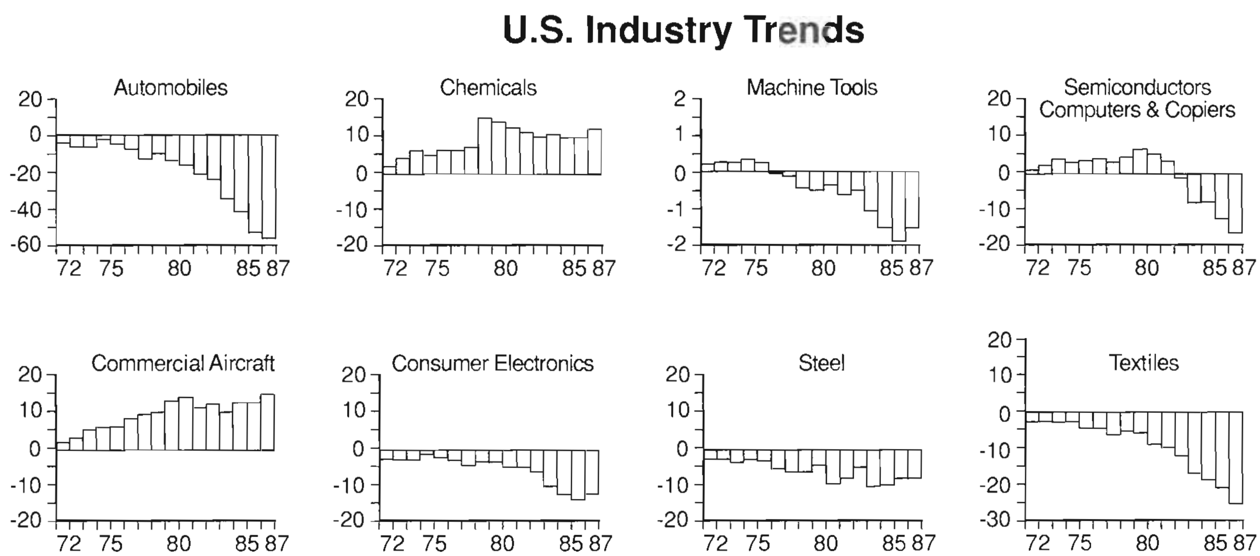

Figure 1. Trade Balance in Industries Studied
Trade balances are in terms of billions of current U.S. dollars. Data made available by the U.S. Department of Commerce, International Trade Administration, Office of Trade Information and Analysis.

As the above items indicate, American manufacturing is taking a beating worldwide. A nation that was once number one in most manufacturing categories has now lost its preeminence. Figure 1 clearly shows the declines of the past 20 years in six major basic industries: automobiles; machine tools; semiconductors, computers and copiers; consumer electronics; steel; and textiles. The only bright spots in this gloomy picture are the chemical and aerospace industries, which continue to hold their own in world markets. [It should be noted, however, that even aerospace is now being challenged by the European company Airbus Industrie, which is government-subsidized (5)].

As recently as the late 1970s, American manufacturers were leading in a number of high-tech industries that are now beginning to experience negative trade imbalances. Among them are:

Electronic displays in laptop computers;
Optical information-storage systems for compact disc players;
Integrated circuit fabrication;
Numerical controllers for machine tools;
Robotics [5,6].

And the worst may be yet to come. By 2002, Japan (with a population half our size) will equal or surpass the United States in total manufacturing output. The most conservative estimate is that Japan will out produce us two to one on a per-capita basis [7].

How important is the manufacturing sector to the American economy? One simple statistic tells the story: 68% of America's wealth is generated by manufacturing [8]. With American manufacturers continuing to falter, it is no wonder that the nation's economy has slowed in recent years.

What Happened?

- The number of hours it takes to build a car in United States has increased; in Japan, it has decreased (by 60% between the years 1970 and 1981 alone). It now takes half as much time to assemble a Toyota as to assemble a GM car [3, 9].

- In numerically control machine tools, it took the United States nine years to go from research to product. In Japan, it took two years [10].

- Typical Japanese machine tool accuracy and repeatability are better than that of equivalent U.S. machines [8].

- Japan uses fifteen times more robotics than the United States and five times more flexible machine systems than we do (adjusted for population) [8].

