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ABSTRACT

This document records the oral and written testimony of witnesses who addressed the issue of how to strengthen research and education in engineering design and manufacturing at U.S. universities. The testimony includes a review of recommendations from two studies of the National Research Council and of the plans and programs of the National Science Foundation and other federal agencies that fund research relative to these recommendations. Witnesses included representatives from the National Research Council, engineering professors and department chairs from university, representatives from engineering education associations, and the assistant director for engineering of the National Science Foundation. They stressed that the United States has lost its competitive edge in manufacturing and technology and that more research is needed. Suggestions were made for increased research in and federal funding for programs in engineering design, changes in engineering education, and a design education clearinghouse. Other recommendations included bringing increased design knowledge to industry and promoting industry-university-government collaboration in research and education. (KC)

MANUFACTURING RESEARCH AND EDUCATION

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED SECOND CONGRESS

SECOND SESSION

MAY 12, 1992

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WITNESSES

MANUFACTURING RESEARCH AND EDUCATION

TUESDAY, MAY 12, 1992

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON SCIENCE,
Washington, DC.

The subcommittee met, pursuant to call, at 9:35 a.m., in room 2325, Rayburn House Office Building, Hon. Rick Boucher (chairman of the subcommittee), presiding.

Mr. BOUCHER. The subcommittee will come to order.

This morning the Subcommittee on Science will address the highly important question of how to strengthen research and education in engineering design and manufacturing at American universities. We will review recommendations from two separate studies of the National Research Council and address the plans and programs of the National Science Foundation and other Federal agencies that fund research relative to these recommendations.

From the mid-1940s until the 1960s, U.S. industry dominated world markets in manufactured goods. But by the 1980s, the commercial success of Japanese and European consumer and high technology products caused many U.S. firms to lose significant share in both international and domestic markets.

The success of foreign companies has been due less to their being first to market with new products than to offering the most reliable version of a product with the features that are most in demand and at a competitive price. Consumers, who have come to expect products having no defects and high reliability, have rewarded companies that excel in making incremental improvements to products at a faster pace and at a lower cost than their rivals.

Our economic competitors have made effective uses of advances in manufacturing and engineering design to gain an advantage in the international marketplace, but U.S. industry has been slow to embrace manufacturing innovations. Contributing to this problem has been the failure of American universities adequately to prepare engineers with skills in advanced manufacturing and design. Research in these fields has also been largely neglected by universities and there has been a tendency on the part of industry to ignore even that research which is carried out.

The studies of the National Research Council conclude that major reforms are needed in engineering education. Both reports stress the important interdisciplinary aspect of instruction in design and manufacturing and the importance of closer connections between engineering schools and industry.

To make major changes, engineering faculty will need to devote significant time and intellectual effort to the development of curricular materials and new teaching techniques. Since the current faculty reward system mainly values research accomplishment and success at generating grant support, one of the questions that we will be asking this morning is whether engineering faculty can be expected to support the effort that will be needed to institute major and sweeping changes in engineering education.

The NRC studies also present specific research priorities in engineering design and in five critical areas of manufacturing. We have asked the witnesses to comment on how changes in Federal plans and programs at agencies such as the National Science Foundation that will be needed in order appropriately to address these recommendations.

The connection between cutting-edge capabilities in manufacturing and societal well-being is so direct that it is difficult to imagine a stronger candidate for Federal support than the field that we are addressing this morning. The deficiencies in research and education in engineering design and manufacturing that have been brought to light argue for immediate and effective remedies. In consequence, we will seek from our witnesses today assessments of whether the resources currently planned for this task by the National Science Foundation and other agencies are adequate and whether the focus of current and planned research and education programs is properly targeted.

We welcome our witnesses this morning. We will look forward to your testimony on this important subject. And before calling on this first panel, I would like now to recognize the ranking Republican member of the subcommittee, the gentleman from California, Mr. Packard.

Mr. PACKARD. Thank you, Mr. Chairman.

The connection between advanced manufacturing and U.S. competitiveness is undeniable. We need only to look to the successes of our international competitors, especially the Japanese and the Europeans, to verify this critical link.

To compete in the world market and excel as we did in the post-World War II era, the U.S. must develop advanced manufacturing technologies and educate the future work force that will utilize such technologies.

There is a growing awareness of the importance of manufacturing and engineering design research in the U.S. Today we will review two recent reports by the National Research Council on the state of research and education in this area. We will also look at current NSF programs to improve manufacturing design education and research as well as the new programs focusing on advanced manufacturing which has been proposed in the fiscal year 1993 budget request.

This hearing provides an excellent opportunity to review the recommendations of the National Research Council and the programs at the NSF.

I welcome the witnesses and look forward to a very productive session.

Thank you very much, Mr. Chairman.

Mr. BOUCHER. The Chair thanks the gentleman.

The gentleman from Oregon, Mr. Kopetski.

Mr. KOPETSKI. Thank you, Mr. Chairman. I do not have an opening statement.

[The prepared opening statement of Mr. Costello follows:]

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STATEMENT OF U.S. REPRESENTATIVE JERRY F. COSTELLO (D-IL)

SCIENCE, SPACE, AND TECHNOLOGY SUBCOMMITTEE ON SCIENCE

"MANUFACTURING RESEARCH AND EDUCATION"

MAY 12, 1992

MR. CHAIRMAN, THANK YOU FOR CALLING THIS HEARING. I AM PLEASED TO BE HERE TO DISCUSS THE IMPORTANT TOPIC OF MANUFACTURING RESEARCH AND EDUCATION. I WOULD LIKE TO TAKE THIS OPPORTUNITY TO WELCOME OUR EXPERT PANEL OF WITNESSES. I AM LOOKING FORWARD TO HEARING THEIR TESTIMONY.

WE KNOW, FROM THE POST WORLD WAR II PERIOD UNTIL THE 1960S, U.S. INDUSTRY DOMINATED WORLD MARKETS IN MANUFACTURED GOODS. HOWEVER, BY THE 1980S, THE COMMERCIAL SUCCESS OF JAPANESE AND EUROPEAN CONSUMER AND INDUSTRIAL HIGH-TECH PRODUCTS CAUSED NUMEROUS FIRMS IN THE UNITED STATES TO LOSE SIGNIFICANT DOMESTIC MARKET SHARE. IT IS MY UNDERSTANDING THAT A REASON FOR THIS DECLINE IN U.S. MANUFACTURING IS INFERIOR QUALITY ENGINEERING DESIGN.

I AM INTERESTED IN ADDRESSING TODAY THE DEFICIENCIES IN THE TRAINING OF AMERICAN ENGINEERS. I AM INTERESTED IN HEARING THE RECOMMENDATIONS THE PANEL HAS FOR STRENGTHENING MANUFACTURING AND ENGINEERING DESIGN RESEARCH AND EDUCATION AT U.S. UNIVERSITIES.

AGAIN, MR. CHAIRMAN, THANK YOU FOR CALLING THIS HEARING. I AM LOOKING FORWARD TO AN INSIGHTFUL DISCUSSION OF OUR NATION'S NEEDS IN THE AREAS OF MANUFACTURING RESEARCH AND EDUCATION.

Mr. BOUCHER. We would now like to welcome our first panel of witnesses:

Dr. J.B. Jones, the Co-Chairman of the Committee on Engineering Design Theory and Methodology for the National Research Council and, I am pleased to say, a distinguished professor of engineering at Virginia Tech, which is located in the Chair's congressional district.

Mr. Gary Markovits, member of the Panel on Rapid Product Realization Process, Committee on Analysis of Research Directions and Needs in U.S. Manufacturing, of the National Research Council.

And Dr. George Dieter Engineering Deans' Council of the American Society for Engineering Education, also Dean of Engineering at the University of Maryland.

Without objection, your prepared statements will be made a part of the record, and we would welcome your oral summaries.

Dr. Jones, we will begin with you this morning.

STATEMENTS OF DR. J.B. JONES, COCHAIRMAN, COMMITTEE ON ENGINEERING DESIGN THEORY AND METHODOLOGY, NATIONAL RESEARCH COUNCIL, AND RANDOLPH PROFESSOR EMERITUS, DEPARTMENT OF MECHANICAL ENGINEERING, VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY, BLACKSBURG, VA; GARY MARKOVITS, MEMBER, PANEL ON RAPID PRODUCT REALIZATION PROCESS, COMMITTEE ON ANALYSIS OF RESEARCH DIRECTIONS AND NEEDS IN U.S. MANUFACTURING, NATIONAL RESEARCH COUNCIL, AND VICE PRESIDENT, SAVANT SOLUTIONS CO, WAPPINGERS FALLS, NY; DR. GEORGE E. DIETER, ENGINEERING DEANS' COUNCIL, AMERICAN SOCIETY FOR ENGINEERING EDUCATION, AND DEAN OF ENGINEERING, UNIVERSITY OF MARYLAND, COLLEGE PARK, MD

Dr. JONES. Thank you, Mr. Chairman.

Mr. Chairman, members of the subcommittee, I appreciate having the opportunity to testify here and to point out just some of the key findings of this report of the NRC, "Improving Engineering Design: or Designing for Competitive Advantage."

It is well-known now that manufacturing competitiveness, clearly a key to economic vitality of the Nation, depends on three things in products: first, high quality; low cost; and timeliness to market.

Now, engineering design is critically important for all three of these, and it has a very high leverage on them. You cannot manufacture quality into a product or inspect it in or test it in. It has to be designed in. Over 70 percent of the total final cost of a product is committed—determined—during the design phase. And likewise, the time to market is essentially established during the design phase.

The best design practices, though, are not widely used in American industry. Those firms that do succeed very broadly, though, always do certain things well, and one of these is to use advanced design practices. These advanced design practices require a steady infusion of new knowledge, and this knowledge can only be provided by research and education.

Design education in this country is broken. Despite the great strengths of engineering education in many aspects, typically the engineering design part is weak. This has been noted more and more frequently recently in print by leaders from industry as well as some academics. Now the initiative for improving design education lies with the schools, no question about it, and the report does spell out several steps that need to be taken.

The need for design research comes from this fact. Surprisingly, we do not know how best to design for certain goals: design for manufacturing, design for assembly, design for field repair, design for the environment, which is becoming more important. We need new knowledge, and it will not come fast enough as a spin-off from ongoing design activities. Also, if you depend on the practices that are developed by other companies, especially competitors, you are guaranteeing that your firm will never be a leader.

Therefore, intense focused research in engineering design is needed to develop the new knowledge, and the report presents what I think is a rather well-thought-out, structured research agenda.

The general reaction to the report has been quite favorable. It has been commented on widely in the engineering literature. Entire sessions of engineering meetings have been devoted to it. And, in fact, there are some entire conferences that are taking as the theme of the conference this report.

There are a number of recommendations. I am going to touch on only three of them. One of them is a recommendation that NSF should propose and Congress should fund an initiative in engineering design to support a large increase in design research and a greatly increased interaction between universities and industries. Although design is usually coupled with manufacturing, there are great needs for improving the engineering design process itself. Therefore, the recommended initiative should not be subsumed under some other heading such as "Manufacturing."

What should be done? The research that we recommend is spelled out in the research agenda in the report. Funding would start at, initially, $6 million, increase so that in 4 or 5 million—4 or 5 years it would be at a level of $20 million annually. Now, these figures were arrived at by carefully studying both the need for design research results in industry and the design research capability in the country.

Engineering design research in this country has been neglected for many years. At the same time, design practice, the high-leverage key to manufacturing productivity, urgently needs the revitalization that the research results can provide. So you put these two things together and the impact of these relatively small sums of money can be enormous. No other investment of this size has the potential to increase competitiveness and thereby provide more jobs across the manufacturing industries.

The design research supported by this initiative should require two things a little bit different from the normal academic research. One is there must close, long-term interactions with industrial firms in defining research topics and strategies and in evaluating results. And secondly, there must be prompt publication of these results where they count, in periodicals that are read by design engineers in industry, not just in the scholarly journals.

Now NSF generally does a very good job, so no suggestion is made for changing its general approach or goals. The initiative for engineering design is intended to establish a sound basis for a new area of research vital to the Nation's mid-term and long-term economic growth.

I will mention just briefly two other recommendations. One is for a National Consortium for Engineering Design to perform several functions. The committee studied this, conceived several models for its organization, and decided the best thing to do is make an in-depth evaluation before moving. So the recommendation is that the Department of Commerce and the National Science Foundation jointly, with the assistance of people from industry and academia, study the possible structuring and operation of such a consortium.

The final recommendation I will mention is one for a Design Education Clearinghouse. Although the improvement in design education needs to come chiefly from the institutions themselves, a good deal of help can accelerate that process. So we do recommend the formation of a clearinghouse, not as a permanent organization—perhaps as something that might be taken over by the consortium, if it is formed—but rather something that over the next few years would accelerate the improvement of design education.

The report makes several other recommendations, but the NSF initiative for engineering design is the most urgent of these. It can clearly provide the basis for improved manufacturing competitiveness of American industry.

I thank you very much, and I would be happy to address any questions.

[The prepared statement of Dr. Jones follows:]

ENGINEERING DESIGN RESEARCH AND EDUCATION

Statement of

J. B. Jones
Cochairman of National Research Council Committee on
Engineering Design Theory and Methodology
and
Randolph Professor Emeritus of
Mechanical Engineering
Virginia Polytechnic Institute & State University

before the
Subcommittee on Science
Committee on Science, Space, and Technology
U. S. House of Representatives

May 12, 1992

Mr. Chairman and Members of the Subcommittee:

Thank you for the opportunity to testify on engineering design research and education and to highlight the findings of the National Research Council report, *Improving Engineering Design: Designing for Competitive Advantage*

Manufacturing competitiveness, which is a key to national economic vitality requires in products (1) high quality, (2) low delivered cost, and (3) timeliness to market.

Engineering design is critically important to and has a very high leverage on all three of these elements. Quality cannot be manufactured in, inspected in, or tested in; it must be *designed* in. More than 70 percent of the total delivered cost of a product is committed during the design phase. Likewise, time-to-market is largely determined by design. Still, the crucial role of design as part of the total manufacturing enterprise is sometimes missed because people see only the readily visible part; that is, the part that occurs on the factory floor. Most of the production costs are incurred during the factory operations, but how *much* money is spent and how *effectively* it is used is determined during the engineering design.

The National Research Council report, *Improving Engineering Design: Designing for Competitive Advantage* (National Academy Press, 1991), addresses the state of engineering design practice, education, and research in this country.

Overview of report, *Improving Engineering Design*

Design Practice. A clear finding of the report is that the best design practices are not widely used in American industry. Those firms that are broadly successful always do the following four things well: (1) They commit to continuous improvement of products and also of design and production processes. (2) They establish a corporate product realization process (PRP) supported by top management. (3) They develop and/or adopt and integrate advanced design practices into the PRP. (4) They create a supportive design environment. These steps all bear on design, and doing them well requires a continual supply of new knowledge that can be provided by research and education.

The product realization process (PRP) that is mentioned frequently in the report is the overall process by which new and improved products are brought to market and supported. It includes determining customer needs, designing products, designing production and support processes, and carrying out those processes. The PRP is the means for bringing the talent of all the people in the firm to bear on continual product improvement. The PRP is known by different names in various firms, but those that use design successfully all have some *process* of this sort.

Sometimes, the term "Manufacturing" is used to refer to the entire PRP, including design. At other times, "manufacturing" refers only to that part of the PRP that occurs on a factory floor. This double usage causes confusion. Moreover, it can distract attention from the critical and high-leverage function of design itself. Design practice must be improved in various ways, including some that are not closely coupled to manufacturing.

Design Education. Undergraduate and graduate engineering education is the foundation for successful practice, effective teaching, and relevant research in engineering design. Despite great strengths in many areas, engineering education is typically weak in design. Leaders in industry as well as some academics are making this point in the engineering literature with increasing frequency.

The initiative for improving design education lies clearly with educational institutions. Such improvement will require: recognition of the deficiencies of design education, strong high-level leadership in establishing goals for design education, development of metrics to measure progress, increased interaction between industrial firms and academia, and extensive training programs for design teachers. The report makes several recommendations for improving engineering design education.

Design Research. Surprisingly, we do not know how best to design for many needs: design for assembly, for manufacturing, for maintainability, for field repair, for the environment. We need new knowledge. It will not come rapidly enough as a spin-off from ongoing design activities, and using design methods developed by others relegates a firm always to a trailing position. Intense focused research is needed to develop the new knowledge. The report presents a structured research agenda.

The report makes recommendations in all three areas: practice, education, and research. I will outline some of these later.

Response to the report

The report has been commented on widely in the engineering literature and has been the subject of numerous articles. Sessions at engineering meetings have been devoted to it, and it has been chosen as the theme of entire conferences. Two of the series of satellite television courses presented by the National Technological University have been largely based on the work. Members of the committee that prepared the report have spoken on it at several universities and professional society meetings.

Reactions of industrial representatives, engineering educators, and design researchers have been highly favorable. Many have stated their intentions to implement various recommendations of the report. It is too early to judge the extent of implementation.

Recommendations

1. **Initiative for Engineering Design**

NSF should propose and Congress should fund an Initiative for Engineering Design to support both a large increase in design research and greatly increased university-industry interaction in engineering design.

Although design must usually be closely coupled with manufacturing, there are great needs for research in improving the design process itself. Therefore, the recommended initiative should address those needs and not be subsumed under some broader heading of which design is only a part.

Funding should start at $6 million for the first year and increase to a level of $20 million annually in five years. These figures were arrived at by carefully studying both the needs for design research and the design research capability in the country. (For comparison, although support for research in engineering design is not spelled out clearly in the current NSF budget, it appears that expenditures for such research are currently less than $1.5 million, down from approximately $3.4 million three years ago.)

Engineering design research in this country has been neglected for many years. At the same time, design practice -- the high-leverage key to manufacturing competitiveness -- urgently needs the revitalization that research results can provide. Consequently, the impact of these relatively small sums of money can be great. No other investment of this size has the potential to increase competitiveness and thereby provide more jobs across the spectrum of manufacturing industries.

Design research clearly requires such an initiative. It will be exceedingly difficult, if not impossible, for NSF, the logical funding agency for this research, to allocate substantial funds from its regular budget for this purpose. Various NSF constituencies will not willingly accept funding cuts in their areas, and the "proposal pressure" that drives some reallocations is unlikely to be strong in an area having a short history and limited past funding.

The design research supported by this initiative should require

(1) close, long-term interactions with industrial firms in defining research topics and strategies and in evaluating results,

(2) prompt publication of results in periodicals widely read by design engineers in industry, not just in scholarly journals.

Leadership of the engineering design program within NSF should be provided by personnel identified with engineering design.

NSF provides strong leadership in a number of research areas, and no suggestion is made for changing NSF's general approach or goals. The Initiative for Engineering Design is intended to establish a sound basis for a new area of research vital to the nation's mid-term and long-term economic growth.

2. National Consortium for Engineering Design (NCED)

The NRC report discusses the creation of a National Consortium for Engineering Design for several purposes, including

• gathering and disseminating information on international best engineering design practices;

• transferring existing and new design knowledge, especially in the form of software, into industry and academe;

• performing pre-competitive research to improve design methods and tools;

• promoting industry-university-government collaboration in research and education.

The committee studied possible models of such an organization and concluded that an in-depth evaluation of several alternatives should precede the formation of a consortium. The Department of Commerce and the National Science Foundation, with the assistance of industrial and academic representatives, should jointly study the possible structuring and operation of such a National Consortium for Engineering Design.

3. Design Education Clearinghouse

Although improvement in engineering design education must be initiated by educational institutions, their efforts would be much facilitated in the short term by a design education clearinghouse that would

• collect information on best design practices and research worldwide;

• facilitate the synthesis of this material into textbooks, problem sets, case studies, descriptions of modern design theory and practice, video tapes, computer software, course outlines, and candidate curricula;

• publish reviews of design research, teaching methods, and software tools;

• facilitate the adoption of standards for use in design.

The Clearinghouse is not envisioned as a permanent organization, and its functions might well be absorbed by the National Consortium for Engineering Design if the Consortium is established.

The report, *Improving Engineering Design*, makes several other recommendations, but I have outlined here only those directed to Federal agencies. The NSF Initiative for Engineering Design is the most urgent of these. It clearly can provide the basis for improved manufacturing competitiveness of American firms.

This concludes my statement, and I would be pleased to address any questions you may have.

Mr. BOUCHER. Thank you, Dr. Jones. We will have questions. First, we will hear from the other two panel members.

Mr. Markovits, we will be pleased to proceed with your testimony.

Mr. MARKOVITS. Good morning, Mr. Chairman, and members of the subcommittee. Thank you for the opportunity to report to you on the results of the Committee on Research Directions and Needs for U.S. Manufacturing.

The committee tried to consider four to five areas of advanced manufacturing technology, and we had three criteria in selecting those areas. Number one, the area had to have widespread benefit to multiple industrial applications. Two, it had to promote fundamental change in the management practices and culture, because we don't believe that we are going to achieve the maximum benefits in terms of productivity and yield without those changes accompanying the hard science changes. And three, any projects that were recommended on the basis of these areas had to expand the scientific research relevant to manufacturing processes and problems, and had to take an interdisciplinary approach and encourage more rapport between researchers and practitioners. It had to break down the walls between academia and the manufacturing line.

There were four technical areas that were, and they are four areas that we recommend that more research be done in. One is rapid product realization, the processes and practices that will help this country and its manufacturing companies deliver more products, more innovative products, higher quality products in a shorter period of time.

The second one was intelligent manufacturing control. More and more as we look to the future and we look at what our products look like they have a higher and higher intellectual content. More and more information is required to manufacture those. Intelligent manufacturing control is the sensor technology and other advanced manufacturing technology which basically provides the autonomic nervous system of your manufacturing line. It will provide us with all of the information that we need to understand what it is we are actually producing and how we are producing it.