- Use of robots [8]:

Japan	550,000
Europe	69,000
Former Soviet Union	62,000
United States	37,000

Why has America fallen behind its competitors in manufacturing? Some claim that unfair trade practices were used to gain the advantage. This may have played a part, but the above items illustrate another equally compelling factor: The Japanese, Germans, and others have found ways to manufacture products more efficiently than we have. They can make products faster and at a lower cost, and in world markets, those efficiencies have spelled market domination.

"Today's advanced flexible manufacturing techniques are a web of interdisciplinary technologies, from computer-aided design (CAD) and engineering workstations to computer numerically controlled (CNC) machine tools that produce parts with high precision and can be quickly reset for vastly different products" [11]. Our competitors have done a much better job of keeping pace with these advancements. High-tech manufacturing methods are used in many foreign factories to a much greater degree than in ours.

These efficiencies allow our competitors to take an idea and turn it into a product much faster than our manufacturers can. And catching up to the current pace of our competitors will not be enough. Forecasters predict that in upcoming decades, the time it will take to move from idea to product will shrink even further. Manufacturers will have to develop new product ideas, quickly put them into production, and then, as competitors catch up, move on to newer generations of products.

Again, the question must be asked: Why have we fallen behind? Why have other nations advanced in manufacturing science and methodology while America has lagged? Analysts point to a variety of factors, including complacency and unwillingness to try something new on the part of U.S. industry (economic problems have shaken this complacency); outdated management techniques emphasizing hierarchy instead of teamwork (industries are beginning to give serious attention to improving management of technology); and a lack of long-term investment. Manufacturers themselves must address these problems and are beginning to do so.

But there is another part of the problem that industry cannot solve alone.

Capturing Knowledge

- The United States spends $150 billion a year on research and development more than the U.K., France, and Japan combined [11].
- The United States produces about one-third of the world's scientific papers. Our nearest competitors are the United Kingdom with 8.2%, Japan with 7.7 %, and the former Soviet Union with 7.6% [12].
- Almost 50% of all the scientific papers cited in other papers are American. Our nearest competitors are all below the 10% mark [12].

As the above statistics indicate, the United States spends huge sums on research, and American universities are ahead of all competitors in production of scientific knowledge. Many of the basic scientific discoveries that led to our competitors' products and to the manufacturing efficiencies that made their implementation possible were developed in American universities. And the future of American knowledge is bright also. We have plenty of good ideas for new methods, new technologies, and new products at our universities right now.

As a nation, we have not suffered from a lack of ideas or knowledge. What we have lacked in the past and still lack today are good mechanisms to capture this knowledge for industry and transform it into marketable products and manufacturing techniques. The issue is crucial, because the creation of new technologies and new products may well be the principal source of economic growth now and in the future [5].

Finding ways to increase the necessary technology transfer from university to industry will require the cooperation of industry, government, and universities. If we are to be competitive again, these three groups must work together to answer the question: Why hasn't the scientific and technological knowledge produced in our universities, especially in the area of manufacturing science, made its way into our industries?

In November 1991, business, government, and academic leaders from across the country met in Ann Arbor, Michigan, to address this question in an NSF-sponsored workshop entitled *Fundamental Research in Manufacturing for National Competitiveness.*

II. Workshop Structure

The purpose of the workshop was to explore the reasons why American preeminence in science and research has not been translated into preeminence in manufacturing. Through direct exchange among researcher and policy makers, it was hoped that the first step in an effective strategic plan for fundamental research in manufacturing for NSF might be articulated.

To meet this challenge, the organizing committee carefully selected 61 representatives from three sectors: academia (28), industry (20), and government (13). Selected from each of these categories were prominent administrators (who can change policies) and established researchers (with at least 10 years beyond the Ph.D.) who carry out the day-to-day work and understand the technical problems of manufacturing science (see list of participants in Appendix A).

The workshop's organizers provided a framework for carrying out the discussion by conceptualizing research and development efforts as a pipeline (see figure 2). The pipeline comprises three main segments: (1) Government, which provides funding to universities for manufacturing research through NSF and other agencies; (2) Universities, which carry out funded research in manufacturing science; and (3) Industry, which receives knowledge and trained students from the university with which to improve manufacturing technologies. These improvements then pay off in the form of jobs and economic growth, which, in turn, increase the government's tax revenues, feeding resources back into the pipeline.