The third area that we chose was equipment reliability and maintenance. It is very important that if you are going to take and transfer the factory into a learning organization that you have as stable an organization as possible. To get those high quality yields, to get as many learning cycles as we can out of our manufacturing organizations, we need to have stable, reliable equipment.

And the fourth technical area that we chose was advanced engineered materials. We believe that in the future advanced engineering materials will provide properties far beyond anything that we could imagine today that will enable us to enter marketplaces that we've never even dreamed of.

Finally, when we got done selecting the four technical areas we chose one more area which we thought was really the foundation and underpinning of all the others, and that was manufacturing skills improvement. Our feeling today is that the work force that we have is inadequately prepared to participate in the advanced manufacturing technology lines of the future.

In fact, if we were to characterize the transformation, what we think should happen is that manufacturing has to go from a craft to a science as our products have greater and greater intellectual content. You can pick on any product you want to look at, whether it be the Boeing 777 or if you look at something like Intel's I-486, all these have much higher intellectual content than products of the past. We have to have a better prepared work force. The implication is that they have to be skilled in multiple disciplines and at a much higher level than they are today.

You know there was a report in the Economist that said a sample of 20-year-olds, said 60 percent of those 20-year-olds could not add a lunch bill. Sixty percent of them cannot read a road map. You can't have that. In IBM where I've done some work what we found was that the level of education that we needed for the technicians on a semiconductor line has risen from a high school graduate equivalent to the equivalent of a second-year AS degree. So the implication is that we must raise the level of education.

And it's important. Because if you take a look at an advanced manufacturing technology it's going to have a tremendous impact upon us. I think that before Mr. Boucher or Mr. Packard talked about the comparison between our industries and the Japanese industries. If you just pick one, if you just pick metalworking, you will find that with the advanced manufacturing technology that the Japanese use in metalworking that they have only one-fifth the labor required, one-half the number of machines required that we require in the U.S., they have 20 percent higher utilization of their machines, they have almost 100 percent delivery on time, and they have less than 2 percent unscheduled down time, and their quality is tremendous, as you noted before.

Advanced manufacturing technology makes the difference, and it makes the old modes of manufacturing obsolete and it makes the old education obsolete. In fact, the paradigm shift that has to happen is we have to look at the manufacturing line as a learning organism. And I think that when we introduced Taylorism in the 1800s we went and actually eliminated learning for new manufacturing lines. We said, "We're going to break these jobs down into such small sections that anyone can do it," and that was fine when we had to integrate a lot of immigrants—we had to integrate a lot of immigrants into our manufacturing line. But that is not the direction we need for tomorrow.

Successful organizations will be total learning organizations, and learning will occur at every step in the product life cycle from conception to consumption. The factory, as well as the R&D department, has to be involved in that learning.

Along the way, as was mentioned, measurements are very, very key. You mentioned that the measurement system drives people in the universities to go after grants. Well, the measurement system that we have today in manufacturing is really a remnant from the 19th century and is aimed primarily at financial measures. We have to do studies to understand how we put in place measurements that are going to address skills, competencies, the value of a company's technology, how it uses time, what's the company's learning cycle and how rapidly can it learn. Because as quickly as a company can learn, that's how it's going to make those incremental improvements that you were talking about, Mr. Packard, that will make—leading to higher quality, better products that customers are going to buy more frequently, and that's the strength in the manufacturing organization.

Steps for change: I think (1) that we have to restructure the organization to support learning and experimentation in the factory—this is the factory as a laboratory idea; and (2) we have to develop new methods of performance measurements and process life-cycle costing.

Now, in the report that the committee generated, "The Competitive Edge"—it's documented in this book here—there are many recommendations as far as detailed research to be done in things like sensor technology and adaptive knowledge bases. I won't go into those in detail. You can read those in the book.

But what I would like to say is, I would like to close and talk about the character of how that research has to be conducted. There has to be both a fundamental change in the methods and not only just the kinds of research. The typical laboratory experiment that's concerned with absorbing a piece of the system is done in a very controlled environment. The notion of control itself is of concern in the factory, and the performance of an integrated production system can only be evaluated by observing the system as a whole in the factory. And so what I implore you to do is when you fund your research the research should be such that it is deeply intertwined with and works with the factories. It shouldn't be research that's done somewhere in academia in isolation. It should support a close rapport between the academicians and between the manufacturing practitioners.

Thank you.

[The prepared statement of Mr. Markovits follows:]

REVIEW OF THE NATIONAL RESEARCH COUNCIL REPORT

THE COMPETITIVE EDGE: RESEARCH PRIORITIES FOR U.S. MANUFACTURING

Statement of

Mr. Gary Markovits
Member, Panel on Rapid Product Realization Process
Committee on Analysis of Research Directions and Needs in U.S.
Manufacturing Studies Board
Commission on Engineering and Technical Systems
National Research Council

and

Vice President
Savant Solutions Co.
Wappingers Falls, New York
May 12, 1992

Goals

The Committee on Research Directions and needs in U.S. Manufacturing was chaired by Dr. Cyril M. (Sonny) Pierce of GE Aircraft Engines. The goals of the committee were to:

- o Identify and Prioritize Manufacturing-Related Technologies to Produce a Comprehensive National Research Agenda.
- o Conduct a Series of In-Depth Analyses of Some of the Technologies and disciplines in that Agenda.

Criteria and Agenda

To focus committee efforts, three criteria were applied to select the technologies for in-depth analysis.

- The technology must have wide benefits across multiple industrial applications and provide capabilities or experience that can lead to broad improvements in manufacturing operations and competitiveness.
- The technologies should promote fundamental change in management practices and culture to achieve maximum benefits.
- Any recommended project should expand scientific research relevant to manufacturing processes and problems, take an interdisciplinary approach, and encourage closer rapport between researchers and practitioners.

The four advanced manufacturing technology areas selected were:

- Rapid Product Realization Process,
- Intelligent Manufacturing Control,

- Equipment Reliability and Maintenance,

- Advanced Fngineered Materials.

Because of the importance of an educated work force to manufacturing competitiveness, a fifth special area was examined:

- Manufacturing Skills Improvement.

The five areas span the spectrum of people, processes, product, machines, organization and information that is so essential to a complete "systems" understanding of the problems facing American manufacturing competitiveness. A panel of experts for each area was asked to assess the current state of the art and research needs to meet long-term objectives.

Environment

Today's manufacturing environment is vastly different from that which America knew, and dominated, only a few decades ago. Both markets and competitors have become global. High quality products and services, and time-based-competition, have become facts of life.

Producers and consumers have become part of a closed system, where producers have to be as concerned with the success of their customer as with the success of their product. The committee feels that "systems" thinking will be a key ingredient in tomorrow's competitive advantage.

Craft to Science

It is in this light that the committee feels competitiveness will depend upon manufacturing moving from a craft to a science.

Implications for Workforce

One implication is that manufacturing will require a work force possessing multi-disciplinary skills of a much higher order. The committee is concerned that today's educational system is not producing sufficient numbers of graduates possessing such skills. This was the impetus for adding the fifth special area, "Manufacturing Skills Improvement", and is the focus of several recommendations for NSF research.

Learning Organizations

In the last century Taylorism was introduced into the American manufacturing system as a means of absorbing thousands of non-English-speaking immigrants from largely agrarian societies. While highly successful at the time, its legacy has been to eliminate learning from the American factory. In the classical hierarchical American firm, learning is the domain of the research and development organizations. Factories are for "doing", not learning.

Successful organizations will be total "learning organisms". Learning will occur at every step in the product life-cycle, from conception to consumption, in the factory as well as the R&D department.

Soft and Hard Science

While the firms that succeed will be characterized by advanced manufacturing technology that integrates their people, processes, and products, the committee wants to emphasize that "hard" science or technology alone will not suffice. Advanced manufacturing technology will seldom yield the anticipated flexibility and productivity, unless corresponding changes are made in the organization. Basic changes must be made in the processes, structure, and attitudes that are common in engineering management. In engineering, manufacturers must strive to improve interaction among design engineers, production engineers, and marketers. Managers need to reevaluate common management practices and tools, such as accounting methods, investment criteria, inter- and intra-firm cooperation, and relationships with customers, to ensure that all the firm's resources, including manufacturing, constantly are driven to improvement.

Information, Integration & Intelligence

The committee considered four specific technical domains; Rapid Product Realization, Advanced Engineered Materials, Intelligent Manufacturing Control, and Equipment Reliability and Maintenance. It identified an advanced manufacturing technology paradigm common to all four domains -- information, integrated with business functions, achieves various forms of intelligence which are the source of competitive advantage.

Intelligent manufacturing control technology establishes the "central nervous system" of the corporation, providing information on the state of the product, process, people, and equipment. Combined with information on the business strategy, product design, markets and costs, the appropriate business functions derive the intelligence from the relations between these data that generate a competitive advantage.

Beliefs, Values, Goals & Skills

The same paradigm applies to "Manufacturing Skills Improvements". Career esteem, basic literacy, management skills, communications, teamwork, and group dynamics are all forms of information that, when integrated through the proper business functions, become the foundation of a highly adaptive work force. Such a work force will be capable of operating in the complex human-machine cooperative systems environment that will typify advanced manufacturing.

The committee believes current value systems, implicit in the measures of performance, are inappropriate. Devised in the nineteenth century, these primarily financial measures are incapable of assessing skills and competence levels of a corporation, the relative effectiveness of its technology, the value of knowledge gained through continual refinement of its products and processes, its use and conservation of time, or the long term impact of rapid learning-cycles. Increasingly, the product of manufacturing is knowledge. Advanced manufacturing technology will accelerate this trend.

Products are no longer simply discrete physical objects; they are that and all of the people, processes, and information that surround them from conception to consumption. Boeing's 777 will be designed, built, tested, marketed, and sold as much in the form of a "product image", in the "meta-factory" of the computer's information plane, as in the real physical world. Intel's 486 micro-processor is a product that is almost pure knowledge. In fact, its value can only be realized in the information plane, its few grams of silicon having almost no value when separated from the information systems it powers.

How measurement systems value such capabilities will profoundly influence the rate of progress of American manufacturing competitiveness. If we fail to value and fund our ability to manufacture new knowledge, to develop the "learning organization" and the "teaching factory", American manufacturing will almost certainly loose its competitive edge.

Steps for Changing

The committee believes the barriers to manufacturing competitiveness are not insurmountable. To use the enormous amount of information that is available to achieve integration and intelligence in the factory, however, it will be necessary (1) to restructure the organization to support learning and experimentation in the factory (the notion of the factory as laboratory), and (2) to develop new methods of performance measurement and process/life-cycle costing that will enable management to evaluate problems, process improvements, resource utilization, and production management in economic terms. Some industries are already moving on these fronts.

Recommendations

The recommendations of the five panels reporting to the committee can be categorized into domain specific research recommendations, and those related to education and learning for the workforce, management and the organization.

In domain specific categories, the panels' recommendations include research in:

- Developing technique-oriented communication standards,
- Sensor technology for data integration, pattern recognition, and actionable models,
- Adaptive knowledge bases of design, manufacturing, and management,
- Dynamic models of manufacturing,
- Use of human-machine interface to facilitate learning
- Integration of processing methods into design and development of new materials,
- Integration of materials-specific issues in manufacturing paradigms,
- Definition and development of standards for intelligent product images,
- Requisite connections between product, process, and factory images.

Recommendations related to education and learning include research in:

- Basic literacy,
- General engineering knowledge and communication, team, and group dynamic skills,
- Cultivation of apprenticable and job-specific skills in the workplace,
- The factory as a laboratory,

- Knowledge-based organizational structures,
- Performance measurements.

Implicit in the research topics identified by the panels is a need for fundamental change in both methods and kinds of research. The typical laboratory experiment is concerned with observing a piece of a system. The notion of control, taken for granted in the laboratory, is itself the object of experimentation in the factory. The performance of an integrated production system can only be evaluated by observing the system as a whole in the factory.

The factory as laboratory is the new research imperative. It implies new ways of doing research, new forms of collaboration across functions and engineering disciplines, and cooperation between academic scientists and industrial practitioners. Therefore, development of an architecture for learning is critical. How to sponsor and promote the needed new forms of research is a fundamental question that must be addressed.

Close

I would like to thank the chairman and members of the Subcommittee on Science for this opportunity today. I hope my explanation of the work and recommendations of the Committee on Analysis of Research Directions and Needs in U.S. Manufacturing, sponsored by the National Research Council, has clarified the issues and will aid you in making informed decisions on future research and curriculum development in manufacturing and engineering design.

Sincerely,

Gary Markovits

Attachment: Chapter 1 - Overview, from The Competitive Edge: Research Priorities for U.S. Manufacturing.

THE COMPETITIVE EDGE

Executive Summary

ADVANCED MANUFACTURING technology is emerging as a major corporate advantage in world trade. Strategic application of such technology can markedly improve manufacturers' product quality, reponsiveness to customers, process control and flexibility, and flexibility of capital investment—all determinants of global manufacturing competitiveness.

Progress in U.S. manufacturing-technologies and competitiveness faces significant barriers: inflexible organizations; inadequate technology; inappropriate performance measures; and lack of appreciation for the importance of manufacturing. These barriers are addressed in this report of the Committee on Analysis of Research Directions and Needs in U.S. Manufacturing, Manufacturing Studies Board, Commission on Engineering and Technical Systems, National Research Council The report identifies and analyzes research needs in five critical areas of manufacturing: intelligent manufacturing control, equipment reliability and maintenance, advanced engineered materials, manufacturing skills improvement, and the product realization process.

Intelligent manufacturing control requires research in several areas. They include: sensor technology in data integration and pattern recognition; adaptable knowledge bases of design, manufacturing, and management intelligence; and creation of a dynamic model of manufacturing.

Equipment reliability and maintenance programs are underutilized in this country largely because of manufacturing managers' lack of awareness of their economic benefits. Technology problems associated with these programs are more tractable than the associated people problems.

Needs in advanced engineered materials include integration of processing methods into the design and development of new materials from the beginning. A need exists also to instill sensitivity to materials' properties into process design schemes.

The product realization process—from initial idea through marketing—has research needs in three areas: developing intelligent product images, establishing the requisite connections among them, and devising an organizational structure in which these concepts can be made operational.

Manufacturing skills improvement is critical to advanced manufacturing technology with its need for work-force skills that U.S. schools are neither cultivating nor preparing students to acquire. The first need is basic literacy. The goal is a manufacturing work force with multidisciplinary skills of a high order.

Fruitful pursuit of the recommended research could transform U.S. manufacturing. Potential results include:

- Highly specialized processing of metals, ceramics, and polymers to yield radical improvements in materials' strength and toughness;
- Equipment operators working synergistically with intelligent control systems that are capable of predicting, preventing, or automatically remedying equipment failure;
- Autonomous manufacturing control systems that exploit human powers of perception, pattern recognition, and problem-solving in conjunction with machine capacity for manipulating vast amounts of data;
- Global information systems that enable electronic virtual enterprises to access and coordinate the localized design and manufacturing capabilities of village industries all over the world; and
- Production handled by highly skilled professionals working as components of human-machine systems that are linked integrally with management functions.

To achieve such results the manufacturing community must learn from and adopt the fruits of the research proposed, and the nation must reinvigorate its educational system. Manufacturing would then come to be viewed as a national asset and careers in manufacturing would be highly regarded.

1

Overview

ADVANCED MANUFACTURING technology, because its strategic application results in important competitive advantages, including higher quality, greater responsiveness to consumer demands, and greater flexibility of capital investment, is emerging as a major corporate advantage in world trade. Development and deployment of advanced manufacturing technology will be affected by a host of factors, including capital, markets, tax and trade policy, corporate management, and skills.

In a world that has come to expect zero defects and high reliability, manufacturing[1] will move from a craft to a science, thereby requiring a much smaller work force that possesses multidisciplinary skills of a high order. Figures 1-1 to 1-3 show this projected decline in manufacturing employment to the year 2000. In Figure 1-1, manufacturing employment is shown to decline by almost 20 percent between 1950 and 2000. In Figure 1-2, employment in more highly skilled occupations (i.e., computer specialists, electrical engineers, etc.) shows an increase from 9 to 52 percent between 1988 and 2000, while less highly skilled job categories (i.e., machine tool operators) showed a 5- to 44-percent decline. And in Figure 1-3, manufacturing is shown to be the only occupational group to show declining employment, in contrast to groups such as professional and technical workers, which shows a 24-percent projected increase between 1988 and 2000. The new skills that this smaller work force will need are dictated by three characteristics of advanced manufacturing technology:

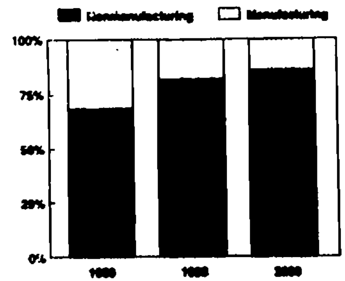

FIGURE 1-1 Employment by industry sector, 1950, 1983, and 2000. Source: W. B. Johnston and A.H. Packer. 1987. Workforce 2000: Work and workers for the 21st century. Hudson Institute. 51-73.

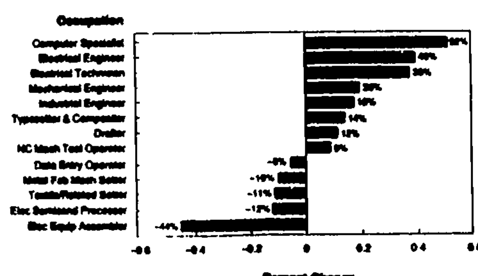

FIGURE 1-2 Projected employment changes, 1988-2000. Source: Projections of occupational employment, 1988-2000. 1989. G. Silvestri and J. Lukasiewicz Monthly Labor Review (112:11): 42-65.

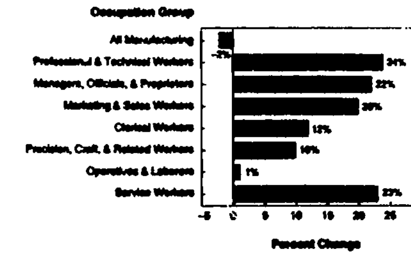

FIGURE 1-3 Projected manufacturing employment changes, 1988-2000. Source: Projections of occupational employment, 1988-2000. Source: G. Silvestri and J. Lukasiewicz. 1989. Monthly Labor Review (112:11):42-65.

- its integration of information and materials handling and processing, which are separate in traditional automation;
- its reliance on higher levels of human and machine intelligence rather than on the skill of operators; and
- its placement of the production process largely under the control of computer programs into which product and process specifications are fed as computer instructions.

Firms that use advanced manufacturing technology will thus be distinguished less by their manufacturing processes than by the integrated systems that drive those processes. Creative use of the technology will yield greater competitive advantage. That is, the benefits of advanced manufacturing technology will depend more heavily on the people who develop the systems that determine the range and types of products that can be produced and resolve the contingencies that arise in production, than on the hardware that is likely to be available to any company that can pay for it. Figure 1-4 shows for the period 1973 to 1983 the educational attainment in manufacturing as a percentage of all manufacturing employees.

The nature of the new skills required is perhaps best understood in terms of the changes that will accompany the development and deployment of advanced manufacturing technologies. Tight integration of information and materials processing (see Chapter

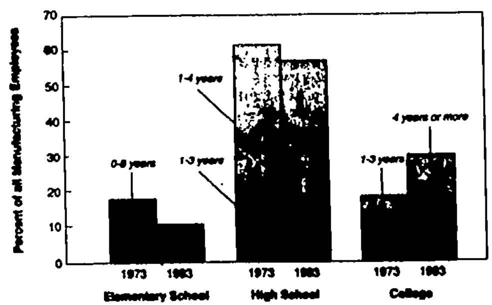

FIGURE 1-4 Educational attainment in manufacturing, 1973 and 1983. Source Projections of occupational employment, 1988-2000. Source: G. Silvestri and J Lukasiewicz 1989. Monthly Labor Review (112:11):42-65.

5) will extend from choice of product, to design, to materials transformation and/or product assembly, and, finally, to marketing and distribution. Scheduling and resource allocation will be integrally linked to, and occur simultaneously with, planning in both the extremely short term (e.g., product time to market) and very long term (e.g., technology development and/or acquisition). Intelligent manufacturing control (see Chapter 2) will provide a means of controlling and recording continuous information about what is happening on the factory floor, and means of reporting the information on which operators and managers rely to make decisions. Control will be exerted primarily at the level of the work cell, will require significant intercell coordination, and will involve skills that have both human and machine components. Decision making in this context will require an understanding of logical relationships and statistical correlation and involve teamwork among peers. A growing portfolio of products and processes, machines and operators, and external forces will provide multiple windows for viewing problems, creating a concomitant demand for broader experience.

Time-to-market pressures that attend advanced manufacturing technology will drive organizations to compress their organizational hierarchy become flatter—in order to push more responsibility down

to the factory floor. Operators, for example, will be called on to perform tasks that formerly were divided among several workers with different job classifications (e.g., machine setup and adjustment and quality monitoring, as well as operation). To maintain production while performing the frequent adjustments that are required by complex, integrated manufacturing systems, operators will have to be able to analyze problems and implement solutions, often in the form of computer programming. Operators will increasingly control production rather than be controlled by it.

The growing importance of manufacturing skills is best seen in light of the significance of advanced manufacturing technology. Product and process specifications that exist as computer instructions are highly transportable. Such transportability, together with the flexibility inherent in advanced manufacturing technology, creates a context in which a product can be produced anywhere, at home or abroad, by anyone with the requisite hardware. This situation renders production capacity a commodity.

The Japanese metalworking industry, using advanced manufacturing technology, has demonstrated remarkable increases in productivity: fivefold reductions in labor, reductions by half in the number of machines required, increases in machine utilization of more than 20 percent, delivery performances of 100 percent over three months, unscheduled system downtimes of 2 percent, and quality problems at the level of 0.006 percent (see Tables 1-1 and 1-2). Advanced manufacturing technology makes traditional

TABLE 1-1 Comparison of Flexible Manufacturing Systems Studied in the United States and Japan

Manufacturing Systems Variables	United States	Japan
System development time (years)	2.5 to 3	1 25 to 1 75
Number of machines per system	7	6
Types of parts produced per system	10	93
Annual volume per part	1,727	258
Number of parts produced per day	88	120
Number of new parts introduced per year	1	22
Number of systems with untended operations	0	18
Utilization rate* (two shifts)	52%	84%
Average metal-cutting time per day (hours)	8.3	20 2

*Ratio of actual metal-cutting time to time available for metal cutting.

SOURCE. R Jaikumar Post industrial manufacturing 1986 Harvard Business Review, Vol 64.

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TABLE 1-2 Human Resource Requirements for Metal-Cutting Operations to Make the Same Number of Identical Parts

	Conventional Systems		Flexible Manufacturing Systems
Operation	United States	Japan	Japan
Engineering	34	18	16
Manufacturing overhead	64	22	5
Fabrication	52	28	6
Assembly	44	32	16
Total workers	194	100	43

NOTE: At the time of this study, no U.S. machine tool producer had a flexible manufacturing system on line.

SOURCE: R. Jaikumar. Post-industrial manufacturing. 1986. Harvard Business Review, Vol. 64.

modes of production obsolete. Firms that hope to compete in the world market have no choice but to adopt it and learn to use it to their greatest advantage.

A 1988 Department of Defense report[2] found serious, if irregular, indications of decline in sectors of the industrial base that are critical to continued U.S. leadership in advanced technologies and, by extension, to national security. The report finds particularly devastating the erosion of production technologies and equipment in vitally important sectors such as machine tools and electronics manufacturing equipment (see Tables 1-3 and 1-4). Noting

TABLE 1-3 Top 10 Merchant Integrated Circuit Makers

Rank	1976	1986	1996
1	Texas Instruments	NEC	IBM
2	Fairchild	Texas Instruments	NEC
3	Signetics	Fujitsu	Fujitsu
4	National	Hitachi	Hitachi
5	Intel	Motorola	Toshiba
6	Motorola	Toshiba	Texas Instruments
7	NEC	Philips	Matsushita
8	GI	National	Mitsubishi
9	RCA	Intel	Samsung
10	Rockwell	Matsushita	Seimens

SOURCE: Microelectronic Engineering at RIT Manpower for Tomorrow's Technology

TABLE 1-4 Percentage of the World Semiconductor Market

Year	United States	Japan	Total (in billions of dollars)
1980	60%	27%	$10
1988	36%	53%	$46
2000	?	?	$200

SOURCE: Semiconductor Industry Association.

that these are but the leading edge of scores of other technologies in which other nations are developing advanced manufacturing technologies for advanced products, the report suggests that U.S. industry cannot hope to compete in the world market with only technological equivalence. Nor can it expect to develop advanced technology without concurrently developing a work force that is competent to use it.

CHANGING GROUND RULES OF MANUFACTURING COMPETITIVENESS

Product quality, responsiveness to customers, process control and flexibility, and development and maintenance of an organizational skill base capable of spurring constant improvement have become the determinants of global manufacturing competitiveness. Manufacturers must adapt in order to succeed in these circumstances.

This report examines five critical areas in which such adaptation must be pursued. First, to improve equipment reliability, decrease cycle times, and achieve the greater precision dictated by demands for higher quality, manufacturing will have to adopt and further develop *intelligent manufacturing control.* Second, manufacturing must maximize the productivity of its capital invesrments through improved *equipment reliability and maintenance* practices. Third, manufacturing must enhance product characteristics—for instance, by using *advanced engineered materials* to reduce weight, broaden service temperature capabilities, impart multifunctionality, or improve life cycle performance. Fourth, to speed time to market, manufacturing must employ *product realization* techniques and adopt organizational changes that foster effective use of these techniques. Finally, creation of the new work force—highly adaptable and possessing multidisciplinary skills of a high order—that is critical to the application of these techniques and technologies will necessitate a focus on *manufacturing skills improvement.*

Effective management of modern enterprises is characterized by a high degree of interfunctional integration and coordination at a variety of levels. In short, it requires a systems view. The new learning organization is depicted in Figure 1-5. A competitive environment imposes a continuing need for an organization to move from the present state to a more competitive state. The catalyst of change may occur at any level, but a successful transition cannot be made unless the ramifications of change are assessed and accommodated at all levels.

Advanced manufacturing technology will seldom yield the anticipated flexibility and/or productivity in an organization unless corresponding changes are made in the organization itself and in its information systems and resources. Basic changes must be made in the processes, organization, and attitudes that are common in engineering and management. In engineering, manufacturers must strive to improve interaction among design engineers, production engineers, and marketers. Managers need to reevaluate common management practices and tools, such as accounting methods, investment criteria, inter- and intrafirm cooperation, and relationships with customers, to ensure that all the firm's resources, including manufacturing, constantly are driven to improvement.[3]

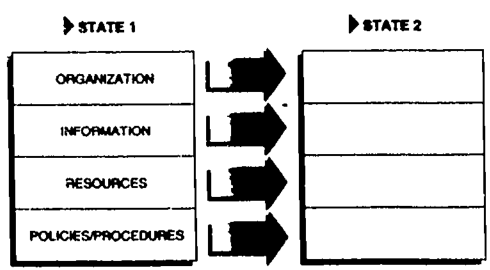

FIGURE 1-5 The new learning organization.

Implementation of advanced manufacturing technology has a pervasive effect on engineering, management, and the whole manufacturing environment. Advanced manufacturing technology has made information and materials processing effectively one entity. Management's responsibility for directing the flow of information is diminishing as information about manufacturing efficiency and capability is increasingly captured at the factory level. Teams working in the factory can use this information to solve problems and achieve superior process capability. The vast amounts of data collected by advanced manufacturing technology enable workers to supplement experience and trial-and-error problem-solving approaches with scientific method—for example, by performing experiments and building and refining models of production. Increasingly, learning is becoming the focus of the manufacturing plant.

The rest of this overview examines conditions antecedent to establishing a research agenda for manufacturing—specifically, a three-pronged theoretical basis for manufacturing and barriers to competitiveness—and suggests steps for changing. The research agenda is developed in the subsequent chapters.

A THREE-PRONGED THEORETICAL BASIS

The changes that attend the development and deployment of advanced manufacturing technology involve the availability of *information* and the *integration* of that information with business functions to achieve various kinds of *intelligence*. Figures 1-6 through 1-10 illustrate, for each of the topics covered in subsequent chapters, representative forms of organizational intelligence that can be realized from integration of domain-specific information.

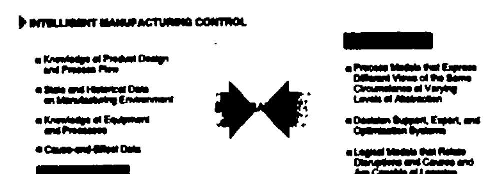

FIGURE 1-6 Organizational intelligence realized from integration of domain-specific information: Intelligent manufacturing control.

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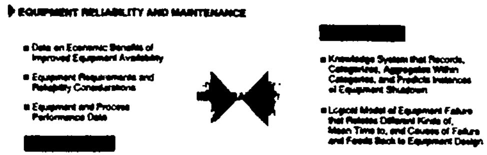

FIGURE 1-7 Organizational intelligence realized from integration of domain-specific information: Equipment reliability and maintenance.

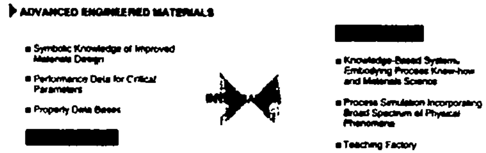

FIGURE 1-8 Organizational intelligence realized from integration of domain-specific information: Advanced engineered materials.

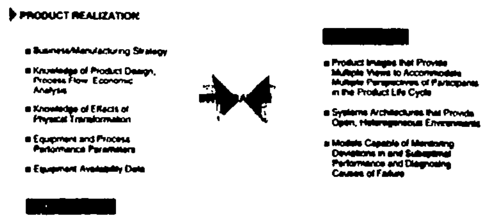

FIGURE 1-9 Organizational intelligence realized from integration of domain-specific information: Product realization.

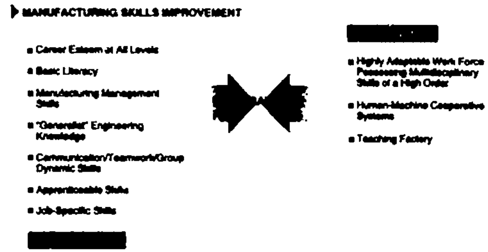

FIGURE 1-10 Organizational intelligence realized from integration of domain-specific information: Manufacturing skills improvement.

Information

Advanced manufacturing technology facilitates the collection of enormous amounts of data. The controlling computer in a computer-integrated manufacturing system records every finite state in manufacturing operations as a series of snapshots. Computers can record hundreds of thousands of these states every second; they can examine one state, control its activity by some defined procedure, and then move on to the next state. The ability of a computer to observe a phenomenon in one state and use that observation to control an activity in the next is the essence of intelligent manufacturing control (IMC).

Many computer-controlled snapshots must be aggregated to provide a picture of a time period that is sufficiently long to be useful to managers. Aggregated snapshots permit managers to compare the current state of a system to the expected state and to relate events to corrective actions. The large volume of data that such systems collect necessitates additional programming to identify and store only dynamic information that typically is part of an investigative problem-solving activity.

The enormous quantities of data include a variety of types of information. At the raw materials end are property data bases, performance data for critical parameters, and information on safety, environmental, economic, and educational factors. Equipment data range from information about what constitutes reliability and maintenance, to scheduled and actual equipment and process performance data, to data that illustrate the benefits of improved reliability and performance. Data relevant to IMC include state and historical data on the manufacturing environment as well as cause and effect data. The product realization process (PRP) relies on information on products and processes, control of equipment, and the effects of physical transformations of materials, as well as on the organization of production work, market and production problems, and variations in practice in different industries and national settings.

Integration

Information must be integrated into manufacturing operations at two levels: across process control and improvement, and across functions. Consider the integration at the raw materials end. Functional integration occurs, for example, when symbolic knowledge of improved materials design is integrated with process planning. The need to integrate measurement and control of critical process parameters with data on the performance of advanced engineered materials is addressed by IMC. Other types of integration relevant to IMC include machine and process flows in the factory, and human knowledge and machine intelligence.

With respect to reliability and performance data collected on the factory floor, integration is needed between (1) equipment user and supplier, (2) equipment requirements and reliability considerations, and (3) equipment reliability and cost accounting.

Product realization relies on integration of design and manufacturing to support parallel product development, of business logistics (to include supplier and codesigner), and of IMC with design and production. On the organizational side, the PRP relies on integration of (1) knowledge of the viability of alternative concepts, accurate evaluation of costs (e.g., equipment reliability and maintenance), market-imposed constraints, and opportunities afforded by technological change, and (2) the conception and implementation of new manufacturing technologies. (Figure 1-11 illustrates the integration of product realization, IMC, and equipment reliability and maintenance.)

Intelligence

Information is incorporated into business functions to gain a better understanding of the manufacturing process and its ele-

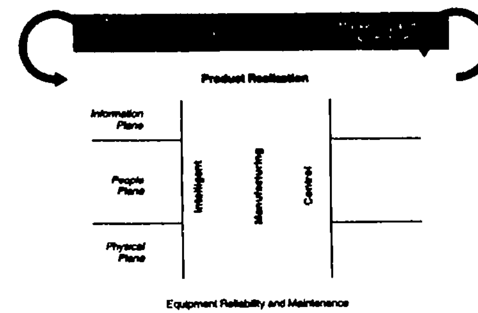

FIGURE 1-11 Integration across functional areas.

ments. The benefits of incorporating raw materials information include, for example, process simulations that incorporate extensive physical parameters and expert systems that embody both processing knowledge and materials science. Incorporation of equipment reliability and maintenance (ERM) data yields both knowledge systems that record, categorize, aggregate within categories, and predict instances of equipment shutdown; and logical models of equipment failure that relate different kinds of, mean time to, and causes of failure and uses this information in equipment design. Incorporation of the vast stores of data gathered by IMC systems facilitates the development of process models that express different views of the same circumstance at varying levels of abstraction; decision support, expert, and optimization systems; and logical models that relate disruptions to causes and are capable of learning. Pairing such developments with product realization yields product images that accommodate the multiple perspectives in the product life cycle; system architectures that provide open, heterogeneous environments; models capable of monitoring performance deviations and suboptimal performance and of diagnosing causes of failure; systems that encourage and foster nontraditional thinking; and organizational ability and incentives to be open to change.

BARRIERS TO COMPETITIVENESS

This section addresses four significant barriers to U.S. manufacturing competitiveness: inflexible organizations, inadequate technology, inappropriate performance measurer, and a general lack of appreciation for the importance of manufacturing. The first three barriers may be changed from within. Industry, however, contributes to the fourth barrier by failing to provide financial and psychological incentives that might promote careers in manufacturing.

Inflexible Organizations

Manufacturing behavior in the future will continue to be driven by market as well as nonmarket factors. Market factors are those defined by technological opportunity, business strategy, and the competitive environment, and they interact to determine the investments a firm must emphasize to maintain a chosen competitive advantage. Trends in manufacturing competition and technological possibilities, for example, are driving firms to emphasize production flexibility in order to maximize their responsiveness to customers without sacrificing cost competitiveness. Nonmarket factors are outside forces such as national security, demographics, urban congestion, the regulatory regime, and social concerns over the integrity of the environment that force particular types of investments and technological developments. Nonmarket factors force firms to explore nontraditional approaches to organization and to reevaluate conventional product and process technologies. Standard approaches to solving the varied and conflicting problems that arise as a result of both market and nonmarket factors often are inadequate or completely ineffective New manufacturing solutions, unconstrained by existing infrastructures, technologies, modes of business, or investment, are needed.

Inadequate Technology Base

The technology base of U.S. manufacturing has many types of problems, ranging from quality control to evaluation. A fundamental deficiency is the lack of standards—for design and test, for measurement and evaluation, for data communications, and for operator-equipment interfaces Standards also are essential to the development of dynamic knowledge bases that are capable of adapting to change. Lacking as well is an information architecture that integrates hu-

man and machine intelligence to yield knowledge acquisition techniques that can support rapid start-up. Ultimately, these knowledge bases must give rise to a dynamic model that encompasses design, manufacturing, and management. Also needed is sensor integration, which will be a key ingredient of the dynamic model. Sensor integration is essential for developing reliable process models that represent the physical characteristics, structure, processing, manufacturing, performance, and cost of advanced engineered materials. And, finally, predictor maps are needed to achieve a better understanding of the interdependence of these considerations.

Such modeling and integration will rely on the development of a host of high-performance tools, including design compilers and synthesizers, rapid imaging devices, and selection analysis systems based on artificial intelligence and expert systems.

Because of the increasing importance of advanced manufacturing technology to international competitiveness, strong consideration also must be given to improving the U.S. technology skill base. This base includes both operators capable of learning to interact with intelligent equipment and managers capable of making informed decisions about acquiring and deploying such equipment.

Inappropriate Performance Measures

Much of the apparent weakness of U.S. manufacturing is attributed to reliance on inappropriate financial measures to evaluate manufacturing efficiency and corporate performance. Devised in the nineteenth century, and still the basis of the entire manufacturing infrastructure, these measures have failed to keep up with the major changes in the nation's manufacturing systems. Management analyst Peter Drucker cites four examples: (1) cost accounting systems assume that blue-collar labor accounts for 80 percent of all manufacturing costs (excluding raw materials), even though 8 to 12 percent is rapidly becoming the standard; (2) the benefits of changing a process or system are measured primarily in terms of labor cost savings (rather than in optimization of equipment utilization); (3) since only costs of production are measured, nonproduction costs, such as machine downtime or defective products, are ignored; and (4) because the factory is considered an isolated entity, only cost savings realized in the factory are significant—process changes that might increase service quality or product acceptance in the market are ignored.[4]

Alternative measures, and creative ways of substituting them for financial measures, are badly needed. In particular, measures are needed to assess the skills and levels of performance of an enterprise's employees, the relative effectiveness of its technology, the value of knowledge gained through continual refinement of its products and processes, its use and conservation of time, and concepts such as the impact of speeded cycle times or flexibility. Unfortunately, little is known about how to quantify, represent, use, and report these criteria, even though they will increasingly determine manufacturing competitiveness.

Lack of Career Esteem

The image of manufacturing as a career has not evolved at the same rate as the manufacturing environment. Despite the advanced manufacturing technology that requires operators with high-level, multidisciplinary skills, manufacturing retains a sweatshop image, characterized by dirty work in noisy environs. Manufacturing receives little promotion from career guidance counselors and the generally low esteem in which manufacturing is held is reinforced by companies' recruitment policies, which often rank manufacturing engineers below design engineers.

Even if this image problem were to be solved, manufacturing will still face a very real, and growing, shortage of qualified people. The current applicant pool from U.S. schools is largely unqualified for highly skilled, professional manufacturing jobs. The state of education in the United States is exemplified by *The Economist's* report of a sample group of 20-year-olds, of which 60 percent could not add a lunch bill or read a road map,[5] and by one employer's experience of soliciting 15,000 applicants to find a pool of 800 who could pass an elementary entrance examination.[6]

The qualifications of manufacturing management also come into question. Among Japanese users of advanced manufacturing technology, most managers have been trained as engineers. Most U.S. manufacturing managers have graduated from programs that stress financial management and have spent little or no time on the shop floor.

STEPS FOR CHANGING

The barriers to manufacturing competitiveness recounted above are not insurmountable. To use the enormous amount of information that is available to achieve integration and intelligence in the factory, however, it will be necessary (1) to restructure the organization to support learning and experimentation in the factory (the

notion of the factory as laboratory), and (2) to develop new methods of performance measurement and process/life-cycle costing that will enable management to evaluate problems, process improvements, resource utilization, and production management in economic terms. Some industries are already moving forward on these fronts.

The approach to process control costing can be changed fundamentally by focusing on the cause of process or product variance and attempting to capture all of the associated economic consequences. The costing system would view the production process as running exactly as expected unless disrupted by an event, would recognize such events, identify the effects of each event on the entire production process, and report this information to management. The power of this approach lies in the ability to identify events and their economic consequences simultaneously. To relate an event to performance measures and, subsequently, to make an economic decision to control a process requires:

- the ability to translate the event and the performance measure into monetary terms,
- a scientific model that relates production parameters to process parameters,
- an economic model that relates resource utilization to process capacity,
- knowledge of all the controllable parameters and constraints on production,
- a time scale for every controllable feedback and feed-forward loop, and
- knowledge of the relationship between a set of controllables and a set of resources.

As an example of costing events, contingencies, and process improvements, consider machine downtime. It is first necessary to determine for the machine a value per unit of time. This shadow cost of capacity can be obtained through a variety of methods related to capacity utilization. A production monitoring system provides information about all machine shutdowns (e.g., causes, durations). These events are classified by category and aggregated within categories. Given the opportunity cost of downtime, it is possible to calculate the benefit of reducing or eliminating each category of downtime. The example can be taken a step further, to the development of a logical model of machine failure that relates different kinds of failure, mean times between failure, and causes of failure. As information is gathered about production processes, one can begin to assess the impact of different causes of machine failure. The model needed for process control costing is precisely the model needed to control a process. A process control costing system adds to this model the economic value and economic cost of reducing or eliminating the different causes of failure. The benefit realized equals the time saved multiplied by the opportunity cost of that time. The cost is the cost of the resources—in terms of new procedures, maintenance, new sensors or tools, and personnel—required to make a given change.

FINDINGS OF THE PANELS

Each of the five critical areas of manufacturing examined in this report is covered in a separate chapter. Summaries, including research needs, are provided below.

Intelligent Manufacturing Control

Chapter 2 examines the tight coupling of sensor technologies and software systems that manifests machine intelligence when some degree of synergy with a human interface is achieved. A framework is established for thinking about IMC in terms of domains of control that correlate with a compressed organizational hierarchy and levels of feedback time. Research efforts should be aimed at (1) developing technique-oriented communication standards; (2) refining sensor technology in data integration, pattern recognition, and actionable models; (3) building knowledge bases of design, manufacturing, and management intelligence that can adapt to changing knowledge and organizational structures; (4) creating a dynamic model of manufacturing; (5) identifying ways to use the human-machine interface to facilitate learning in an integrated environment; and (6) redefining methods to accommodate holistic research in a production environment (i.e., the factory or laboratory).

Equipment Reliability and Maintenance

ERM, covered in Chapter 3, includes both manufacturing equipment and the technical, operational, and management activities required to sustain the performance of such equipment throughout its working life. ERM has the potential to affect three key elements of manufacturing competitiveness: quality, cost, and product lead time. Several cases illustrate effective applications of ERM

programs, both in the United States and abroad. The limited penetration of such programs in this country is attributed in large measure to manufacturing managers' lack of awareness of the economic benefits of improved equipment availability. Technological problems that are associated with the implementation of ERM programs are considered to be more easily solved than are people problems.

Advanced Engineered Materials

Chapter 4 focuses on manufacturing involving advanced engineered materials (AEMs). Barriers to optimization outside the normal scope of manufacturing science and engineering are considered, as are future needs and directions. Challenges to the integration of AEMs into manufacturing operations include (1) both the need to integrate processing methods into the design and development of new materials from the beginning and the need to instill awareness of and sensitivity to materials' properties into process design paradigms; and (2) deficiencies in process simulation and modeling, knowledge-based systems applications, sensor applications, and technical cost modeling. Research should focus on needs in the areas of materials science and engineering, expanded and revised educational programs and objectives, and methods for better integrating materials-specific issues in manufacturing paradigms.