Ideally, this system should assist manufacturers to compete in the world marketplace by providing a steady stream of new ideas, new technologies, and highly trained employees. The workshop participants were asked to identify weak links in the pipeline that have prevented this ideal from being realized. Workshop organizers identified three possible weak links and challenged the participants to address them:

1. Lack of coordination among the government's funding agencies;

2. Inadequate transfer of technology from university to industry;

3. Inadequate preparation of students for work in industry.

The workshop opened with speakers providing background comments from different perspectives: DOD, industry, university research, university education, and comparison between Japan and the United States (see agenda in Appendix B and summary in Appendix F).

Participants then broke up into three working discussion groups. Their meetings were followed by a panel discussion summarizing the ideas generated throughout the day (see summary of the panel discussion in Appendix G).

At the end of the workshop, participants contributed questions to a questionnaire about concrete recommendations. The questionnaire was distributed to all participants, and responses were received from 52 (25 from universities, 22 from industry, and five from government). The questionnaire is included in Appendix C, and a tabular summary of the responses is given in Appendix D.

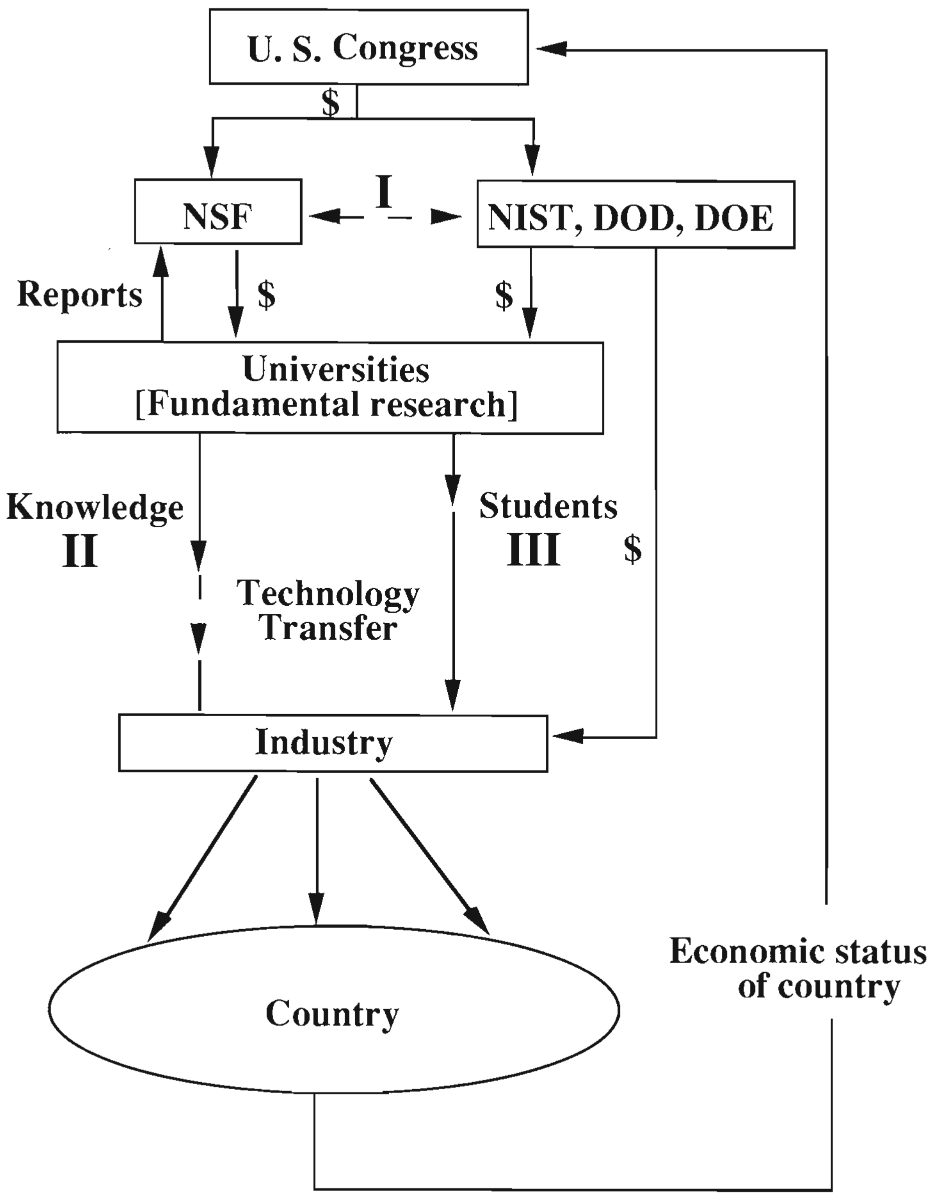

Figure 2. Flow Chart of Funds and Technology
The workshop evaluated the vertical integration and horizontal coordination.

III. Conclusions

The working groups identified and discussed many problems within the research and development pipeline. They concluded, however, that the following seven problem areas are of the greatest significance and should be addressed first by NSF.

Government Funding and Coordination

1. Inadequate research programs in basic manufacturing science.

Participants noted a problem at the very top of the pipeline: inadequate attention to the manufacturing sciences from government funding agencies. NSF devotes only 13% of its budget to engineering and only 1.2% to manufacturing. The largest share of the budget goes to other sciences.

By contrast, America's competitors place much more emphasis on manufacturing science. In Germany, 30% of research funding goes to engineering and 15% to manufacturing [13]. The largest portion of Japanese research funding goes to engineering instead of science [14]. During the past four decades, the Germans have built a network of 37 research institutes dedicated to joint university-industry development projects, of which no fewer than eight deal with manufacturing [8]. Japan has 170 government-run technology centers bringing new manufacturing techniques to business, whereas the U.S. Commerce Department has only five [15].

Participants noted that three-fifths of America's research budget is assigned to military research, and, unfortunately, the benefits of this research rarely are felt in industry. As General Motors executive Jamie Hsu noted in his opening remarks to the workshop: "The technology trickle-down effect doesn't work. Military composites are very different from the civilian's requirements. They need to be industry- or customer-specific to have true impact" [16].

At the same time that we have been surging ahead in military research and applications, our manufacturing research programs have suffered. In the Fifties and Sixties, the United States led the world in basic research in manufacturing (e.g., the invention of numerical control). However, during the Seventies and Eighties, the Europeans (Germany, France, Italy, Sweden, and recently Spain) and the Japanese have gradually taken the lead in many manufacturing disciplines. How has this affected our competitiveness? Massachusetts Institute of Technology (MIT) professor Nam Suh summed it up nicely: "We need much better understanding of basic design and manufacturing theories in order to compete with Japan."

2. Lack of coordination among funding agencies.

The government funding portion of the pipeline has another problem. Participants commented that, not only is there inadequate funding of manufacturing sciences research, but there is also a lack of coordination among different funding agencies (DOE, DOD, NIST, etc.). The result is that research programs funded by different agencies do not complement one another. In addition, there are no uniform guiding principles to direct research in ways that will best plug the technology gaps that exist in our manufacturing sector.

Edward Miller, president of NCMS, stated: "Government's goal must be to establish a consistent, coherent policy that institutionalizes a collaborative paradigm among government, industry, and academia."

3. Inadequate linkages between industry and university.

Successful research often fails to make its way into industry because there are few avenues of communication between university and industry.

Finding an American Model

Prof. Nam Suh of MIT noted that if technology transfer is to be successful, people in industry need to have face-to-face contact with people in academia – something that doesn't happen often enough in the American research pipeline. Participants noted that university professors often have little or no experience in manufacturing, while engineers in industry often do not keep up on the latest scholarly research. Professors lament the lack of research money from industry, and manufacturers complain that university research often is not relevant to their needs. The two groups almost function as ships passing in the night. Each has something that the other needs, but effective contact is seldom made.

This is in stark contrast to our two most successful competitors, Germany and Japan. They have evolved models for maintaining strong links between university and academia.

- The German model:
  Professors have industry experience;
  Leaders in manufacturing industries have Ph.D.s;
  Universities run manufacturing institutes, which are funded 50/50 by agencies and industry.

- The Japanese model:
  Emphasis on engineering synthesis;
  Students exposed to wide range of technologies;
  Alumni network for building an industrial-university relationship;
  Great trust between industry and university 17].

Participants agreed that the United States should not imitate the German and Japanese models, but should, instead, develop quickly an American model for university-industry linkage.

The Importance of Small Business

Participants discussed some special problems that small businesses have in establishing linkages with academia. Whereas large businesses can afford to spend money on internal research or to sponsor university research, smaller businesses often must operate without research budgets. Although these businesses are small, their impact on the economy is not. There are 350,000 small manufacturing firms in the United States, which supply about 60% of domestic components and employ 50% of manufacturing workers. Eighty-five percent of these companies have fewer than 50 employees [18].