Product Realization Process

Product realization is both a consequence of and a response to pressures of time-based competition. The product realization process (PRP), discussed in Chapter 5, has both technological and organizational components. Technological enablers are needed to support the development of a universal product image that will be in sync with the views of the many participants in the product life cycle. Existing information architectures will not support the development of such images. Development of a universal product image also will rely on and engender a need for alternative organizational structures. Tomorrow's business organization is expected to resemble less a hierarchy than a peer network configured for mutual benefit. Research in this area should be directed at defining, identifying specific instances of, and developing intelligent images; identifying and establishing the requisite connections among these images; and devising an organizational structure in which these concepts can be made operational.

Manufacturing Skills Improvement

Effective deployment of advanced manufacturing technology, as pointed out in Chapter 6, relies on a host of skills that U.S. schools are neither cultivating nor preparing students to acquire. The first need is basic literacy. Then, beyond primary and secondary education, is a need for general engineering knowledge and the development of communication, team, and group dynamics skills. In the workplace, greater concentration is needed on the cultivation of apprenticeable and job-specific skills. Finally, the public must be made more aware of the importance of manufacturing to the national economy, starting with the development of career guidance materials for all levels of the educational system. The new manufacturing work force, destined to function increasingly as a component of human–machine cooperative systems, must be highly adaptable and possess multidisciplinary skills of a high order.

Implicit in the research topics identified in each chapter is a need for fundamental change in both methods and kinds of research. The typical laboratory experiment is concerned with observing a piece of a system, e.g., the signal-to-noise ratio is artificially high, and many of the variables are controlled. The notion of control, taken for granted in the laboratory, is itself the object of experimentation in the factory. In a production environment, it is necessary to study an enormous amount of information, including production histories, for a variety of integrated processes. The performance of an integrated production system can only be evaluated by observing the system as a whole in the factory.

The factory as laboratory is the new research imperative. It implies new ways of doing research, new forms of collaboration across functions and engineering disciplines, and cooperation between academic scientists and industrial practitioners. Therefore, development of an architecture for learning is critical. How to sponsor and promote the needed new forms of research is a fundamental question that must be addressed.

VISION

If the research proposed in this report is undertaken and proves fruitful, if manufacturing learns from and adopts the fruits of that research, if manufacturing gains well-deserved esteem, and if the nation proves equal to the task of redirecting and reinvigorating its educational system, manufacturing might achieve the vision summarized here.

Next-generation manufacturing will add more value during fabrication by placing greater emphasis on tailoring the specific properties of materials to specific uses. Highly specialized processing of metals, ceramics, and polymers stacked in interpenetrating layers will yield radical improvements in materials' strength and toughness and greatly reduce weight. Techniques for producing semiconductor materials at lower temperatures will dramatically reduce defects in devices of extremely small geometry. The design of next-generation manufacturing equipment will occur along with the design of the processes that will use this equipment and will draw on extensive bodies of performance data and user experience. Recognizing the productivity gains that can be realized from improved equipment availability, manufacturing managers will implement extensive programs of predictive maintenance. Maintenance will be performed by equipment operators, interacting synergistically with intelligent control systems capable of predicting and, in some instances, preventing or automatically remedying, equipment and control systems failures.

Intelligent control will extend throughout the manufacturing system. Autonomous control systems that achieve synergy between human and machine will exploit human powers of perception, pattern recognition, and problem solving in conjunction with machine capacity for manipulating vast amounts of quantitative data to learn from each situation encountered and decision made. The plant will become a locus of learning; linkages among individual intelligent controllers will support a systemwide view of the interrelationships among unit operations in the manufacturing cycle, facilitating the timely sharing of important process revisions, quality information, and overall system objectives.

Product realization techniques will increasingly substitute the content of a burgeoning knowledge base for traditional material inputs to the manufacturing process. The reduction of product and process specifications and manufacturing capabilities to intelligent images, capable of interacting with one another, will permit entire product life cycles to be simulated to evaluate trade-offs before producing a prototype. Indeed, prototypes will increasingly become the first units of production rather than preproduction models. Emphasis on maximizing capacity utilization and minimizing investment will shift production to a largely subcontracted function. Firms, radically restructured internally, will use advanced communications technologies to manage external relationships in a constantly shifting pattern, often cooperating and competing on different contracts at the same time. Global information systems will enable electronic virtual enterprises to access and coordinate the localized design and manufacturing capabilities of village industries all over the world. Nations' competitive positions will be determined by their positions in the world information market, which in turn will be determined by investment in the information infrastructure. World boundaries will be determined less by national affiliation than by class affinity for information categories.

Production will increasingly be handled by highly skilled professionals functioning as components of human–machine cooperative systems, and integrally linked with management functions in a compressed ("flat") organizational hierarchy that is characterized by peer-to-peer relationships. Manufacturing careers will be highly regarded and avidly pursued by well-educated youth who have been familiar with manufacturing enterprise since elementary school. Colleges will turn out Renaissance engineers and business schools managers who understand technology and the workings of their plants as well as the composition of their balance sheets. Job-specific skills will be imparted through nationally coordinated vocational and apprenticeship programs and satellite distribution networks.

Manufacturing will be regarded as a national asset, to be protected, cherished, and nurtured. Esteem for manufacturing will rise to the level of its technology.

NOTES

1 Manufacturing in this report is understood to be the processing of raw material inputs and the assembly, mixing, or other coalescence of outputs into high-quality, low-cost, salable products. The contrasting use of "manufacturing" in Chapter 6, Manufacturing Skills Improvement, is not a definition but a very important image issue It reflects a perception of the definition that is increasingly at variance with the reality of manufacturing that employs advanced technologies Qualifying this perception is very important to building career esteem

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IMPROVING ENGINEERING DESIGN

Designing for Competitive Advantage

Committee on Engineering Design Theory and Methodology
Manufacturing Studies Board
Commission on Engineering and Technical Systems
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1991

Executive Summary

Engineering design is a crucial component of the industrial product realization process. It is estimated that 70 percent or more of the life cycle cost of a product is determined during design. Effective engineering design, as some foreign firms especially have demonstrated, can improve quality, reduce costs, and speed time to market, thereby better matching products to customer needs. Effective design is also a prerequisite for effective manufacturing. Improving the practice of engineering design in U.S. firms is thus essential to industrial excellence and national competitiveness.

Unfortunately, the overall quality of engineering design in the United States is poor. The best engineering design practices are not widely used in U.S. industry, and the key role of engineering designers in the product realization process is often not well understood by management. Partnership and interaction among the three players involved in this endeavor—industries, universities, and government—have diminished to the point that none serves the needs of the others. Engineering curricula focus on a few conventional design procedures rather than on the entire product delivery process, and industry's efforts to teach engineering design tend to be fragmented. A revitalization of university research and teaching in engineering design has begun, but is not well correlated with the realities or scope of design practice, and research results are not effectively disseminated to industrial firms. Finally, the U.S. government has not recognized the enhancement of engineering design capabilities to be of national importance.

This state of affairs virtually guarantees the continued decline of U.S. competitiveness. To reverse this trend will require a complete rejuvenation of engineering design practice, education, and research, involving intense cooperation among industrial firms, universities, and government.

DESIGNING FOR COMPETITIVE ADVANTAGE

To use design effectively as a tool for turning business strategy into effective products, a firm must (1) commit to continuous improvement both of products and of design and production processes, (2) establish a corporate product realization process (PRP) supported by top management, (3) develop and/or adopt and integrate advanced design practices into the PRP, and (4) create a supportive design environment.

Converting to operation under the discipline of a PRP is not easy. Often, complete reorganization from top to bottom and a dramatic change in the way of doing business are required. An effective PRP generally incorporates the following steps: define customer needs and product performance requirements; plan for product evolution beyond the current design; plan concurrently for design and manufacturing; design the product and its manufacturing processes with full consideration of the entire product life cycle, including distribution, support, maintenance, recycling, and disposal; and produce the product and monitor product and processes.

The PRP is a firm's strategy for product excellence and continuous improvement; design practices are its tactics. Because not all practices are applicable to or useful in the design of a given product, each company must carefully identify a set appropriate to its uses and incorporate them into its PRP. Practices (such as Taguchi methods) and tools (such as CAD and CAE) must be fully integrated into the PRP if they are to have more than minimal effect. Companies must also develop means of assimilating new practices as they are developed by researchers and others because currently effective practices are being improved and even superseded.

Design is a creative activity that depends on human capabilities that are difficult to measure, predict, and direct. An understanding of the design task and the characteristics and needs of people who design effectively is essential to the creation of a stimulating and nurturing design environment.

IMPROVING ENGINEERING DESIGN EDUCATION

Undergraduate and graduate engineering education is the foundation for successful practice, effective teaching, and relevant research in engineering design. The current state of that foundation is attested to by employers who find recent engineering graduates to be weak in design. Reasons for the inadequacy of undergraduate engineering design education include: weak requirements for design content in engineering curricula (many institutions do not meet even existing accreditation criteria); lack of truly interdisciplinary teams in design courses; and fragmented, discipline-specific, and uncoordinated teaching. Of the curricula that have strong design components, few consider state-of-the-art design methodologies.

There are simply too few strong graduate programs focusing on modern design methodologies and research to produce the qualified graduates needed by both industry and academe. Limited funding for design research impairs the quality of graduate programs in design and reduces the number of graduate students in the field that can be supported. Even the stronger programs rarely involve industry experience that would elucidate the realities of engineering design practice.

Significant improvement in engineering design is unlikely without strong, knowledgeable, enthusiastic faculty who interact with a broad base of colleagues in industry as well as academe. However, few faculty today are trained to teach design or are cognizant of its importance. Most have no significant industrial design experience, possess little understanding of manufacturing, and have only limited contacts with industry. Relevant textbooks are lacking, and many faculty are unfamiliar with the instructional techniques that best support design education. Faculty who would consider design as a career focus face a significant time commitment and institutional obstacles.

The initiative for immediate improvement of design education and for laying the groundwork for its longer-term sustained improvement lies clearly with educational institutions. Faculty and administrators, who sometimes disclaim responsibility for the problem and blame instead the "system," must take the lead if it is to change. To improve the teaching of engineering design in universities will require: recognition of the deficiencies in design education; strong high level leadership in establishing goals for improving design education; development of metrics to measure progress toward these goals; creation of designated change agents to plan and implement improvements; and extensive training programs for both new and experienced design teachers.

Actions must also be taken to facilitate the teaching of design and to increase university-industry cooperation in design education. A national clearinghouse for design instructional materials could make the task of teaching design easier for many faculty. Industrial firms could help improve engineering design by encouraging faculty to work in industry, aiding universities in setting goals and planning curricula, and supporting research in engineering design.

A NATIONAL AGENDA FOR ENGINEERING DESIGN RESEARCH

Research is a central ingredient in repairing the national infrastructure in engineering design. It will contribute new knowledge, new ideas, and new people to industry and education and stimulate the creation of new business enterprises. Over time, a well-conceived, sustained program of engineering design research will gradually reduce U.S. companies' reliance on ad hoc design methods and improve their ability to produce higher-quality, lower-cost products and reduce lead time to market for new or modified products.

Ten topics in three broad areas—developing scientific foundations for design models and methods, creating and improving design support tools, and relating design to the business enterprise—were deemed crucial to reforming the practice and teaching of engineering design. Collectively, they comprise a national research agenda that will serve to guide the National Science Foundation, other government agencies, private foundations, industrial firms, and individual researchers in the assignment of research priorities and selection of projects.

The proposed research is essential to the revitalization of the engineering design infrastructure in the United States and hence to U.S. competitiveness. Significant and useful intermediate (i.e., four- to five-year) results should be achievable for most topics. It is extremely important that this research, whether applied or basic, be of the highest quality and be conducted with frequent and close interaction between researchers and industry design engineers, and that results be disseminated to industry as well as to academe.

Results of university research in engineering design can find their way into industrial practice by a number of routes. However, even well developed research results cannot simply be "given" to industry; new methods must be refined and packaged as products, a task that cannot readily be performed by most universities or by most companies that might take advantage of the results. The creation of a National Consortium for Engineering Design (NCED) to perform this technology transfer role should be considered.

RECOMMENDATIONS

Industrial design practice, engineering education, and design research all can be improved. Many of the report's recommendations require only initiative by the actors and little investment. Companies must reorganize their product realization processes and at least adopt existing best design practices. They must also communicate better with universities in order to secure new design methods and well-prepared graduates. Universities, in turn, must make a high-level commitment to improve engineering design education and research and better relate them to the needs of industry. The government must make engineering design a national priority and encourage research by increasing funding and assisting in the establishment of clearinghouses for design information and teaching materials. Specific actions are recommended in the report.

Recommendations from NRC Reports

I. The Competitive Edge: Research Priorities for U.S. Manufacturing

Top 4 recommendations on skills improvements in priority order:

1. NSF should establish a program to subsidize the initiation of large consortia to collaborate on the development and dissemination of programs of manufacturing skills education for engineers and managers. The effort could be couched as research on collaborative education in manufacturing skills, including nationwide access and hands-on experience at appropriate centers, to include a number of teaching factories.

2. NSF should establish a Faculty Professional Development Program in manufacturing with the goal of reaching 20 percent of engineering faculty within two years.

3. NSF should fund and coordinate research that involves business and management schools, engineering colleges, and industry in collaborative studies of manufacturing management in particular and technology management in general.

4. NSF should work with other government agencies to develop a program to establish consortia on manufacturing in specific areas, such as microelectronics, automotive, and aerospace.

In addition to the preceding recommendations related to education and training, the report identifies and analyzes research needs in the following critical areas of manufacturing:

- Intelligent manufacturing control
- Equipment reliability and maintenance
- Advanced engineered materials
- Product realization process

II. Improving Engineering Design

Recommendations are given for actions by industry, universities, professional engineering societies and government. The following are recommendations to NSF:

1. In order to support faculty in improving the teaching of design, NSF should establish a clearinghouse for design instructional materials and methods.

- Should be established quickly

- Facilitate the synthesis of this material into textbooks, case studies, video tapes, computer software, etc.

2. NSF should support both a large increase in design research and increased university-industry interaction in engineering design.

- Establish a Design Scholar program that would enable university faculty and graduate students to spend one or two years with a best-practice industrial firm, followed by three years of joint NSF-industry research support.

- Expand and emphasize the Design Theory and Methodology program by providing a clear identity, strong leadership, and stable funding ($6 to $8 million annually).

- Strongly encourage initiation of additional design-related Engineering Research Centers.

3. NSF and the Department of Commerce, with the assistance of industrial and academic representatives, should study the possible structuring and operation of a National Consortium for Engineering Design to:

- perform precompetitive research to improve design methods and tools;

- gather and disseminate information about international best engineering design practices;

- transfer existing and new design knowledge to industry and academe;

- develop and promote industry-university-government collaboration in research and education; and

- provide brokerage services for personnel exchanges and arrange privately funded research between universities and industry.

The report also includes a topical research agenda for engineering design research.

Mr. BOUCHER. Thank you, Mr. Markovits.

Dr. Dieter?

Dr. DIETER. Thank you, Mr. Chairman, for this opportunity. I'm speaking today on behalf of the American Society for Engineering Education's Deans Council, which represents more than 300 colleges of engineering in the United States.

The role of the engineering colleges in helping to meet the competitiveness challenge is growing and changing. Engineering schools are moving away from the post-World War II focus on engineering science and the creation of new knowledge, and they're moving towards a broader role which includes not only creation of new knowledge but a renewed focus on the business of engineering; that is, the creation of new products, processes and systems. Manufacturing and design are integral elements of this reorientation.

Now, the National Science Foundation through its research and engineering initiatives is helping to make this change. While it's too early to gauge the success of all of these initiatives, we believe they are generally headed in the right direction and are hitting the right leverage points. In fact, we believe the goals of these initiatives are so important to the Nation that they justify increasing support for the Engineering Directorate faster than the rest of the agency.

In considering the term "manufacturing," what we mean by manufacturing, we feel it should encompass a broad group of generic technologies and processes. This includes not only systems management technologies and conventional processing, but also such areas as environmentally friendly chemical processes, intelligent processing equipment, flexible computer-integrated manufacturing, and micro- and nanomanufacturing. All of these areas, particularly related to processing, could use significantly increased levels of research funding from the Foundation.

Because the real advances in manufacturing research and education require industry participation—we've heard that from two previous speakers—we strongly endorse the Foundation's approach as sponsoring manufacturing-related research through a variety of centers and small group awards. Center grants make natural targets for industry participation. For example, at the Systems Research Center on my campus, we have already spun off two major activities with industry—a center on electronic packaging and one on satellite communications. We believe it would be most valuable to expand the Engineering Research Centers program as well as a smaller scale collaborative centers and the strategic manufacturing initiative.

In general, undergraduate teaching materials need to be improved. The Foundation might want to designate funding for manufacturing and manufacturing-related course and curriculum development. Although it's not specifically focused on manufacturing, the NSF's Engineering Education Coalitions are really making a difference in this area. For example, the ECSEL Coalition, to which my engineering college participates, is working to integrate design across the entire curriculum. At the freshman level, our main objective is to show students where engineering design fits into the heavy concentration of analysis courses that follow. We do this by having the students undertake a complete design, including manufacturing and assembly. But because the students do not have a very great background in engineering, they make their design of familiar products like swing sets and seesaws. This experience in the complexity of design leads them into the rest of the curriculum.

Given the innovation and collaboration we are seeing in the Engineering Education Coalitions, we would like to see their number expanded.

A key to reorienting engineering education towards the creation of new products and processes is, of course, the faculty. Since most of our faculty go directly from research-oriented graduate school into teaching, very few have industrial experience. While some of our faculty are gaining industry experience through the research centers and the Engineering Directorate's Industrial Internship Program, another avenue for change is summer support for faculties to work in industry, particularly the young faculty. Support could be focused on the faculty member's first summer of employment, which should be early enough to provide the individual with industry background and would, perhaps, reorient research activities into more industrial mode.

At the undergraduate level, while we know that the Nation needs more of our best engineering graduates to go into manufacturing, we also know that our students respond to financial incentives. When industry demonstrates that it values manufacturing engineering through greater prestige and salaries, I am confident more of the students will be attracted to manufacturing programs and degree options.

One thing industry could do to make manufacturing centers more interesting to students is to establish a small grants program to enable faculty members to hire undergraduates during the summer to work in applied research projects, preferably with industry. This program would complement, and not replace, the existing Manufacturing Experiences for Undergraduates program which the Foundation runs through the Research Directorates.

At the graduate level, we believe the Foundation should sustain and expand the new graduate traineeship program. This would be especially valuable in manufacturing areas because traineeships can be targeted at specific fields and university departments. Although the Foundation-wide traineeship program would not focus solely on manufacturing-related fields, proposals with a manufacturing focus could be provided extra consideration.

To sum up, the deans of engineering strongly support the Engineering Directorate in its effort to promote a return to the business of engineering in our engineering colleges, including the revitalization of manufacturing engineering research. Because this effort is so important to the Nation's technological development and to the education of tomorrow's engineers, we believe that financial support for the Engineering Directorate should grow faster than even the rest of the Foundation.

I'd be pleased to answer any questions.

[The prepared statement of Dr. Dieter follows:]

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TESTIMONY

on

Manufacturing Research and Education at the National Science Foundation

Presented To the
U.S. House of Representatives
Committee on Space, Science and Technology
Subcommittee on Science

By

Dr. George E. Dieter, Dean of Engineering
University of Maryland, College Park

On Behalf of the
Engineering Deans Council
American Society for Engineering Education

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Mr. Chairman, thank you for this opportunity to appear before the Subcommittee to discuss the role of the National Science Foundation in manufacturing engineering education and research. My name is George Dieter and I am dean of engineering at the University of Maryland, College Park and incoming president-elect of the American Society for Engineering Education (ASEE). I am speaking today on behalf of the ASEE Engineering Deans Council, which represents the more than 300 colleges of engineering in the United States.

As you know, industrial competitiveness has become a major concern in the nation. It is clear that the nation's economic and military security depend on our ability to develop and deploy technology more effectively than our competitors.

The role of the nation's engineering schools in helping meet this competitiveness challenge is growing and changing. We are moving away from the post-World War II focus on engineering science and the creation of new knowledge, toward a broader role that includes not only creation of new knowledge but a renewed focus on the business of engineering--that is, the creation of new products, processes and systems. Manufacturing and design are integral elements in that re-orientation. But it also includes developing new modes for engineering research; a major reshaping of curricula to make engineering education more interesting, integrated and relevant to engineering practice; and major efforts to open up the profession to traditionally under-represented groups such as women and minorities. Taken together, these changes will reshape academic engineering for meeting the challenges of an increasingly competitive world.

Through its education programs and research thrusts, the National Science Foundation's Engineering Directorate is helping engineering colleges initiate and speed these changes. While there is manufacturing activity in other portions of the Foundation--notably the Computer and Information Science and Engineering Directorate--Engineering is an important catalyst in directing new education and research attention to manufacturing and manufacturing-related areas.

It is too early to gauge the success of many of these initiatives, but we believe they are generally headed in the right direction and are hitting the right leverage points. And in fact, the goals of these initiatives are so important we believe they justify increasing support for the Engineering Directorate faster than the rest of the agency. The greater the support, the greater the leverage and the faster the change in the academic engineering community.

I would like to discuss four inter-related areas that need to be addressed in order to accomplish this shift in focus: research, course & curriculum development, faculty rewards and student needs.

Research. The term "manufacturing" should be viewed quite broadly, to encompass the wide array of generic technologies and processes that ultimately contribute to effective product development. This includes not only systems management technologies, but also research in such areas as environmentally-friendly chemical processes, intelligent processing equipment, flexible computer integrated manufacturing, and micro and nano-manufacturing.