Jeff Clevenger, president of Saginaw Machine Systems, summed up the frustration of small business. "Most machine tool builders," he said, "can only afford to commit resources to programs that they feel will result in immediate sales and profits. This precludes true R&D and new product development. So even with government and academic programs to transfer fundamental research to our industry, most small machine- tool builders cannot and do not capitalize on the available technologies. Finding mechanisms to help small, private industry capture university research is important."

4. Lack of coordination between university researchers.

Other problems appear in the pipeline once research has been funded. One of these is a lack of coordination between researchers from different universities. Duplication of effort occurs when researchers are working on the same problem without communicating. Even more troublesome is the fact that many research problems require a cross-disciplinary approach to be successful. Unfortunately, most research funding goes to one investigator from one university working in one narrow area.

Yoram Koren noted that an effective technology strategy requires not only developing mechanisms for technology transfer between universities and industry, but also developing collaborative mechanisms within each sector.

Education in Manufacturing

5. Poorly educated work force in technical and scientific areas.

A technically educated work force is necessary to receive and implement new technologies developed through research. The implementation of technology in our manufacturing enterprises is only as good as the training the work force receives. Unfortunately, our education system has not done well in this respect. A comparison with Japanese and German education in manufacturing is revealing. In the United States, only 10% to 12% of high-school graduates have adequate science and math backgrounds to pursue studies in engineering and science [19].

In Germany, 5000 to 6000 students with post-high-school training in manufacturing technology enter the work force annually: 150 Ph.D.s, 500 to 800 at master's level, and the rest from two- or four-year engineering technology colleges [20].

Japan graduates two times as many engineers per capita as we do, and in Japanese industry, 80% of engineers work on the factory floor [21]. "Because of the presence and the working population of engineers in production shops, innovative improvements in production technology are made by these engineers through their daily exposure to production problems. This is one of the most important reasons why Japanese production technology is very advanced with innovative, technical excellence and is far more advanced than the United States" [22]. Jobs on the shop floor that are held by engineers in Japan are often held by high-school graduates in the United States. American engineers are found in offices, far from the action on the floor.

U.S. industry also suffers from a lack of engineers with advanced degrees. Instead of seeking employment in industry, doctoral students typically seek work as professors in academia [23]. Also, half of U.S. engineering doctoral degrees go to foreign students. Although many of these students stay in the United States, at least half return to their homelands [24].

There should be a mechanism for encouraging engineers with industrial experience to come back to the university for advanced education in manufacturing. A professional master's degree based largely on coursework and a study project should be offered by universities. In addition to that, we need a mechanism to encourage students who enter master's programs directly from undergraduate school to be trained in how to conduct research as part of their master's education.

In his State of the Union address on January 28, 1992, President Bush stressed the importance of education. "If we want to keep America competitive in the coming century, we must accept the responsibility for educating everyone among us."

6. Inadequate university infrastructure.

The infrastructure is showing signs of strain. Federal funding for research facilities declined by 95% in the past 20 years [6]. As a result, laboratories and equipment available for research in manufacturing science in our universities are often obsolete and poorly maintained. Also, modern manufacturing science is increasingly systems oriented. This means that manufacturing cells made up of a number of different machine tools working together are becoming the norm instead of single stand-alone machine tools [25]. Participants noted that it is difficult to carry out relevant research or to teach using obsolete equipment or stand-alone equipment. Young people are biased away from manufacturing since training on obsolete equipment has become increasingly irrelevant. At the same time, the participants stressed the difficulty of obtaining funding to make the necessary improvements.

Organizational Structure of NSF

7. NSF internal organization lacks a manufacturing emphasis.

Manufacturing is a complex, cross-disciplinary field that is not well served by NSF's present internal organization. In the current structure, manufacturing is one subdepartment within the Engineering Directorate, a situation that tends to narrow the scope of manufacturing research.

Fundamental research in manufacturing sciences is different from other engineering disciplines for the following reasons:

- Manufacturing science is very broad and includes many engineering disciplines such as materials processing, control, systems integration, and electronic assembly; as well as computer science disciplines such as robotics, information and intelligent systems; and economics, business management, and social sciences such as studies of the effect of automation on job quality.

- There is growing public pressure to shift more resources to support R&D that directly benefits civilian technologies, because this would have a far more direct impact in stimulating long-term economic growth. The relationship of manufacturing science to civilian technologies and commercial products and, in turn, to economic growth, is more obvious than in many other federal programs directed toward advancing the frontiers of human knowledge.

- Unlike the situation with other disciplines, technology transfer is critical to the impact of manufacturing science and, therefore, should also be supported by NSF. This is an expansion of the present mission of NSF, but NSF should adapt its missions to global changes in economic competition.

- Equally important in achieving technological leadership is having educated and skilled people to use complex, innovative manufacturing systems. Training engineers in industry and educating teachers for this task is another piece of the complex puzzle of economic growth. NSF should consider taking this on as its responsibility.

There is no central agency within the government to formulate a national vision for success in manufacturing, a vision that would provide a framework so that the most needed projects are funded by the relatively small NSF budget. Japan and Europe, in the meantime, already have central organizing agencies for manufacturing research. The European Economic Community (EEC) in Europe and the Ministry of International Trade and Industry (MITI) in Japan have been playing an important role in integrating university-industry research in manufacturing and consolidating research results generated at different universities.

IV. Recommendations

As first steps in addressing the problems identified in Section III, the workshop makes the following recommendations.

- **Enhance technology transfer to industry.**

1. Consider the inclusion of a technology transfer plan with active participation of industry in the research proposal when sponsoring research in manufacturing by NSF.

By far the major concern of all workshop participants was the issue of technology transfer, or the interface between universities and industry. Accordingly, the first four recommendations deal with strengthening the university-industry interface.

In recommendation number one, we do *not* recommend that in sponsoring new research, NSF require evidence of technology transfer resulting from previous grants (see question 11 in Appendix C), since high-risk/high-payoff research does not always produce transferable results that can be converted into products.

2. Increase the funding of the Division of Design and Manufacturing (DDM) at NSF by $4 million to sponsor involvement of small businesses in university research as subcontractors to facilitate technology transfer (up to 15% of the grant).

Examples of small businesses in the manufacturing field are the machine tool industry, numerical control producers, and manufacturing software houses. Recommendation number two should be started on an experimental basis with only 15% of the funded proposal set aside for small businesses as subcontractors (about $15,000 per year on the average). The researcher will have to shop around and find an industrial partner to work with, and this partner will be paid. If this program is successful, we recommend that the percentage be increased to 33%, parallel to the SBIR program that allows small businesses to have a university partner for up to 33% of the grant.

3. Urge universities to waive the indirect cost of Phase-I SBIR subcontracts offered by an industrial partner in order to encourage small businesses to cooperate with universities.

This recommendation strengthens the university-industry link and complements recommendation number two. We believe that NSF should use its authority to ask universities to waive some of the indirect costs for SBIR involvement.

4. Increase DDM funding by $3 million to encourage hardware construction or prototyping for manufacturing theory validation.

This recommendation is based on the DARPA model, which funds early stages of research, placing heavy weight on demonstrations. A technology demonstration of a hardware prototype allows industry to evaluate the technology under semi-realistic conditions and also facilitates a decision on technology transfer.

- **Enhance coordination of funding within government agencies.**

5. Team up with other federal agencies (e. g., NIST, DARPA) to implement new programs to complement NSF's basic research role in manufacturing engineering.

6. Form a national steering committee to identify the weakest links in our manufacturing technology and to formulate a long-range plan for strengthening these weak links.

These recommendations deal with the subject that was the second major concern of the workshop participants: the need for federal research and development agencies to coordinate their research agendas in manufacturing. We realize that implementation of these recommendations might be the role of OSTP rather than NSF. However, NSF might take the first steps toward their implementation.

- **Build interfaces between researchers from different universities.**

7. Increase DDM funding by $5 million to establish a new program on consolidated research on a focused manufacturing topic that combines the talents of the best researchers on this topic from several universities. The topic should be related to a product or process development or improvement needed by industry.

Another concern articulated by workshop participants is the lack of interaction among researchers working on similar problems at different universities. We propose the development of a new model of research that brings together the best available talent nationwide to work on a specific manufacturing topic identified as essential by industry (e.g., next-generation numerical controllers for machine tools). Universities will make joint proposals with one university acting as the primary contractor in charge of coordination and integration, and the other universities operating as subcontractors with close ties to industry. (This recommendation combines questions 3, 6, and 34.)