All of these areas, particularly related to processing, could use significantly increased levels of funding. Since support for these technologies and processes is spread throughout the Engineering Directorate, as well as in other directorates, funding increases should not be highly concentrated. One cannot always predict where new advances will be made that contribute to manufacturing or systems capability. Moreover, the Directorate must keep in mind its mission to broadly support basic engineering research and not starve out important areas that may not be immediately applicable to manufacturing.

Research Centers. We support the Foundation's approach of sponsoring manufacturing-related research through a variety of centers and small group awards. Real advances in manufacturing research and education, we believe, require the participation of industry. Center grants, both large and small, are targets of opportunity for industry participation.

The Engineering Research Centers (ERCs) are significantly strengthening the ties of university researchers and students with industry. The long-term involvement of industry in these centers is both enhancing the research and educating students in a cross-disciplinary, systems approach to problem solving that is vital to the new world of flexible manufacturing. At the Systems Engineering Research Center on my campus, for example, we have already spun off two major activities with industry: a center for electronic packaging which focuses on the design and reliability of electronics packaging, and a NASA center for the commercialization of space which deals with satellite communications. Our students are in high demand from industry.

There would certainly be value in adding new centers--such as the Foundation is proposing in FY 1993--to focus on critical technologies in manufacturing and materials.

The deans also support expansion of the Directorate's smaller-scale center and group award programs. These include the industry and state/university collaborative centers program, as well as the strategic manufacturing initiative which NSF is funding in cooperation with the Department of Defense.

These smaller-scale centers, geared toward specific manufacturing problems and regional economic development issues, can be accessed by a broad array of engineering schools--both large and small--and still provide faculty and students with the direct interaction with industry and real-world manufacturing problems associated with the larger centers. We might recommend that in order to provide greater leverage, the maximum annual grants allowed in the strategic manufacturing initiative be increased from $300,000 to $500,000. The higher level of funding would enable university researchers to attract greater industry support and end up with perhaps $3-4 million a year, a good amount for making things happen.

I would like to add that the engineering deans applaud the Engineering Directorate for initiating, in cooperation with the Social, Behavioral and Economic Sciences Directorate, a new program in the management of technology. We believe this program holds great promise for interdisciplinary research in this important area.

Course and Curricula. In general, undergraduate teaching materials in manufacturing could use improvement. The Engineering Directorate, or the broader Foundation, might want to designate funding for manufacturing and manufacturing-related course and curriculum development. The funding should be linked in some fashion to the manufacturing research activities of the Directorate. This should include development of design and manufacturing case studies.

The Engineering Education Coalitions are also making an important contribution in this area. While the four existing engineering education coalitions are not explicitly focused on manufacturing, they are aimed at promoting practices that will contribute to manufacturing expertise: student and faculty teamwork, integration of disciplinary material with design and practice, total quality management, and a focus on real-world applications. For example, the Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL), in which my engineering college participates, is focusing on integrating design across the entire curriculum. We are having some real success. At the freshman level, the chief objective is to show students where engineering design fits into the heavy concentration of analysis courses that follow. We do this by having students undertake a complete design--including manufacture and assembly--of familiar products like swing sets and seesaws. This experience leads them into the rest of the curriculum.

Given the innovation and collaboration we are seeing in the Engineering Education Coalitions, we would like to see the number of coalitions expanded.

__Faculty Rewards.__ As in most aspects of engineering education, the key to change is with the faculty. If we want to re-orient engineering colleges toward the creation of new products and processes, we need to provide faculty with incentives to gain industry experience. Since most of our faculty go directly from research-oriented graduate programs into faculty positions, very few have any experience in industry, much less in manufacturing. Providing them with relevant industrial interaction would make a big difference.

The NSF research centers and manufacturing-related group awards are addressing this issue by requiring faculty to work together with their industry colleagues and developing appropriate recognition for their contributions. But the effort needs to be broader. Along with the Engineering Faculty Internships, which enable faculty members to conduct research in an industrial setting, the Foundation could develop a program to support summer experiences for faculty in industry. Young faculty members could be specifically targeted, with support focused on their first summer of employment. This would give them industry experience early in their careers without interfering with their efforts to gain tenure.

We as deans of engineering can also do more. For example, we can provide our young faculty members with time out from the tenure process in order to pursue year- or two-long sojourns in industry.

__Students.__ We know that for the technological benefit of the nation our engineering graduates will need strong skills in integration and design and that more of our best students should go into manufacturing-related careers. But engineering students are smart and respond to financial incentives. They look at the low starting salaries of manufacturing engineers and decide to look elsewhere. When industry demonstrates that it values manufacturing engineering through greater prestige and salaries, I am confident more of our students will be attracted to manufacturing programs and degree options.

One way that NSF could make manufacturing careers more interesting to students is to establish a grant program that would enable faculty members to hire undergraduates during the summer to work on applied research projects. The focus should be on practice-oriented research--preferably in direct collaboration with industry--and should be open to all faculty, not just those with NSF research grants. In this way, the program would complement, not replace, the existing Research Experiences for Undergraduates (REU) program the Foundation runs through the research directorates for more traditional research activities.

At the graduate level, the Foundation should be encouraged to sustain and expand its new graduate traineeship program. Traineeships would be particularly valuable for manufacturing programs because they can be targeted at specific departments in specific fields. We recommend that eligibility for funding include both practice-oriented masters degree and doctoral programs. While the Foundation-wide traineeship program would not focus solely on manufacturing-related fields, proposals with a manufacturing focus could be provided extra consideration for funding.

Summary. In sum, the deans of engineering are quite supportive of the general directions of the Engineering Directorate in promoting a return to the business of engineering in our engineering colleges, including the revitalization of manufacturing research and education. Because this job is so important in technological development and in the education of tomorrow's engineers, and because NSF is such an important catalyst in the academic community, we believe Congress would be fully justified in increasing support for the Directorate at a faster rate than the rest of the Foundation.

Mr. BOUCHER. Thank you very much, Dr. Dieter.

The subcommittee expresses its appreciation to each of the witnesses for their carefully prepared and well-presented testimony this morning.

I'd like to direct my first question to you, Mr. Markovits, as a representative of the private sector. Could you give us some sense of the extent to which industry is aware of these shortcomings and is making an active effort to recruit the kinds of engineers that have skills in manufacturing design and in new manufacturing technologies? And, if there is some sense that industry is not doing this very aggressively, then should we not be worried about the extent to which young people could be encouraged to go into these fields? If they are not going to have jobs waiting for them on the other end, why would they choose this course of study?

So, would you care to address that range of concerns and tell us what's going on in industry and what the perception is there today?

Mr. MARKOVITS. Yes. Yes, I would. Let me give you my perception, but I'll do it primarily from the perspective of the high tech industries, mainly the computer and the semiconductor industry because that's basically what I'm familiar with. All right? And I think in those particular industries there is an awareness of the need for design skills. There is an awareness of the need for overall educational skills.

As I mentioned before, within IBM, they put in place a significant amount of resource in programs to up-level the education of the particular technicians, the line technicians. At a higher level, they are working with various universities in other companies that I've worked with, like Intel and National Semiconductor– are working with various universities to put in place programs to do two things: One, to affect the curricula of those various schools. All right? Two, to form more interaction between the universities and industry to bring university teachers into industry on sabbaticals and things like that, so that when they go back to the universities they understand how it is they have to mold and change the substances of their courses. All right? And three, to actually educate the people themselves right on the job.

So I would say that at least in the high tech industries they are very aware of these problems and there is a great demand.

Mr. BOUCHER. So the demand is there in the industrial sector for engineers who have these skills?

Mr. MARKOVITS. In the high tech industrial sector, yes.

Mr. BOUCHER. Do you have any sense about the lower tech industries? Is the same true there?

Mr. MARKOVITS. No, I am sorry, I don't. I don't have that level of interaction with them.

Mr. BOUCHER. Let me ask our other two witnesses this morning, both of whom serve on the National Research Council and undoubtedly have had much interaction with industry. Do you have the sense that across industry generally there is an awareness of this problem and some desire on the part of most companies to recruit engineers with these skills?

Dr. JONES. I would say among the leading firms, yes. But a thing we've been talking about just this morning, there is a great mass of companies that provide an awful lot of jobs for the manufacturing industries that are just barely making ends meet. Day to day everyone is putting out fires, and we cannot honestly say that these people even recognize what in addition they need. In fact, that's one of the jobs—is to get the word out to these many, many companies that they can improve their performance greatly.

And, to make the comparison some people object to, that is one of the big differences between the structure and interactions of American companies and Japanese companies, where the well-known mode there is for a large company to actively nurture quite a number of suppliers, and those in turn will nurture a number of suppliers.

Mr. BOUCHER. Dr. Dieter?

Dr. DIETER. One of the major manufacturing concerns in the State of Maryland is Black & Decker, and their vice president for technology recently served on a task force of our Higher Education Commission on Engineering Education. And he made very sure that in the recommendations of this Commission that steps will be taken to strengthen manufacturing engineering education in our engineering colleges.

I think a program that also needs to be mentioned here is the program that's funded and managed through NIST that establishes regional manufacturing centers that are directed chiefly at interacting with the small companies that Dr. Jones was talking about. I think that program is a very good one and needs to be encouraged and expanded, because I think it works at that level where the high tech companies and the high tech input really doesn't get.

Mr. BOUCHER. Let me get you to address, if you would—and I'll ask all three panel members this question—the attitude and the procedures that exist within the engineering schools themselves. First, from the standpoint of the simple question of prestige, is it considered to be a good thing to do professionally to pursue a career in manufacturing design, high technology manufacturing—engineering design, I think, is the phrase you used? Is that considered to be a prestigious thing to do? And, if not, does the lack of stature that attends that endeavor tend to retard entrance into the field? And, if that is true, what do we need to do about it?

And then, secondly, the faculty reward system itself. Given the paucity of research funds that are placed into this discipline today, and the emphasis at universities on obtaining research grants as a means of demonstrating success and getting promotions, is there an imbalance in that that is also causing faculty to shy away from these very important disciplines?

So, address, if you would, the effect of the faculty reward system and also the question of prestige on encouraging faculty to go into these fields.

Dr. Dieter?

Dr. DIETER. Ten years ago I would say that there was very definitely a problem with prestige for design and manufacturing. I think that one of the things that has changed that very much is the entry of the Engineering Directorate of NSF very heavily into the areas of design and manufacturing.

In the pecking order of universities, the National Science Foundation funding is the best, and faculty who can obtain funding from NSF, it is a factor of prestige. So I think that NSF's participation is crucial and vital in changing this situation, and it has changed.

Mr. BOUCHER. Has it changed to the point that it is considered as prestigious today to be a design engineer or a manufacturing engineer as it is to be someone who is involved in basic research in the high tech area or something such as that? Is it as prestigious to be involved in design today?

Dr. DIETER. Well, if you can do research in design and manufacturing and couch it in such a way as to publish it in the more prestigious journals, then it is. But, if what you do is very applied, and therefore can't be published in prestigious places, then it could be a problem.

What we have found is that our faculty do both. Again, in the State of Maryland in recent years we have established a program for matching funds between industry and the university to do what you would call applied research, and I'm very pleased to say that these funds are very highly sought after, and by some of our most prestigious researchers. That doesn't mean they don't do their line of fundamental research and publishable research, and they continue to do that. But they are very interested in seeing their research results applied.

Mr. BOUCHER. Should we conclude that the question of prestige is no longer a problem in terms of encouraging people to enter this discipline today? Do you think it has been remedied to the point that we shouldn't consider that?

Dr. DIETER. Well, I don't know about that, but I would say that the ability to attract people into this field is very much a function of the perceived funding—the stability of the funding and whether it looks like someone starting out building a career in this field is likely to be able to go for some period of time.

Mr. BOUCHER. Let me ask the other two panelists to comment on that question.

Dr. Jones?

Dr. JONES. I think we still have a serious problem on prestige. In fact, even the terminology "prestigious journals" indicates the bias because we have found that some of the most prestigious journals have circulations of the order of 200 worldwide. So that a paper in a prestigious journal may really have very, very little influence compared with an article in something like Machine Design or Design News or many of the periodicals that are actively read by people in industry.

Prestige is still a serious matter. And, as Dr. Dieter says, here is a place where NSF leadership can truly make a difference. Because the NSF stamp of approval, their funding of work in a given area just attaches prestige to that area within the academic community. That's why the NSF—investment, I think, of the Nation in NSF pays great returns, because it does change the way people think and it changes the areas that people work in.

The other thing is, let's face it, one of the comparisons made among universities is simply on the basis of research dollars. It may be a spurious measure, but it's a measure. Even U.S. News & World Report in comparing graduate schools list that as a primary factor, as unsound as it may be, as a primary factor. And there again, as Dr. Dieter says, as we have the research funding in a given area, that adds stature, prestige to that area. That's why I would like to see the moves made that are going to bring those things to fruition.

Mr. BOUCHER. You know, that's the kind of concise answer I was looking for. We do have a problem and the answer to it, you say, is NSF giving a higher stature through its research budget to these disciplines.

Mr. Markovits, would you care to comment on this?

Mr. MARKOVITS. Yes. Yes, I would like to. But I'd like to address it a little bit differently. I think my colleagues have addressed the issue of prestige as it pertains to the university and university professional. But I think the problem actually starts earlier than that. I think the problem starts in our high school with the fact that most students don't believe that it's a prestigious career to pursue in terms of basic engineering. All right? They believe that either a business career or a career in basic research or science is much more prestigious to pursue. And so I think the NSF funding has to be directed at that problem too.

I think you have to address it an earlier stage. Because by the time these students get to pick their college direction, their mind is made up. Their perception of the prestige of different areas is formed, and they are not going to change it.

Mr. BOUCHER. How would you suggest that we do that at that earlier stage?

Mr. MARKOVITS. Well, I'll give you an example. In New York State, there is a program called the Visions Program in which various high tech companies in the New York area have brought in high school teachers to work with them over the summer, and the high school teachers then learn what it is to be involved in manufacturing and basic design engineering. They then bring this back to their students, and they encourage their students then to get involved in this, and they tell their students what the rewards are being involved in this. This is the kind of communications that has to happen.

Now, we had it, I think, back in the Sixties. I mean, back in the Sixties it was a given that you were going to be an engineer because it was the greatest thing in the world. It was part of, you know, the way to go. You are going to put a man on the Moon. You don't have that today. I mean, today the picture is pictures of Ivan Boesky and other manipulators. Right? I'm sorry, but it's true.

Mr. BOUCHER. Back in the Sixties, I guess, a lot of engineers also did a stint with industry.

Mr. MARKOVITS. Right.

Mr. BOUCHER. And that was part of the career path. In fact, part of the training was tied up with a fellowship in industry. That is less typically true today, is it not?

Mr. MARKOVITS. Yes.

Mr. BOUCHER. Would it be helpful if we tried to instill that kind of partnership again?

Mr. MARKOVITS. I think so. I think the companies have to take a part in this too. Again, I hate to keep—everybody keeps referring to the Japanese, but in many Japanese companies they will take their new, young graduates and they will make them go through a stint in manufacturing. And they will learn what it is; so that, when they go later on into research and development, they know what it is they are developing, and they know what the implication is going to be to the manufacturing line. We tend not to do that, and we need to do more of that.

Mr. BOUCHER. Are there any problems inherent in the faculty reward system that discourage people from pursuing this field, that discourage faculty from investing appropriate intellectual and other kinds of resources in it? Dr. Jones?

Dr. JONES. Absolutely. You mentioned the faculty reward system in your opening statement, and no study of education, higher education, today is complete unless it does address this very, very serious problem, which is a close-in type of problem. The promotion, tenure, salary actions in universities are determined within the university. When outside help is asked for, it is asked for of other faculty members who are in the same kind of thing.

I detest writing letters to support the promotion of some colleague in another institution I may never have visited. I don't know what goes on there exactly. And yet I do it, because I'm going to need some letters to get some of my people promoted. And that system definitely needs change. Mostly it needs a bright light on it.

And I think the pressure that comes from outside, whether it be NSF, prospective employers, prospective students and their parents, to bring this promotion and tenure system out into the open is all to the good. And there has been some literature on it. Of course, the Charles Sykes book "Prof Scam" and Paige Smith's book "Killing the Spirit" both address this, and I think we need the broad light of day on those.

Mr. BOUCHER. Thank you. Other comments on that question?

Dr. DIETER. Only that a very respected person in higher education, Ernie Boyer, has written a book called "Scholarship Revisited" which addresses this subject and attempts to show how the criteria for promotion and tenure could be broadened and still meet the rigorous standards that universities are conducting.

So I think there is a trend in this direction, but, as Dr. Jones says, it's very, very slow.

Mr. BOUCHER. This is a question that is uniquely within the hands of the universities and colleges themselves. Is there any realization at the administrative level internally within the various schools, within a university or universitywide, that this problem exists and that it needs to be addressed?

Dr. DIETER. I think there is a slow realization of this. You need to realize that what happens in an engineering school in a large, broad-based university is very different from what happens across the board. Attitudes there very often are not the norm. But I think it is coming slowly.

Mr. BOUCHER. Dr. Jones, do you agree?

Dr. JONES. Yes, I agree. It is very difficult to change. And I must confess, you know, I'm part of the system, and I've prospered and was promoted and so forth. And the system is currently in the hands of people who have prospered under it. That makes it very difficult to change.

Mr. BOUCHER. The public sort of complains about us the same way, I might add. [Laughter]

Well, that concludes my question of this panel, at least for the initial round. I thank you very much.

And I recognize the gentleman from California.

Mr. PACKARD. Thank you, Mr. Chairman. You mentioned about fellowships and the process of faculties going into manufacturing, a first stint, and broadening their experience level. The reverse also. What about manufacturers and those in industry coming back into the classroom? Is that being done as much as it was? Or should it be done more? And how could that be done effectively?

Dr. Jones?

Dr. JONES. It's being done a little bit. Certain companies have been very helpful on this. IBM has supplied some excellent people on faculties around the country. Otherwise, the arrangements are usually made on a one-on-one basis. I have done it. I have had faculty members come in and spend a year, key people from companies such as Dupont, General Motors, General Electric, TRW.

These things were done simply on a one-to-one basis because, if you are looking for someone and an industrial firm says, "Here's a man we can spare," we don't want him. You want the man that they really can't spare. Occasionally you can find some key person who is between assignments or has just completed a big assignment, and you can do it. That is a very healthy thing. It works beautifully. But it is done on a very, very small scale.

There is not an average of one such person per university across the country at this time.

Mr. PACKARD. Dr. Dieter——

Dr. DIETER. That was a very good answer.

Mr. PACKARD. Do you confirm that?

Dr. DIETER. Yes, indeed.

Mr. PACKARD. Your university.

Dr. Jones, you mentioned in your testimony that the study shows that $6 million for this first year and $20 million thereafter for 4 or 5 years would be adequate. Has NSF factored that into their budget, or could they? Or would that require additional appropriations?

Dr. JONES. We are suggesting an additional appropriation because we do not see it in the NSF budget submittal. Now the design research has been within the design and manufacturing program in the Engineering Directorate. I believe that about 3 years ago when I was on an advisory committee there that the expenditures were about $3.5 million. And I don't have firm figures, but I believe from talking with people there that it is about $1.5 million into design research during the current year.

We think it is very difficult for NSF to reallocate funds to do that within their budget because there is always that reluctance, you know, of any other organization to give something up. Therefore we would suggest that this be an initiative; that is, a funding specifically for the purpose of supporting research in engineering design.

Does that answer your question?

Mr. PACKARD. Yes. Very well.

Mr. Markovits, in your report you have recommended that the factory be viewed as a laboratory. How do you suggest re-establishing the mind-set of our industries and universities in terms of using industry as a learning laboratory for design manufacturing processes?

Mr. MARKOVITS. Right. I think that the NSF could have a significant impact upon this by funding the type of research that would require joint collaboration between the universities and people from our manufacturing lines, and that funding also predicate that research has to be done to some extent in the manufacturing lines. I think the important point we were trying to make in that report was that it's one thing to isolate a problem and to do it in a laboratory. It's another thing to try and make that same study, if you will, in the manufacturing line where control itself is an object of— or desire that you may not have. Right?

So I think if you can so direct the research so that it has to happen in a manufacturing line and it has to be this close collaboration and they have to take into account the entire systemic view on it, understanding that a small change here is going to impact the entire line, that's the way that the NSF could have an impact.

Mr. PACKARD. You also mentioned in your testimony—excuse me—that the Japanese metalworking industry using advanced manufacturing technology has demonstrated remarkable increases in productivity and that we need to do more of that. How can we make that transition? How can we implement—what would be necessary for us to show the same kinds of increase in productivity by using the same process?

Mr. MARKOVITS. Well, I think I'll pick up on a comment that Dr. Jones made before. I think his comment was the fact that many of our industries, especially the smaller industries, are not aware of what's out there. They are not aware of the technology that's available today. And some sort of effort on the part of the NSF to bring these people into the circle and have them understand the technology that's here.

We're not talking about technology that doesn't exist. It's there. All you have to do is go over to Japan, like I did a couple of years ago, and tour the Mazak plant and you'll understand that it's here today. Right? But for some reason it's not being picked up by and used by our manufacturers, and we have to somehow bring these people into the circle, educate them, show them the benefits of this. And then, I think, if you show the business benefits of it, that they'll pick up on it.

Mr. PACKARD. Are we going to have the same kind of competition from some of the Third World countries, Korea, in the metalworking areas—Taiwan as well as the European Community?

Mr. MARKOVITS. Definitely. Something you need to understand about advanced manufacturing technology is that, once you've been able to codify this knowledge, that is, the advanced manufacturing technology—put it into computers into knowledge bases and databases; put it into these highly automated machines—those are highly transportable. You can take those anyplace, and you can train people how to use them, and then you have that sort of productivity.

You are seeing it now. You are seeing it with the Pacific Rim.

Mr. PACKARD. Have we not already relinquished our willingness to compete in those areas?

Mr. MARKOVITS. No, I don't think we have.