- **Rebuild the university infrastructure**

8. Increase DDM funding by $4 million to rebuild the infrastructure in manufacturing research and education at our universities.

The infrastructure of most U.S. universities is old and outdated. There is a need for modern equipment such as CAD systems, laser-beam cutters, part-quality measuring equipment, modern machine tools with computerized numerical controllers (CNC), assembly robots, and much more. This equipment is needed to provide education for the next generation of engineers and to conduct first-class research relevant to industry. We recall that in 1987 the total budget for equipment of the Equipment and Processes Program at DDM was only $40,000.

- **Broaden manufacturing research programs.**

9. Increase DDM funding by $4 million to augment its programs in control of manufacturing processes.

Because of the many current demands on the federal budget, we feel it is prudent to request additional funding in only one area of expanded research: control of manufacturing systems (question 9). It should be noted that a U.S. Air Force-sponsored workshop in 1987 also listed this area as its highest priority. Control means not only CNC for machine tools, but also autonomous diagnostic systems, adaptive control of laser cutters and welders, intelligent workstations, smart sensor interfaces, neural networks, control of ceramic processes, and quality control on automobile assembly lines. This area has the potential for a huge payoff- to- investment ratio.

■ Broaden education programs in manufacturing.

10. Increase DDM funding by $6 million to directly support domestic master's-degree students with institutionally awarded traineeships to support their studies in fields related to design or manufacturing.

Industry needs more engineers trained in advanced manufacturing science at the master's level. The NSF will make awards to universities that have programs for a master's degree in manufacturing. These awards will finance two kinds of students: (1) Students with industrial experience returning for advanced studies. They will be granted traineeships by the universities for intensive studies in manufacturing science for one year. (By one year, we mean one full calendar year: two semesters of course work and one of project activities.) (2) Students going directly from undergraduate school into an 18-month master's program emphasizing research. The award will cover tuition costs, living expenses, and a standard amount, such as $5000 per student, to cover the cost of project activities.

11. Increase DDM funding by $4 million to support new initiatives at both regular universities and undergraduate institutions to enhance manufacturing teaching methodologies.

This recommendation aims to support an undergraduate curriculum in manufacturing. We emphasize undergraduate institutions since their role is so important in educating manufacturing engineers, training manufacturing school teachers, and upgrading the skills of existing school teachers.

■ Reorganize NSF to better utilize intellectual resources in manufacturing.

12. Create a study team to investigate the potential effectiveness of establishing a Manufacturing Sciences Directorate, which will include the present Division of Design and Manufacturing combined with part of the present Division of Information, Robotics, and Intelligent Systems, augmented by intellectual resources from the business administration and social science disciplines. It will be characterized by its interdisciplinary approach (engineering, computer science, business, and social sciences) and by its close ties with industry. One of its roles will be to formulate a national vision for success in manufacturing.

The future of the manufacturing sector of the U.S. economy depends on continued innovations in manufacturing methodologies, the education of increasing numbers of manufacturing science engineers, the creation of methods for transferring university breakthroughs into the private sector, and the establishment of a national vision for manufacturing success. If these goals are to be met, manufacturing science must attract many more students, must become a cross-disciplinary field, and must receive greater emphasis in government funding decisions. A Manufacturing Sciences Directorate, under the proper leadership, could provide the impetus for accomplishing these goals.

V. Summary

Some of the recommendations in this report can be implemented without high cost. For example, it would not be costly to make policy decisions that increase coordination in all parts of the research and development pipeline: between government agencies, between university and industry, and among university researchers. But implementation of other recommendations will require a financial commitment on the part of the government – an additional $30 million annually – for manufacturing science and education. The impact of this small investment on the research community would be profound because of the new direction and objectives it would indicate.

Even with such an increase, manufacturing will remain a small part of the total NSF budget, only 3%. If the US is to remain a world-class economic power in the twenty-first century, we must invest at least this much more in manufacturing research, education, and infrastructure. The long-term benefits, in terms of new marketable products and jobs, will vastly exceed the investment.

Implementation of the recommendations in this report is a first step in returning our manufacturing sector to competitiveness, but, as our rivals in Japan and Europe have taught us, lasting success requires an ongoing effort. An NSF Directorate in Manufacturing Sciences is necessary to formulate a vision of national manufacturing success and to provide the leadership to fulfill that vision.

The most efficient manufacturing nations already make a strong financial commitment to manufacturing research and development, already have smoothly running coordination between university-government-industry, and already have centralized leadership for manufacturing policy. The United States cannot afford to continue to lag in these areas.