Mr. PACKARD. Dr. Dieter, you mentioned in your testimony that the Engineering Research Center on your campus has been very successful. Has industry been involved in that Center, and how could that same experience be transferred to other centers?

Dr. DIETER. Well, I think all of the Engineering Research Centers—one of their major requirements is to have very significant interaction with industry, and indeed they all do. I think at our school we have about 25 companies that participate with our Center in various ways.

And the thing that I think is significant about these Centers is that they are large enough and they work on big enough problems that they can attract companies and indeed provide opportunities for students to get industrial experience. Every summer a significant number of our graduate students go out and work with our sponsoring companies. And, of course, the companies are intimately involved in planning and helping the research to be done.

This I think is a model. Maybe the scale does not have to be as large as some of the Engineering Research Centers, but I think we need to create more of these opportunities around the country and at more universities so that this interaction can take place.

Mr. PACKARD. As students graduate now in engineering areas, is it more difficult than it was 10 or 20 years ago or less difficult to find good jobs, well-paying jobs?

Dr. DIETER. Well, of course, there is a recession on right now and the recession has affected the employment opportunities in the last 2 years. But, if you discount that, the opportunities for engineering students have been very fine. They have been very sought after.

Mr. PACKARD. Has that had a change or effect on the enrollment in the engineering fields in schools by virtue of being more attractive?

Dr. DIETER. Well, there was a very great enrollment in engineering students starting around the mid-seventies and going through, I guess, the mid-eighties. Engineering enrollment has always tended to be fairly cyclical, and we are now on a downward trend. I don't think it's a precipitous drop, but it is down in the last 3 or 4 years, probably reflecting the general downturn of the economy.

Mr. PACKARD. Can that be changed with better educational practices?

Dr. DIETER. Well, of course, the number of students who study engineering is determined, first of all, by the general level of interest, but then by the math and science background that the students get in high school. You're almost predetermining the number of students who would be eligible to study engineering in the Nation by the number who take appropriate math and science in high school.

Mr. PACKARD. In the last decade we have emphasized that very thing.

Dr. DIETER. Yes.

Mr. PACKARD. Have we seen an effect?

Dr. DIETER. I think there has been some improvement, but it certainly has a long way to go.

Mr. PACKARD. Thank you, Mr. Chairman.

Mr. BOUCHER. Thank you very much, Mr. Packard.

The gentleman from Alabama, Mr. Browder?

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Mr. BROWDER. I have no questions, Mr. Chairman. Thank you.

Mr. BOUCHER. Thank you, Mr. Browder.

Let me just inquire with this panel into one additional area. You've done an excellent job today in giving us a sense of the scope of this problem and suggesting some broad solutions.

One potential precise solution is the NSF recommendation that for fiscal year 93 there be a program budgeted at $103 million for the advanced manufacturing initiative, the precise title of the program. I'm sure you're familiar with this. It builds on an existing program at the NSF.

Dr. Jones, you in particular had talked about the need for highlighting engineering design. And I wonder if the initiative at the NSF appropriately highlights it or whether it's so subsumed in the overall initiative that it is rendered less significant or inappropriately significant. And, if you could comment generally on that initiative and in particular as to whether engineering design is appropriately underscored in it, I would appreciate that.

Dr. JONES. One thing you should notice is that $104.5 million is not, of course, a program that stands out here labeled as advanced manufacturing per se to the exclusion of other things. More it's a matter of looking at things, principally in the Engineering Directorate, but at about half the level in computer science and some in the social sciences and some in math and the physical sciences, where it's a matter of an overlay. You look at these four directorates and say what programs within those directorates are already established, perhaps identified by other programs such as the Engineering Centers, do bear on advanced manufacturing. And so that is the nature of it.

You want to think of it not the same thing as a separate, stand-alone, $104.5 million program. It doesn't have the structure or the overall direction, to the extent that you do direct research areas, that a stand-alone program would have. That would be one comment.

There is a lot of good work included in that program, in the $104.5 million. Everything I read indicates that you do not have the attention that is needed on the engineering design research. Because while engineering design is almost always very closely coupled with manufacturing, there are some—there is some knowledge we need about the engineering design process that is not closely coupled with manufacturing and that is unlikely to get the attention that it should.

Another reason for having a separate designated program in engineering design is that, as you know, over the years NSF funding responds to proposal pressure—how many people want to do research in the area. Of course, in the area of engineering design, where the sources of stable continued funding have been minimal, I must say the research community is rather discouraged. And so, you don't see the proposal pressure because they feel that it's fruitless to apply. And that's another reason why we believe that a separate identified structured program is essential.

Mr. BOUCHER. A structured program in engineering design per se——

Dr. JONES. Yes.

Mr. BOUCHER [continuing]. Or in the broader field of manufacturing technology?

Dr. JONES. Oh. I think both are needed. But I'm addressing this reason for a structured program in engineering design research.

In the manufacturing, I see much good work in there. I think some of the work being done by the Engineering Research Centers is just marvelous. It is top notch. It has set a good example of how things should be done. And like Dr. Dieter, I don't mean to say that's the only way we should go. We need many other approaches to doing research. I think we need to recognize where success has been achieved. Clearly the Engineering Centers Program is one of those.

So I am highly supportive of the $104.5 million program which we see as advanced manufacturing. But we must remember that that is an overlay-type program, if I'm using the right terminology, not a stand-alone program of itself.

Mr. BOUCHER. Okay. Gentlemen, would you care to comment at all? All right.

Let me—Mr. Markovits, did you——

Mr. MARKOVITS. Yes, I would like to make one comment. I think that when you consider the overall advanced manufacturing initiative proposal be very careful not to exclude the part that has to do with the soft sciences, if you will. For several years I was the worldwide program manager for computer integrated manufacturing for IBM, and I'll tell you that we saw many, many failures, where the technology was put in but we didn't produce the results that we wanted. And the failures occurred because we didn't make changes to the management practices and policies, and I think that's as critical as the technology.

So, when you structure this overall program, be certain to fund that part that really deals with the organizational structure, the practices and the policies. Because if there's a place where the Japanese really beat us, it is in that area.

Mr. BOUCHER. Do you think that NSF should allocate more than 1 percent of its budget for manufacturing technology to the soft sciences?

Mr. MARKOVITS. I do.

Mr. BOUCHER. That's what they're allocating now, about 1 percent.

Mr. MARKOVITS. Yes. I do. I think you need much more.

Mr. BOUCHER. What's a good mix? What percentage would you suggest?

Mr. MARKOVITS. I would suggest at least like a 5 percent.

Mr. BOUCHER. Okay. Let me just ask one additional question along the same line. There is a suggestion that perhaps this general subject rises to the importance that it ought to become part of the FCCSET cross-cutting interagency process. Any recommendations as to whether that would be appropriate? Should we make this one of the FCCSET grant initiatives for the coming year?

Dr. Jones?

Dr. JONES. I agree that you should. Very definitely.

Dr. DIETER. I thought it was.

Mr. BOUCHER. No.

Dr. DIETER. No?

Mr. BOUCHER. It's being discussed.

Dr. DIETER. Oh. Okay.

Mr. BOUCHER. It definitely is being discussed. I think our next panel may address that and mention it, but I wanted to get your views as to whether it's appropriate.

Anything further? Mr. Packard? Mr. Browder?

We greatly appreciate the help that you've provided this morning, and we thank you for the time you've taken. You have enlightened us greatly.

Mr. BOUCHER. We will welcome now our second panel of witnesses: From the National Science Foundation, the Assistant Director for Engineering, Dr. Joseph Bordogna; Dr. James Solberg, Director of Engineering Research Center for Intelligent Manufacturing Systems at Purdue University; and Dr. Alice M. Agogino, the Associate Director for Curricula Reform of the National Engineering Education Coalition and Associate Professor of Mechanical Engineering at the University of California at Berkeley.

We would welcome our witnesses this morning. And, without objection, we will make your prepared written statements a part of the record and would welcome your oral summaries.

And, Dr. Bordogna—did I pronounce that correctly?

Dr. BORDOGNA. Bordogna.

Mr. BOUCHER. Bordogna. We'll be pleased to begin with you, sir.

STATEMENT OF DR. JOSEPH BORDOGNA, ASSISTANT DIRECTOR FOR ENGINEERING, NATIONAL SCIENCE FOUNDATION, WASHINGTON, DC.; DR. JAMES J. SOLBERG, DIRECTOR, ENGINEERING RESEARCH CENTER FOR INTELLIGENT MANUFACTURING SYSTEMS, PURDUE UNIVERSITY, WEST LAFAYETTE, IN; DR. ALICE M. AGOGINO, ASSOCIATE DIRECTOR FOR CURRICULA REFORM, NATIONAL ENGINEERING EDUCATION COALITION AND ASSOCIATE PROFESSOR OF MECHANICAL ENGINEERING, UNIVERSITY OF CALIFORNIA AT BERKELEY

Dr. BORDOGNA. Thank you. Chairman Boucher, Mr. Packard, members of the subcommittee: Thank you very much for the opportunity to testify on the efforts of the National Science Foundation in design and manufacturing education and research. Before beginning I'd like to offer on the basis of the comments I heard from the previous panel that the written statement includes a specific list of enhanced efforts to support improved design and engineering systems for the fiscal year 93 budget, the so-called $25 million addition.

Let me briefly summarize the thoughts in the written statement now. I want to begin by describing a vision for manufacturing that is the focus for the planning at NSF and indeed that of many other related Federal agencies as well. And this vision is being forged out of intelligent and farsighted reports and studies such—for example, the NRC's "Competitive Edge." Its separate components, as discussed by Mr. Markovits in the previous panel, are presently under development on factory floors, at universities and colleges, and in government labs. The challenge is to integrate these efforts for the national good.

Spurred by the global economy, the rapid development of enabling technologies and the advent of a high performance national information infrastructure—the so-called National Research and Education Network is a piece of that—manufacturing is moving toward a new paradigm where both the enhancement of physical power from the Industrial Revolution and now the enhancement of intellectual power from the Computer Age are synergized and concurrently coupled to production, resulting in so-called lean, agile, intelligent and adaptive manufacturing enterprises capable of responding quickly to the demand for high quality, highly customized products at lowest possible cost.

I want to add here, I used four words: lean, agile, intelligent and adaptive. These words tend to surface now and then. They all pretty much mean the same thing, and I want to emphasize we shouldn't get tied into any one word to describe the overall effort.

These highly competitive enterprises will incorporate productive systems that support more rapid product development, shorter production life cycles, and increased flexibility and efficiency in the integration of machinery, materials and human resources. They will incorporate integrated methods for design, production and quality control based on new knowledge and technologies, and they will be responsive to social and environmental concerns.

These enterprises will compete in their capability to react quickly to opportunities for creating shared wealth and to capitalize on a climate of perpetual change and uncertainty. To rapidly develop and introduce salable products at an increasingly faster pace, the design process will be linked closely with marketing and sales at the output end to know what customized features are desired, and at the discovery end with research and development to capitalize on the Nation's extensive science and technologies base.

The new manufacturing enterprises will utilize intelligent manufacturing processes that optimize outputs of the use of sophisticated sensor systems and closed loop feedback control. As an example, on a computer numerically controlled lathe tool wear will be sensed as the part is processed, but the system can compensate for the wear that continuously results, thereby permitting tighter tolerances and fewer rejects. This was not possible previously without the advent of good computer software and sensing techniques.

In a global economy, competitive success will accrue to companies that can absorb and apply new innovations quickly, no matter where those innovations originated and no matter the size of the company. To build this capacity to respond, innovative couplings between universities, industries and government laboratories must be fostered to exploit new discoveries. For example, effective networks must be developed that link multi-level manufacturing expertise with the skilled factory floor work force and the engineers who design, innovate and make things work.

At the discovery end, university researchers who push the limits of process understanding will do in close association with industry in order to focus research agendas on salient wealth creation activities. Government laboratories must work hand in hand with industries and trade associations to develop and improve process technology.

As this new production world emerges, the skill base of the national work force becomes a dominant comparative advantage. Enhancing the capabilities of workers to make decisions, convert ideas into designs and products, and receive and implement new technologies developed through research is the true grand challenge for our Nation. Meeting this challenge requires creating a complex infrastructure that enhances the thinking and information-handling capabilities of the Nation's work force. Indeed, manufacturing must come to be viewed as a national asset, and jobs and careers in manufacturing must be highly regarded.

NSF already has many of the essential elements in place that underlie innovation in design and manufacturing systems and could catalyze efforts to foster development and deployment of the enabling technologies, systems integration knowledge and human resources required to effect a timely shift toward more effective production systems.

In fiscal year 1993 NSF requested $104.5 million for advanced manufacturing research, an increase of $25 million over the fiscal 1992 base of $79.5 million. Within this base, NSF supports a broad array of fundamental research, enabling technologies and educational activities involving a wide variety of partnerships among academe, industry, the States and other Federal agencies. Let me give you some examples.

Within the Engineering Directorate, about 20 university-based centers are supported that focus on various aspects of design and manufacturing technologies. For example, the Purdue Engineering Research Center on Intelligent Manufacturing Systems is making important advances in technology to integrate design, process and quality control in a computer integrated manufacturing system for quick turnaround, small-piece processing. The ERC for Net Shape Manufacturing at Ohio State University focuses on high performance programmable process control technologies to optimize the processes underlying our manufacturing industries overall.

Within the Computer and Information Science and Engineering Directorate research is supported in the high performance computing and communications, hardware and software computing technologies, integrated microelectronic systems, graphics and visualization, databases, automation, and machine intelligence.

The new Social, Behavioral and Economic Sciences Directorate at NSF focuses on the human dimensions of manufacturing, such as examining the ways that individuals function within manufacturing systems and the impacts of different organizational and management structures on manufacturing systems. And I would offer here that the person who has been appointed to lead this new directorate is a sociologist who has done research on the human dimension in manufacturing, and that was a purposeful recruiting aim.

In fiscal year 1993 NSF will build on this existing base of support, focusing on the development and integration of the various elements needed to support improved manufacturing systems. NSF activity will complement related activities at DOD, NASA and NIST.

Last month, the White House announced that the Federal Coordinating Council for Science, Engineering, and Technology

(FCCSET) will be developing a coordinated interagency research and development initiative in manufacturing. This effort will seek to leverage the world-class technological capabilities of the Nation to address the manufacturing needs of a broad sweep of industrial sectors. This is a timely and vital activity, for real success will only be achieved by teaming the top talent and best resources of government, industry and academe working together effectively.

In the end the test will be our ability to integrate an enabling work force with enabling technologies and an enabling information structure to manufacture products and systems which are increasingly salable throughout the world. A corollary asset will be fresh models for adaptive management and organization. And, in fact, part of the NSF fiscal 1993 budget is a new management of technology program closely integrated with this manufacturing initiative.

Mr. Chairman, that concludes my testimony. I'll be happy to answer questions when we get to that.

[The prepared statement of Dr. Bordogna follows:]

Testimony of Dr. Joseph Bordogna
Assistant Director for Engineering
National Science Foundation
Before the Subcommittee on Science
Committee on Science, Space and Technology
United States House of Representatives
May 12, 1992

Chairman Boucher, Mr. Packard, and members of the Subcommittee, thank you for the opportunity to testify on the efforts of the National Science Foundation in manufacturing education and research. Before discussing the NSF programs in some detail, allow me to describe a vision for 21st Century Manufacturing that is driving the planning at NSF and indeed that of other related federal agencies as well.

This vision represents a growing consensus of knowledgeable people, and is being forged out of intelligent, farsighted studies and reports, such as The Competitive Edge (National Research Council), Made in America (MIT Commission on Industrial Productivity), and 21st Century Manufacturing Enterprise Strategy (Manufacturing Forum, Lehigh University). It is also being illuminated by such thought leaders as Lester Thurow and Peter Drucker, and by experience from federally sponsored manufacturing programs, such as NSF's Engineering Research Centers, NIST's Manufacturing Technology Centers, and DOD's ManTech program. Let me briefly describe this vision of manufacturing to give you a context for understanding the efforts of NSF and other agencies.

A Vision for 21st Century Manufacturing

Spurred by the global competitive environment, the increasingly rapid development of new enabling technologies, and the advent of high-performance computing and communications, manufacturing is moving toward a new paradigm: where both human physical and *intellectual power* are synergized and coupled to production, resulting in so-called lean and agile manufacturing enterprises, capable of responding quickly to the demand for high quality, highly customized products at the lowest possible cost. Highly competitive industrial enterprises will incorporate production systems that support more rapid product development, shorter production life cycles, and increased flexibility and efficiency in the use of machinery, materials and human resources. They will have integrated methods for design, production, and quality control based on new knowledge and technology, and they will be responsive to social and environmental concerns.

Future manufacturing enterprises will compete on their capability to react quickly to opportunities for creating wealth and to capitalize on a climate of perpetual change and uncertainty. They will assimilate field experience and technological innovations easily, continually modifying products, processes and services to incorporate them. Since products will be continuously phasing in and out of production, reprogrammable, reconfigurable, continuously changeable production systems, integrated into a new, information intensive, manufacturing system will be required.

Design and manufacture will be highly regarded as a coordinated art and a knowledge-based integrated process. To rapidly develop and introduce new products at an increasingly faster pace, the design process thus becomes a production capability. At the user's end, design information will be linked closely with marketing and sales to know what customized features are desired; at the discovery end, with research and development to capitalize on the nation's extensive science and technology base. In addition, the growing capability to develop new "designer" materials will lead to materials characteristics having an increasingly catalytic impact on product design.

Future agile enterprises will utilize intelligent manufacturing processes that optimize outputs through the use of sophisticated sensor systems and closed-loop feedback control. For example, on a Computer Numerically Controlled (CNC) lathe, tool wear will be sensed as the part is processed so that the system can compensate for the wear that results, thereby producing tighter tolerances and fewer rejects. Indeed the entire product life cycle will be viewed as a "closed loop" process. In this sense, production systems will optimize the use of energy and materials, use environmentally benign manufacturing processes and plan for the eventual recycling of products into reusable starting materials.

In the global economy, competitive success will accrue to companies that can absorb and apply new innovations quickly - no matter where originated. Organizational capacity - rather than specific features of any technology itself - will determine how quickly new technologies are diffused within a company. Helping companies develop that organizational capability becomes an important new mission for government. To respond, innovative couplings between universities, industry and government laboratories must be fostered to exploit new discoveries and apply engineering solutions to manufacturing problems. Effective networks must be developed that link multi-leveled manufacturing expertise with the skilled shop-floor workforce and engineers who design, innovate and make things work.

At the discovery end, university researchers who push the limits of process understanding will do so in close association with industry in order to focus research agendas on salient, "wealth creation" activities. Government laboratories will work hand-in-hand with industries and trade associations to develop and improve process technology. New regional manufacturing centers will focus on advanced process technologies keyed to regional economic development strategies, with technology innovation and deployment, coupled with worker education/training as major goals. These regional foci will promote a "culture" of continuous creativity and innovation, and will be supported by cooperative linkages with industry, state and federal governments, and trade associations.

As the agile production world emerges, the skill base of the national workforce becomes the dominant comparative advantage. Enhancing the capabilities of workers to make decisions, convert ideas into designs, and receive and implement new technologies developed through research is the true "grand challenge" for our nation. Meeting this challenge requires creating a complex infrastructure that enhances the thinking and information handling capabilities of the nation's workforce.

Manufacturing skills improvement is critical to success in advanced manufacturing. The industrial base must be able to use new computer-communications-based technologies, employ statistical quality control, manage just-in-time inventories, and operate flexible manufacturing systems. To do this requires that average workers acquire levels of education and skill that they have not had to have in the past. Alliances must develop between industry and academe to identify and deploy the critical knowledge and skills required for agile manufacturing. New technologies must be harnessed to deliver this knowledge, such as using television and computer-communication links to industrial sites and community colleges to provide seminars and workshops skills.

In the future industrial enterprise, technically-oriented professionals must be able to quickly absorb and integrate new knowledge into the design, production and management process. Education must empower and enable them to assume stronger leadership roles. Currently, manufacturing is of low profile interest at many universities and technical colleges. Many science and engineering faculty have had little experience in how things are made. This must be remedied by changing the culture of academe to value the integration and synthesis of knowledge as highly as is discovery. In the future, manufacturing must come to be viewed as a national asset and careers in manufacturing must be highly regarded.

What the National Science Foundation can do

NSF already has many of the essential elements in place that underlie innovation in design and manufacturing systems, and could catalyze efforts to foster the development and deployment of the enabling technologies, systems integration knowledge and human resources required to effect the timely shift in paradigm toward agile and lean production systems.

NSF's long-term strategy is to catalyze development and deployment of the enabling technologies and systems integration knowledge and to address problems related to the effective use of human resources. This strategy builds on basic research and initiatives in education and human resources, advanced materials and processing, advanced manufacturing, management science, and high-performance computing and communications. The plan is to: (1) support the scientific and technological base for advanced manufacturing; (2) interact with the culture and context of university research and education toward support for "agile" manufacturing, (3) address the need for curriculum and laboratories essential to meeting the human resources needs in manufacturing, and (4) couple industry with academe in order to integrate the effort and deploy human talent and technology. NSF activity complements related activities at DOD, NASA, and NIST.

The FY 1992 Base

In FY 1993, NSF requested $104.5 million for advanced manufacturing research, an increase of $25 million over the FY 1992 base of $79.5 million. Within this base, NSF supports a broad array of fundamental research, enabling technologies, and educational activities involving a wide variety of partnerships among academe, industry, the states, and other federal agencies. Such efforts include basic disciplinary research underlying the technical base and the more focused FCCSET initiatives on advanced materials and processing, education and human resources, and high-performance computing and communications.

Within the Engineering Directorate (ENG), about 20 university-based centers are supported (in cooperation with industry) that focus on various aspects of design and manufacturing technologies. For example, the Purdue Engineering Research Center (ERC) on Intelligent Manufacturing Systems is making important advances in technology to integrate design, processing, and quality control in a computer-integrated manufacturing system for quick-turnaround small-batch processing. The ERC for Net Shape Manufacturing at Ohio State University focuses on high performance programmable process-control technologies to optimize the processes underlying our manufacturing industries. There is a Strategic Manufacturing Initiative for support of group research (currently with DOD participation). Related research is supported on manufacturing and processing technologies aimed at the microelectronics, photonics, and optoelectronics industries and on the design of intelligent control systems. In addition, ENG coordinates the Small Business Innovation Research (SBIR) program, which encourages firms to commercialize manufacturing technology. In FY 1991, SBIR manufacturing grants totaled about $5.5 million.

The Computer and Information Science and Engineering (CISE) Directorate's manufacturing-related research focuses on advanced computer and information technologies that support distributed design and intelligent manufacturing of objects; system-level issues that arise in understanding, modeling, and integrating the component manufacturing technologies to form integrated manufacturing systems; and the computing and networking infrastructure and services necessary to make distributed manufacturing a reality. The CISE base supports research in high-performance computing and communications technologies, hardware and software computing technologies, integrated microelectronic systems, graphics and visualization, databases, automation, machine intelligence, and other enabling technologies, and the application of information science and technology to manufacturing. CISE, DARPA, and MANTECH are supporting a national design study on advanced manufacturing technologies and systems. A workshop on Information Technology and Manufacturing in May 1992 provides a platform for the FY 1993 initiative in this area.

The new Social, Behavioral and Economic Sciences (SBE) Directorate focuses on human dimensions of manufacturing. For example, SBE research is examining the ways that individuals function within manufacturing systems and the impacts of different organizational and management structures on manufacturing systems. It is also examining models and algorithms for designing and managing production processes, and different decision-support systems and related information technologies that affect management of production processes. Many projects are being funded collaboratively by private firms through a special joint private-sector initiative.

The Mathematical and Physical Sciences (MPS) Directorate is exploring dynamic models of materials properties and behavior to provide realistic simulation of materials performance in production processes; and is also using evolving mathematical techniques, such as stochastic modeling, and statistical quality control, to optimize and control physical manufacturing processes.

There are also a number of Science and Technology Centers (STCs) that advance manufacturing technology. Support is also provided for education and human resources, such as student fellowships and traineeships; four large university coalitions aimed at engineering education reform; research experiences for undergraduate students; expanded participation of women and minorities; and laboratory development projects. There are also Engineering Faculty Internships to further encourage faculty to conduct research within an industrial setting.

The FY 1993 Effort

In FY 1993, NSF will build on this existing base of support, focusing on the development and integration of the various elements needed to support 21st Century manufacturing systems. These include:

- Intelligent manufacturing processes that optimize outputs through the use of sophisticated sensor systems and closed-loop feedback controls.

- New technologies for intelligent manufacturing and their integration into complete systems.

- Rapid prototyping of parts and products through the use of CAD tools and fabrication techniques.

- CAD/CAM tools and integrated systems for design, analysis and simulation of manufacturing processes and products that can be used throughout the entire product lifecycle.

- New systems for distributed design and manufacturing and ways to link processes via integrated software and hardware and the development of the necessary interfaces, standards, networks, and databases.

- Models for distributed manufacturing systems and integrating the informational and physical aspects of advanced manufacturing.

- Microfabrication techniques and methodologies to permit the low-cost production of microelectronic, electromechanical, and integrated microelectricalmechanical devices and products.

- Environmentally benign processes that minimize any potential negative impacts on the environment.

- Techniques for the management of new technology.

In the long run, the goal of this FY 1993 integrated initiative is to develop the capability to model and integrate the complete product life-cycle from customer interaction and product conception to final product delivery and distribution, coupling technology to managerial and economic requirements, and incorporating such practices as total quality management, concurrent engineering, and integrated logistics.

In the short run, the vitality of U.S. manufacturing will depend on: (1) successfully incorporating extant and state-of-the-art technologies and best engineering and management practices into industrial enterprises; and (2) improving work force education and training, including applying the latest educational technologies. NSF will network existing design and manufacturing research centers to other efforts focused on education reform and technology transfer, such as the NIST Manufacturing Technology Centers, and the State Industry/University Cooperative Research Centers. There are also plans to establish additional industry/university cooperative research centers focused on advanced manufacturing keyed to economic development strategies for states, with technology transfer and worker education and training as major program components.

In conclusion, let me emphasize that the nation must rediscover and dedicate itself to the development of manufacturing technologies, based upon the realities of the global market. A national effort must be erected to develop the infrastructure requirements for agile manufacturing. Last month the White House announced that the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) will be developing a coordinated interagency research and development initiative in manufacturing. This effort will seek to leverage the world-class technological capabilities of the United States to address the manufacturing needs of a broad sweep of industrial sectors. This is a timely and vital activity, for real success will only be achieved by teaming the top talent and best resources of government, industry and academe, working together effectively.

Mr. Chairman, that concludes my testimony. Thank you for the opportunity to appear here before you today. I will be happy to answer any questions that you or you colleagues may have.

Mr. BOUCHER. Thank you, Dr. Bordogna.

Dr. Solberg?

Dr. SOLBERG. Good morning, Mr. Chairman, members of the subcommittee. Thank you for the opportunity to appear before you today.

I bring a hopeful message. Over the past 7 years, I have seen a transformation at my university driven by the ERC program. Before the ERC, we were like most universities still are, very individualistic, fairly remote from industry, lacking any real cross-disciplinary integration, and educating our students as narrow specialists with strong analytical skills but little emphasis on design. The ERC has changed that. We are now educating students to work in teams with people from other disciplines. We conduct our research with the direct participation of industry. We are carrying out a long range strategic plan.

The way we do research is different, and the nature of the research is different. The way we do the education of students is different, and the character of that education is different. And the way we work with industry is different.

The reward system has been permanently changed. That's something we may want to discuss further.

I think the best thing we have done is to get the best and brightest students to see manufacturing as an appealing career track. I know that other ERCs have had similar experience, and I believe we've had success in changing the culture of the university beyond the hopes of the architects of the program back in 1984 or 1985.

There have been a number of independent studies that confirm this success by the Government Accounting Office, by the National Academy of Engineering and others. To me the most compelling evidence comes from a recent study—I'm not sure it's been released yet. It was conducted for the National Science Foundation by an independent group from, I believe, the University of Washington. And what they did was to survey the employers of graduates of the program. These employers indicated that the students they had hired were superior in several ways. They were better prepared to work in industry. They were better working in cross-disciplinary teams, quicker at getting up to speed, they had a better sense of the whole system, were better at design, and so forth.

The single best indicator of their satisfaction was that they wanted to have more of these same kind of students. So based on that I have three recommendations.

There should be more ERCs. It was originally, I think, an experiment. We now have enough evidence to conclude the experiment was successful, so I think the number of ERCs should be increased. Not that they are the only way to succeed, of course, but this is one method that works.

Secondly, the existing ERC should be sustained and possibly expanded. You know, we have an unfortunate tendency in this country to want to plow new ground rather than harvest the orchards that were planted several years ago. That's one of the ways we differ from the Japanese and other competitors that we're attentive to. So I'm just reminding you that this—when we find something that works we should try to exploit it.

Third, and this is a different issue. We need to be more proactive in involving underrepresented groups in engineering. Particularly, women and minorities are going to be needed as part of the work force, the technical work force in engineering and they have historically been underrepresented, as you know. The ERCs are taking this issue as part of their mission, particularly over the last 2 or 3 years. The National Science Foundation has created some new initiatives in this area. Probably more could be done.

Again, thank you for this opportunity to speak, and I'd be happy to answer questions.

[The prepared statement of Dr. Solberg follows:]

May 12, 1992

Testimony of Prof. James J. Solberg
Director, Engineering Research Center for Intelligent Manufacturing Systems
Purdue University, West Lafayette, Indiana

Before the Subcommittee on Science,
Committee on Science, Space and Technology
U. S. House of Representatives

Mr. Chairman and members of the committee:

Thank you for the opportunity to appear before you today. I am the Director of the Engineering Research Center for Intelligent Manufacturing Systems at Purdue University, one of the ERCs established by the National Science Foundation starting in 1985. The ERC program was designed specifically to help American industry become more competitive by addressing a number of perceived weaknesses in the infrastructure that supports innovation. These weaknesses included such factors as the narrowness of technical disciplines, the gap between universities and industry, an inadequate emphasis on design, and the lack of attention to "systems" issues in our engineering education system.

At the time the program began, the ERCs represented an experiment to determine whether radical new approaches to engineering education and research could really take hold in universities, which, like most of our large institutions, tend to resist innovation. I can now report that the experiment was a success. In fact, the ERCs have accomplished more in less time and with less money than any of the people who created the concept expected. This fact has been confirmed by a number of independent studies.

One very recent study surveyed the employers of graduates of several of the ERCs, including our own. The employers indicated that these students had been better prepared in several important ways for working in industry than the usual engineering students. Perhaps the best indicator of success was that most of the respondents were eager to hire more of the students graduating from these ERCs.

A profound change, which some have called a "change of culture," has occurred at those universities where ERCs are located. It would be better to call it an enrichment of the culture, because we are really adding to the strengths of our traditional approaches to research and education, which are still the envy of the world. Regardless of how the transformation is labeled, the ERCs have cultivated an evolution to a new academic research environment in which the disciplines work together to tackle the larger scale and more technically diverse problems that occur in advanced technology today. The faculty are also working much more closely with partners in industry, which provides direct and indirect benefits to both sides. The smooth transition of research results from the university laboratories into industrial use, the awareness of the real needs of industry on the part of the researchers, and the educational process itself are all better served by this new environment.

The research carried out under the ERC is all cross-disciplinary, and is oriented toward the specific needs of industry. Some fifty companies have collaborated in our center. In addition to leveraging the funding from the National Science Foundation for highly cost effective financing of research, the facilities, expertise, and guidance provided by industry enable the ERC to attack large scale, realistic problems that could not otherwise be addressed in a university. The experience provided to students in dealing with the "real" problems is invaluable in preparing them to assist in the competitiveness challenge faced by American industry.

Examples of the technological advances include a Quick Turnaround Cell for rapid production of one-of-a-kind machined parts, a high-level computer modeling system to support product design and analysis, process models for improved control of several types of manufacturing processes, and basic theory and methodology for planning and control of assembly operations. All of the projects follow a ten year strategic plan leading to an integrated demonstration of the world's first Intelligent Manufacturing System by 1995.

Along with many technical advances, the ERC research has provided new approaches to product design, to manufacturing process control, and to system integration. The pace and quality of technology transfer have been improved by the unique mechanisms for interaction between the university and industry. The ERC has permanently changed the culture of the university, and also promoted changes in industry that encourage innovation for competitiveness. Finally, none of this would have happened without the ERC, or some similar kind of organization.

So what of the future? The coverage of the existing centers, from either a technical view or the number of companies and universities influenced, is still quite small. In order to have a large impact upon the nation's industrial practices and the educational pipeline, there should be more such centers. The evidence that they work is substantial, and the models for how to do it are available.

Secondly, we need to sustain and expand the effort at existing ERCs. Many of the existing centers have developed new concepts in their laboratories which are ready for the next stage in development, which we might call "functional prototyping." These functional prototypes would be working versions of the new technical concepts. They would provide private industry with a proof of the viability of new concepts developed in the universities, and thereby provide a rational basis for a business decision to develop or adopt the new technology. These functional prototypes could go a long way toward filling the gap between what universities can do in their laboratories and what private industry can do based upon profit incentives.

Third, we need to broaden our educational programs. In particular, we need to make a serious effort to bring more women and minorities into the mainstream of engineering. As you no doubt know, these groups have a disproportionately low representation in the profession, but we are trying to change that. The factory worker of the future, as much as in every other sector of our economy, must possess marketable skills to remain employable, and the standards for these skills are rising. Our country must not fail to develop the full technical capabilities of all of our young people.

In closing, I would like to emphasize again that our most important product is our students. We in the universities have the opportunity to influence bright young people at the time they are choosing their careers. It is a time in their lives which is of great importance not only to them as individuals, but to the nation. I hope we can inspire them to turn their talents to productive goals, to prepare them to help American industry maintain its competitive edge, and to stimulate them to continue that thrust throughout their lives. I cannot think of anything more vital to the long term security of America than this.

Biographical Sketch

James J. Solberg is the Director of the Engineering Research Center for Intelligent Manufacturing Systems and a Professor of Industrial Engineering at Purdue University in West Lafayette, Indiana. He received a B.A. degree from Harvard in mathematics in 1964, a M.A. in mathematics and a M.S. in industrial engineering from the University of Michigan in 1967, and a Ph.D. in industrial engineering from the University of Michigan in 1969.

In addition to several teaching awards, Dr. Solberg won the "Book of the Year" Award in 1977 and the David F. Baker Distinguished Research Award from the Institute of Industrial Engineers in 1982. He is member of the National Academy of Engineering.

As Director of the Engineering Research Center for Intelligent Manufacturing Systems since its formation in 1985, Dr. Solberg has managed a cross-disciplinary program in research, education, and technology transfer involving some forty professors and 200 students annually.

Mr. BOUCHER. Thank you, Dr. Solberg.

Dr. Agogino, we have already introduced you. We welcome you this morning. And your written statement will be made a part of the record. We would welcome your oral summary.

Dr. AGOGINO. Thank you, Mr. Chairman, and members of the subcommittee, for the opportunity to testify before this panel.

The Synthesis Coalition is comprised of the following eight educational institutions: California Polytechnic State University at San Luis Obispo, Cornell, Hampton, Iowa State, Southern, Stanford, and Tuskegee Universities, and the University of California—Berkeley, from where I come. We represent diversity in geographical locations as well as variety in size, mission and institutional types.

The patterns of current engineering culture in industry reflect those of our educational institutions. We as educators have an opportunity to change that culture of engineering education which in turn will filter into the industrial environment. Several recent studies from the National Research Council, of which you've been summarized this morning, predict that not only do industrial and academic institutions need to restructure to meet today's competitive pressures, but the engineer of the next century will need a much broader range of skills.

The goals of the Synthesis Coalition are to develop an infrastructure and blueprints for model programs that will (1) systematically restructure our undergraduate curricula to meet the needs and competitive pressures of the 21st century and (2) substantially increase the number of underrepresented minorities and women in the undergraduate engineering programs and our graduate school pipeline. As a coalition with a shared vision and diverse, yet complementary, strengths, we will be able to attain levels not possible by funding individual researchers, and we have structured our efforts and goals such that the NSF funds have provided substantial leverage for additional industrial funds, institutional matches and collaboration.

Our strategy for curricula reform is directed towards solving nine very specific problem areas. I will focus my testimony on those that are related to integrated design and manufacturing education.

Our students today are not exposed to enough synthesis and open-ended problem solving. Our curricula tends to be compartmentalized without enough interdisciplinary content. Students' progress through our curricula are disjointed and poorly integrated. There is little concurrent engineering and life-cycle design synthesis taught. Concurrent application of multiple disciplines through the product realization cycle requires team design experiences which are largely absent from the curricula today.

Not enough exemplary industrial design practice and experience are embedded in the curriculum. In particular, as recommended in the NRC report on improving engineering design, there is a need to communicate successful or design practices from industry.

The consequences of these problems in the engineering curriculum today are that the production of engineering graduates that are skilled at disciplinary analysis. We do do that well. But they lack skills in synthesis, inter- and multi-disciplinary problem solving, concurrent engineering, teamwork and communication. Not only are we producing engineering graduates that are narrowly focused and not prepared for the competitive pressures in industry today. We are also systematically losing those very students that could provide leadership in business and public policy.

In addition, we are not exploiting the diversity and strength of our Nation's human resources. The engineering graduates we produce do not reflect the ethnic diversity of the U.S. population. The appalling lack of female representation in the engineering ranks transmits the perception to our young women that the field of engineering is not open to them, and thus they do not apply to our engineering programs.

I believe the U.S. should exploit this diversity and use it as an asset, not a liability. If large portions of our population are disenfranchised to this Nation's technical leadership and development, our race relations will only continue to suffer and we will not have met the broader needs of our multicultural Nation. Our ability to compete in an international marketplace requires utilizing the broad range of talent that exists in our population. Plus it is appropriate that the engineering pipeline should be a high priority in the Coalition's strategic plan.

Our vision of an integrated curriculum is one in which the separate curricula pieces will be woven into an engineering tapestry to provide breadth while maintaining a commitment to engineering fundamentals. In particular, it is our view that design and manufacturing education should not be separated subjects, but part of an integrated whole within a broader societal context. Sensitivity to market issues, environmental concerns, and quality design and manufacture of engineered products require a change and a mindset that cannot be taught in a single course. One does not provide a catalyst for cultural change by means of a single course. These concepts must be woven throughout the curriculum, starting at the freshman level and preparing students for a career of lifelong learning.

In conclusion, I believe that the NSF Undergraduate Engineering Program is a creative and promising solution to many of the problems that I have outlined. It couples predominately undergraduate institutions with major research universities. It has allowed us an opportunity to work with Historical Black Colleges in setting curricular strategies that are implementable to a wide range of institutional settings and to tackle critical human resource problems.

Going beyond the goal of effecting small level changes at a particular institution, the Coalition program has the potential for making broad-ranging systematic changes across our Nation's system of higher education. Engineering education cannot develop in a vacuum, however. Continued support for research and design in manufacturing methods and technology is of paramount importance. Research and education should be viewed as complementary intellectual endeavors.

That concludes my testimony. Thank you.

[The prepared statements of Dr. Agogino and Mr. DeZutter follow:]

Mr. Chairman and Members of the Subcommittee:

Thank you for the opportunity to testify on Manufacturing Education and the programs of *Synthesis*: an Undergraduate Engineering Education Coalition, partially funded by the National Science Foundation.

I will focus my testimony on three issues: *What* we teach, *how* we teach and *who* we teach.

OVERVIEW OF THE GOALS OF SYNTHESIS

The *Synthesis* Coalition, supported by the National Science Foundation and industrial partners, is comprised of the following eight educational institutions: California Polytechnic State University at San Luis Obispo, Cornell, Hampton, Iowa State, Southern, Stanford, and Tuskegee Universities, and the University of California at Berkeley. We represent diversity in geographical locations as well as variety in size, mission and institutional type. The focus of all our Coalition projects is on synthesis; a blend and fusion of new curricular strategies designed to create a new breed of engineer, who is skilled at multidisciplinary open-ended problem solving and design within the context of broader societal factors.

The patterns of current engineering culture in industry reflect those of our educational institutions. We as educators have an opportunity to change the culture of engineering education which will in turn filter into the industrial environment. Several recent studies have shown that not only do industrial and academic institutions need to restructure to meet today's competitive pressures, but that the engineer of the next century will need even more skills [1-3]. These engineers "will need to play a broader, overarching role described variously as a generalist, a system engineer, one combining technical competence and social-political-financial competence" [1]. "What modern manufacturing needs and is not getting are master technicians and Renaissance engineers. Instruction . . . should emphasize the application of new ways to improve quality and productivity, such as techniques for robust design, quality programs, production control mechanisms, and new accounting systems . . . [2]. " .. design must be distributed throughout the engineering curriculum, beginning with introductory design courses, which serve the dual purpose of introducing the design process and demonstrating the relevance of the engineering courses to design, and continuing as a part of more advanced engineering courses"[3].

The goal of the *Synthesis* Coalition is to develop an infrastructure and

INTEGRATING DESIGN AND MANUFACTURING EDUCATION WITHIN BROADER SOCIETAL GOALS

Statement of

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Synthesis: an NSF Undergraduate Engineering Education Coalition

before the
Subcommittee on Science
Committee on Science, Space and Technology
Hearings on Manufacturing Research and Education
U.S. House of Representatives

May 12, 1992

blueprints for model programs that will (1) systematically restructure our undergraduate curricula to meet the needs and competitive pressures of the twenty-first century and (2) substantially increase the number of underrepresented minorities and women in undergraduate engineering programs and the graduate school pipeline. As a coalition with a shared vision and diverse yet complementary strengths we will be able to attain levels not possible by funding individual research projects. We have structured our efforts and goals such that the NSF funds will provide substantial leverage for additional industrial funds and collaboration.

The major goals of the *Synthesis* Coalition in integrating the undergraduate engineering curriculum are highlighted below in each of four thrust areas:

- Curriculum: Develop, test and implement new engineering curricula through use of interdisciplinary curricular options, modular materials, new information technologies, and horizontal and vertical integration of topics.

- Supporting Technologies: Develop and implement the computer-based National Engineering Education Delivery System (NEEDS) to archive and provide national access to a broad range of curricular materials. NEEDS is an entirely new educational delivery system which will provide widespread, rapid, electronic access to an almost arbitrarily large number of diverse instructional modules. Curricular material in NEEDS will be organized by both disciplinary and interdisciplinary indices. Links across disciplines will be provided in the form of "curricular paths" through the database. Eventually, NEEDS will be available not only to this Coalition but to all engineering schools, both as a library/database and a broad distribution channel for the results of their work in developing new concepts, methods, curricula and tools.

- Pipeline: Recruit and retain to Bachelor's degree more undergraduate students, especially women and under-represented minorities through a program of intervention, retention, enrichment.

- Linkage: Establish strong relationships among institutions with the Coalitions and with the wider engineering education community so that the above results are quickly disseminated and adopted by other engineering schools.

CRITICAL PROBLEMS IN ENGINEERING EDUCATION TODAY

Our strategy for curricular reform is directed towards solving the nine critical problem areas identified below. Compartmentalized curricula have contributed to many of these critical problems, as they hinder the development of open-ended problem solving skills required to perform multi- and inter-disciplinary synthesis. As shown in the schematic of the typical curriculum path in Fig. 1, the student's progress through this compartmentalized curricula is disjointed and poorly integrated.

1. *Synthesis*. Students are not exposed to enough synthesis and open-ended problem solving experiences. We teach too much content and not enough process.