VI. References

1. Ham, Inyong. *Comparative Analysis of Management of Technology in Japan and the U.S.* The Pennsylvania State University. Nov. 1991, p. 40.

2. Jeff Clevenger (Chairman, Michigan Manufacturers Consortium). Opening remarks. *NSF-Sponsored Workshop Fundamental Research in Manufacturing for National Competitiveness.* Nov. 22, 1991.

3. Ham, Inyong. *Comparative Analysis of Management of Technology in Japan and the U.S.* The Pennsylvania State University. Nov. 1991, p. 41.

4. Read, Richard. "Japan's Asian expansion poses challenge." *Ann Arbor News.* Dec. 8, 1991, p. A9.

5. Dentzer, Susan. "Sharpening Our High-Tech Edge." *U.S. News and World Report.* Dec. 16, 1991, p. 72.

6. "Future View: Manufacturing Management in Crisis." *Manufacturing Engineering.* Jan. 1992, p. 32.

7. "Future View: Manufacturing Management in Crisis." *Manufacturing Engineering.* Jan. 1992, p. 31.

8. Tesar, Delbert. "A Proposal for a Program in Mechanical Engineering for Precision Machines in Manufacturing." University of Texas at Austin. Oct. 12, 1990.

9. McTague, John P. "Challenges in Global Competition." *NCAT/AIAA Symposium on Technology Policy for Global Competitiveness.* Washington, D.C. Sept. 5, 1991.

10. Ham, Inyong. Opening remarks. *NSF-Sponsored Workshop on Fundamental Research in Manufacturing for National Competitiveness*, Nov. 22, 1991.

11. Dentzer, Susan. "Sharpening Our High-Tech Edge." *U.S. News and World Report.* Dec. 16, 1991, p. 73.

12. Ham, Inyong. *Comparative Analysis of Management of Technology in Japan and the U.S.* The Pennsylvania State University. Nov. 1991, pp. 25-28.

13. Altan, Taylan. "The Essence of Competitiveness: Training and Education in Engineering." Report to *NSF-Sponsored Workshop on Fundamental Research in Manufacturing for National Competitiveness*, Nov. 22, 1991, p. 4.

14. Ham, Inyong. *Comparative Analysis of Management of Technology in Japan and the U.S.* The Pennsylvania State University. Nov. 1991, p. 31.

15. Dentzer, Susan. "Sharpening Our High-Tech Edge." *U.S. News and World Report.* Dec. 16, 1991, p. 74.

16. Hsu, Jamie (General Motors). Opening remarks to *NSF-Sponsored Workshop on Fundamental Research in Manufacturing for National Competitiveness*, Nov. 22, 1991.

17. Kramer, Bruce (National Science Foundation). Opening remarks to *NSF-Sponsored Workshop on Fundamental Research in Manufacturing for National Competitiveness.* Nov. 22, 1991.

18. "Future View: Who Needs Government?" *Manufacturing Engineering.* Jan. 1992, p. 65.

19. Altan, Taylan. "The Essence of Competitiveness: Training and Education in Engineering." Report to *NSF-Sponsored Workshop on Fundamental Research in Manufacturing for National Competitiveness,* Nov. 22, 1991, p. 2.

20. Future View: Manufacturing Management in Crisis." *Manufacturing Engineering.* Jan. 1992, p. 38.

21. Ham, Inyong. Opening remarks. *NSF-Sponsored Workshop on Fundamental Research in Manufacturing for National Competitiveness.* Nov. 22, 1991.

22. Ham, Inyong. *Comparative Analysis of Management of Technology in Japan and the U.S.* The Pennsylvania State University. Nov. 1991, p. 68.

23. Gilbertson, Eric (President, Saginaw Valley State University). Opening remarks. *NSF-Sponsored Workshop on Fundamental Research in Manufacturing for National Competitiveness.* Nov. 22, 1991.

24. Vetter, Betty. "Demographics in the Work Place: 2001." *Martin Luther King, Jr., Day Symposium,* The University of Michigan. Jan. 20, 1992.

25. National Academy of Engineering. "Statement of the Manufacturing Studies Board on the Need for Industrial-Academic Cooperation for Manufacturing Technology." *Education for the Manufacturing World of the Future.* National Academy Press, Washington, D.C., 1985, p. 118.