2. *Interdisciplinary Content*: Curricula tends to be compartmentalized without enough inter- and multi-disciplinary content. Students progress through our curricula is disjointed and poorly integrated.

3. *Delivery Styles*: Delivery styles are outdated and do not effectively utilize modern information technologies. Learning style differences and cultural/ethnic diversity are not uniformly considered in the classroom.

4. *Concurrent Engineering*. There is little concurrent engineering and life cycle design synthesis taught. Concurrent application of multiple disciplines through the product realization cycle requires team design experience which is largely absent in curricula today. The concepts of designing for manufacturability and quality, meeting market needs, and time to market have been largely absent from the education of engineers until very recently.

5. *Industry*. Not enough industrial practice and experience are embedded in the curriculum. In particular, there is a need to communicate successful or "best" design practices from industry in which the firms develop an environment and commitment to continuous improvement throughout the product realization cycle, which is supported by top management and concurrently integrates life cycle aspects of a product, including design and manufacturing [3].

6. *Laboratory/Hands-On*. Insufficient hands-on and laboratory experiences are offered to undergraduate students. In recent years, this situation has become worse rather than better. In recent years, we have witnessed a deterioration in our laboratory facilities at the undergraduate level.

7. *Curriculum Turnover*: Curriculum turnover is too slow and mechanisms for bringing new research and technologies into the undergraduate classroom are lacking. Even large research universities, which do a good job at adding the latest technology into graduate courses, find it difficult to update their undergraduate programs.

8. *Social Context*: Societal factors are neglected in conventional curriculum. The

engineer as a decision maker must be able to evaluate and communicate to social implications of technology. Another concern is the lack of consideration of ethnic and cultural diversity.

9. *Communication:* Students lack adequate communications skills upon graduation. This is perhaps one of the greatest complaints that we hear from industries who hire our graduates.

The consequences of these problems in the engineering curriculum today are the production of engineering graduates that are skilled at disciplinary analysis but lack skills in synthesis, interdisciplinary problem solving, concurrent engineering, teamwork and communication. Not only are we producing engineering graduates that are narrowly focussed and not prepared for the competitive pressures in industry today, we are also systematically losing those very students who could provide leadership in business and public policy. In addition, we are not exploiting the diversity and strength of our nation's human resources. The engineering graduates we produce do not reflect the ethnic diversity of the U.S. population. The appalling lack of female representation in the engineering ranks transmits the perception to our young women that the field of engineering is not open to them.

STRATEGY FOR CURRICULAR REFORM

Our strategy for curricular reform is based on dual but complementary approaches: *systematic restructuring* and *modular experiments.* Systematic curriculum restructuring is the long range goal of multidisciplinary curriculum working groups of faculty who evaluate and build on the lessons learned from corresponding modular experiments. Broad classes of these curricular and pipeline experiments include: concurrent courseware, self-paced laboratories, synthesis case studies, computer-aided prototyping, research on learning styles, learning centers, computer integration, faculty training and international outreach projects. Many of these projects have active participation from industry and our national laboratories.

Our vision of an integrated curriculum is one in which the separate curricular "pieces" will be woven into the engineering tapestry to provide the breadth needed for the engineers of the future, while maintaining a commitment to engineering fundamentals (Fig. 2). In particular, it is our view that design and manufacturing education should not be separated subjects but part of an integrated whole within a broader societal context. Sensitivity to market issues, environmental concerns, and quality design and manufacture of engineered products require a change in mind set that can not be taught the second semester of the senior year in a traditional capstone design course. One does not provide a catalyst for cultural change by means of a single course. These concepts must be woven throughout the curriculum, starting at the freshman level and preparing students for continuing lifelong learning process after graduation.

Although the Synthesis Coalition is working with industry and several of the NSF Engineering Research Centers to bring good product realization practices into the classroom through a large array of curricular materials, including multimedia design case studies, manufacturing courseware and games, role playing exercises, rapid prototyping software and integrated engineering enterprise concepts, it is clear that the knowledge available is limited. More work is needed at the research level to develop improved design and manufacturing methods.

THE NEED FOR DIVERSITY: WHO WE TEACH

I would like to end with a few comments concerning who we teach. The early part of the nineteenth century gave us an engineering profession that was predominately white and male. In the second half of this century, we witnessed an increasing percentage of foreign-born engineers in our undergraduate and graduate engineering programs, leaving the female half of our population and an increasing percentage of ethnic minorities behind. I believe that the U.S. should exploit its diversity and use it as an asset rather than a liability. If large portions of our population are disenfranchised to this nation's technical leadership and development, our race relations will only further suffer and we will not have met the broader needs of our multicultural nation. The *Synthesis* Coalition has major goals in increasing the number of women and ethnic minorities that enter our undergraduate programs and continue into graduate schools. In addition to improving the content of the curriculum, we have established a strategy for evaluating our programs to take into account diversity in learning styles and addressing those aspects that may adversely affect the retention of engineering students [6].

The question of "who we are teaching" should be an integral part of any program aimed at improving design and manufacturing education and should not be placed as a secondary issue. How we teach and what we teach should only be approached within the context of who we teach. Our ability to compete in the international marketplace requires utilizing the broad range of talent in our population. Any cultural change in industry and government concerning improving the environment for quality engineered products must take the people that make up the engineering enterprise and the changing diversity of its make-up into account.

CONCLUDING REMARKS

In conclusion I believe that the NSF Undergraduate Engineering Program is a creative and promising solution to many of the problems that I have previously outlined. It couples predominately undergraduate institutions with major research universities. It has allowed the research universities an opportunity to work with Historical Black Colleges in setting curricular strategies that are implementable to a wide range of institutional settings and to tackle critical human resource issues. Going beyond the goal of affecting small local changes at a particular institution, the Coalition program has the potential for making broad ranging systematic changes across our nation's system of higher education. Improving integrated design and manufacturing education should be a primary goal of NSF sponsored programs in engineering education, with support from industry, national laboratories and government. It is of primary importance that these large scale efforts be supported and evaluation procedures be established to verify that these goals are being met. Engineering education can not develop in a vacuum, however. Continued support for research in design and manufacturing methods and technology is of paramount importance. Research and education should be viewed as complementary intellectual activities.

On a personal level, I am an enthusiastic supporter of the NSF Coaltion program. I entered into the proposal phase because I and my colleagues believed that major structural changes were needed if the United States was to continue to be a world leader in the production of engineered products. Each of us knew we could not enact lasting change alone. The level of support from industry and our educational institutions has greatly exceeded my expectations. At the University of California at Berkeley I have witnessed a revolutionary change in the attitude of faculty and administration concerning undergraduate education. I have reports of the same trend in our sister Coalition schools. In addition to providing resources for the programmatic changes that were specified in our strategic plan, I am receiving a surprising level of support from the top levels of my administration, including the Chancellor and the President. During this rough period of sharp budget cuts and belt tightening, university matches to Coalition programs have been preserved and strengthened. A significant number of top research and teaching faculty are engaging in Coalition activities. Educational issues are becoming a major factor in the evaluations for promotion, as are affirmative action and outreach programs to support K-12 education. Industry has matched the NSF dollars many fold and they have become equal partners in our developmental efforts. I believe that these changes would not have happened without the monetary and intellectual support of the National Science Foundation and its advisory boards. The NSF funds have truly provided unprecedented leverage from industry and within our own universities.

REFERENCES

[1] *Proceedings of the ASEE Symposium on Engineering Education in the 21st Century*, 1991.

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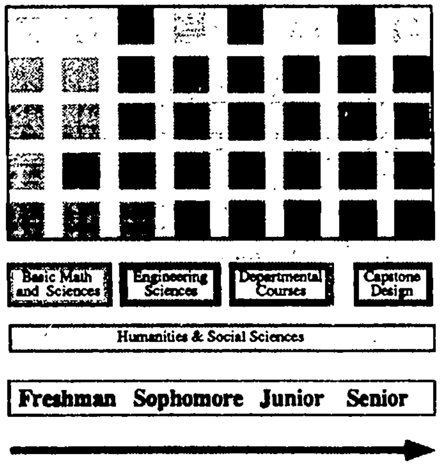
[4] Ingraffea, A.R., T. Henderson, A.M. Agogino, A. Eide, and J. Aceto, "Synthesis: A National Engineering Education Coalition," *New Approaches to Undergraduate Engineering Education III*, Engineering Foundation Conference, Banff, Canada, July 28-Aug. 2, 1991.

[5] Agogino, A.M., "Systematic Curricular Reform," in "Draft Annual Report of Synthesis: A National Engineering Education Coalition" submitted to NSF, April 15, 1992.

[6] Agogino, A.M., "Retention through Curricular Reform," *Proceedings of the Frontiers of Engineering Education Conference, Engineering Education Foundation*, Santa Barbara, CA, Keynote talk, Jan. 9, 1992.

Figure 1

Typical Curriculum Path Today



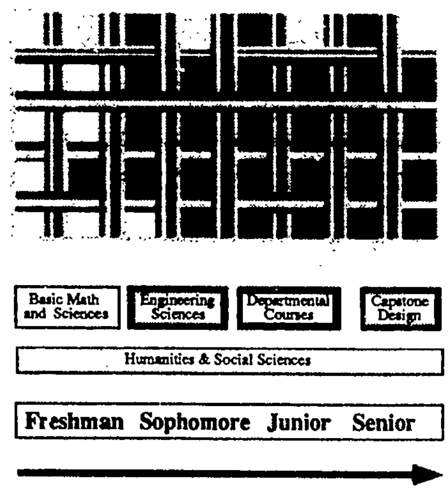
Progress through compartmentalized curricula is disjointed and poorly integrated.

Compartmentalized curricula hinder the development of open-ended problem solving skills required to perform multi-disciplinary synthesis.

Figure 2

Synthesis Curriculum

Our principal goal is to develop curricular strategies, alternate modes of instruction and access, and supporting tools to foster horizontal and vertical integration of engineering knowledge within the context of broader societal factors.



Separate curriculum "pieces" will be woven to provide breadth needed for the engineers of the future, while maintaining a commitment to engineering fundamentals.

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BIOGRAPHICAL SKETCH

Alice Merner Agogino

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Alice M. Agogino is an Associate Professor of Mechanical Engineering at the University of California at Berkeley where she heads the Berkeley Expert Systems Technology (BEST) Laboratory and the Concurrent, Collaborative, Computer-Aided Design (C^3AD) Laboratory. She also serves as Associate Director for Curriculum Restructuring for the NSF-sponsored *Synthesis* Coalition for undergraduate engineering education. She is a registered Professional Mechanical Engineer in California and is actively involved in consulting with industry. Her research interests include multiobjective and strategic product design, nonlinear optimization, probabilistic modeling, intelligent control and manufacturing, graphics and computer-aided design, artificial intelligence and decision and expert systems. She is a member of AAAS, AAAI, ACM, ASME, ASEE, IEEE, ORSA/TIMS, SAE, SME and SWE.

Dr. Agogino received a B.S. in Mechanical Engineering from the University of New Mexico, an M.S. degree in Mechanical Engineering from the University of California at Berkeley in 1978 and Ph.D. from the Department of Engineering-Economic Systems at Stanford University in 1984. She received an NSF Presidential Young Investigator Award in 1985; IBM Faculty Development Award, 1985/86; Pi Tau Sigma Award for Excellence in Teaching, 1986; Ralph R. Teetor Educator Award, 1987; SME Young Manufacturing Engineer of the Year Award, 1987/88; Best Paper Award, ASME Design Theory and Methods (with S. Bradley), 1991 and Most Distinguished Alumnus, ME Dept. University of New Mexico, 1992.

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STATEMENT OF

JAMES E. DE ZUTTER

INTERNATIONAL GOVERNMENT RELATIONS COMMITTEE

SOCIETY OF MANUFACTURING ENGINEERS

CONCERNING MANUFACTURING RESEARCH AND EDUCATION

TO THE

SUBCOMMITTEE ON SCIENCE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

U.S. HOUSE OF REPRESENTATIVES

12 MAY 1992

MR. CHAIRMAN, MEMBERS OF THE SUBCOMMITTEE:

I AM JIM DE ZUTTER, A MEMBER OF THE INTERNATIONAL GOVERNMENT RELATIONS COMMITTEE OF THE SOCIETY OF MANUFACTURING ENGINEERS. I AM CURRENTLY EMPLOYED BY DIGITAL EQUIPMENT CORPORATION AS ITS MANAGER OF MANUFACTURING STRATEGIC PROGRAMS WITH THE GOVERNMENT. I APPEAR TODAY ON BEHALF OF THE SOCIETY OF MANUFACTURING ENGINEERS WHICH IL PLEASED TO COMMENT ON THE CONTINUALLY INCREASING NEED FOR MANUFACTURING RESEARCH AND EDUCATION.

THIS WEEK THE 75,000 MEMBERS OF THE SOCIETY OF MANUFACTURING ENGINEERS CELEBRATE THE 60TH ANNIVERSARY OF THEIR PROFESSIONAL ORGANIZATION. SINCE ITS FOUNDING IN 1932, THE SOCIETY HAS FOCUSED ITS EFFORTS ON THE PROFESSIONAL DEVELOPMENT OF ITS MEMBERS. IT RECOGNIZES THAT CONTINUING IMPROVEMENT IN THE ABILITIES OF THOSE CHARGED WITH MAKING THE PRODUCTS THAT AMERICA NEEDS IS KEY TO GENERATING THE WEALTH REQUIRED TO IMPROVE OUR STANDARD OF LIVING. THROUGH ITS EXTENSIVE PROGRAM OF CERTIFICATION, CONFERENCES, COURSES, CLINICS, PUBLICATIONS, AND EXPOSITIONS THE SOCIETY EXTENDS TO ITS MEMBERS AS WELL AS OTHERS IN THE MANUFACTURING PROFESSION, THE LATEST ADVANCES IN MANUFACTURING TECHNOLOGIES AND PROCESSES.

A PARTICULAR SOURCE OF PRIDE IS THE SOCIETY'S MANUFACTURING ENGINEERING EDUCATION FOUNDATION. IN 1991, THE FOUNDATION AWARDED GRANTS IN EXCESS OF $1.6 MILLION TO UNIVERSITIES AND TECHNICAL INSTITUTES. THESE FUNDS ARE USED TO STRENGTHEN MANUFACTURING ENGINEERING AND TECHNOLOGY PROGRAMS AT NORTH AMERICAN SCHOOLS. THE SIGNIFICANCE OF CONDUCTING THIS HEARING ON THIS PARTICULAR SUBJECT AT

THIS PARTICULAR TIME IS IMPORTANT TO THE SOCIETY AND TO THOSE WHO MAKE MANUFACTURING THEIR LIFE'S WORK.

BEFORE MOVING INTO THE SPECIFICS OF ENGINEERING CURRICULA, FACULTY DEVELOPMENT, AND RESEARCH AGENDAS, I FEEL IT IMPORTANT TO SPEND SOME TIME DISCUSSING THE CONTEXT IN WHICH ALL OF THIS MUST TAKE PLACE. IN JANUARY OF THIS YEAR, THE SOCIETY'S MONTHLY MEMBERSHIP MAGAZINE "MANUFACTURING ENGINEERING" CARRIED AN EXTENSIVE SET OF FEATURE ARTICLES DEALING WITH THE CHALLENGES FACING U.S. MANUFACTURERS ON INTO THE NEXT CENTURY AND BEYOND. ENTITLED "FUTURE VIEW: MANUFACTURING FACES THE NEXT MILLENIUM" THE ARTICLES DEAL WITH GLOBAL COMPETITION AND MANUFACTURING MANAGEMENT, WORKFORCE TRAINING AND SKILLS, MANUFACTURING RESEARCH AND DEVELOPMENT, THE MANUFACTURING ENTERPRISE, AND PRODUCTION TECHNOLOGY.

EACH OF YOU RECEIVED A COPY OF THAT PUBLICATION AS OVER 1000 ADDITIONAL MAILINGS WERE MADE TO U.S. SENATORS AND REPRESENTATIVES, CABINET MEMBERS, HEADS OF FEDERAL AGENCIES, STATE GOVERNORS AND SELECTED CEOS OF FORTUNE 500 COMPANIES. OUR PRESIDENT, DOUGLAS BOOTH, CONTINUES TO RECEIVE AN EXTENSIVE AMOUNT OF CORRESPONDENCE FROM THOSE WHO HAVE READ THE ISSUE. I HAVE ATTACHED A REPRINT OF THE "FUTURE VIEW" ARTICLES AS PART OF THIS TESTIMONY.

WHILE "FUTURE VIEW" IS AN IMPRESSIVE JOURNALISTIC ENDEAVOR WITH A STRONG MESSAGE, IT DRAWS FROM THOSE WHO HAVE DONE SIGNIFICANT WORK ON THE VISION OF WHAT MANUFACTURING WILL BE LIKE IN THE FUTURE. OF PARTICULAR IMPORTANCE IS THE WORK DONE AT THE IACOCCA INSTITUTE WHICH

LED TO THE PUBLISHING OF "21ST CENTURY MANUFACTURING ENTERPRISE STRATEGY."

WHAT IS IMPORTANT IS THAT IN ORDER TO MAKE PROGRESS WE NEED TO KNOW WHICH WAY TO GO. ALL OF US, INDUSTRY, EDUCATION, GOVERNMENT, AND THE RESEARCH COMMUNITY; WE ALL NEED TO GO IN THE SAME DIRECTION.

THE WORK DONE IN "FUTURE VIEW" AND "21ST CENTURY MANUFACTURING ENTERPRISE STRATEGY" CONTINUALLY CALLS FOR A NATIONAL MANUFACTURING VISION. THEY IDENTIFY THE NEED FOR AN INFRASTRUCTURE WITHIN WHICH TO STRIVE FOR THE VISION. THEY CALL FOR SPECIFIC ACTIVITIES WHICH, WHEN ACCOMPLISHED, WILL SPELL SUCCESS FOR THE FUTURE OF MANUFACTURING IN OUR COUNTRY.

WE IN THE SOCIETY OF MANUFACTURING ENGINEERS FEEL THAT WHATEVER INDIVIDUAL EFFORTS ARE UNDERTAKEN TO IMPROVE THE STATE OF U.S. MANUFACTURING, THEY MUST BE ACCOMPLISHED AS PART OF AN AGREED UPON PLAN OF INDUSTRY, ACADEMIA, GOVERNMENT, AND THE RESEARCH COMMUNITY TO ACHIEVE A NATIONAL MANUFACTURING VISION. THAT VISION HAS YET TO BE FRAMED.

THE SOCIETY OF MANUFACTURING ENGINEERS CONCURS WITH THE AUTHORS OF THE NATIONAL RESEARCH COUNCIL REPORT, "IMPROVING ENGINEERING DESIGN"(NATIONAL ACADEMY PRESS: 1991), THAT ".....EFFECTIVE DESIGN IS A PREREQUISITE FOR EFFECTIVE MANUFACTURING; QUALITY CANNOT BE MANUFACTURED OR TESTED INTO A PRODUCT, IT MUST BE DESIGNED IN." HOWEVER, THE SOCIETY FEELS QUITE STRONGLY THAT UNLESS THE ENGINEERING

DESIGN PROCESS FULLY INTEGRATES THE FUNCTIONS OF PRODUCT CONCEPTION, DEVELOPMENT, MANUFACTURING, USE, SUPPORT, AND ULTIMATLY ITS END-OF-LIFE DISPOSITION, QUALITY WILL NOT BE DESIGNED IN. IN FACT, IT IS BECOMING MORE READILY RECOGNIZED AND ACCEPTED THROUGHOUT INDUSTRY AND THE MANUFACTURING PROFESSION THAT THE TERM "MANUFACTURING" IS TAKING ON A MORE ALL-ENCOMPASSING NATURE. IT INCLUDES IN ITS DEFINITION THE INTEGRATED ACTIVITIES OF THE PRODUCT LIFE CYCLE, FROM CONCEPTION THROUGH END-OF-LIFE AND DISPOSITION.

ANOTHER TREND WHICH IS TAKING PLACE IN OUR COUNTRY IS THE MIGRATION OF MANUFACTURING ACTIVITY FROM LARGE, VERTICALLY INTEGRATED CORPORATIONS TO THE SMALL AND MEDIUM SIZED MANUFACTURING COMPANIES. INTEGRATED ENGINEERING DESIGN RESEARCH AND EDUCATION ACTIVITIES NEED TO BE STRUCTURED AND CONDUCTED SUCH THAT THEIR BENEFITS CAN BE EASILY TRANSFERRED AND USED BY THIS INDUSTRIAL BASE. MAXIMUM USE OF THE HIGH PERFORMANCE COMPUTER AND COMMUNICATIONS INITIATIVE AS SUPPLEMENTED BY THE "FACTORY AMERICA NETWORK" CALLED FOR IN THE "21ST CENTURY MANUFACTURING ENTERPRISE STRATEGY" WILL ACCOMPLISH THAT END. THE INTERACTIVE CAPABILITY OF THAT INTEGRATED INFORMATION NETWORK WILL BE ABLE TO BRING THE WORLD OF THE SMALL BUSINESS MANUFACTURER INTO THE REALM OF THE DESIGN RESEARCHER AND VICE VERSA.

THE SOCIETY CONCURS WITH THE AUTHORS OF "IMPROVING ENGINEERING DESIGN", THAT ENGINEERING DESIGN EDUCATION NEEDS TO BE STRENGTHENED. WE FEEL THAT EXPERIENCE WITH THE PRODUCT LIFE CYCLE IS AN IMPORTANT PART OF THAT STRENGTHENING. ACCORDINGLY, WE RECOMMEND THAT PRACTICAL EXPERIENCE IN THE PRODUCT REALIZATION PROCESS FOR A PERIOD OF AT

LEAST TWO YEARS AFTER OBTAINING THE BACCALAUREATE, BE A PREREQUISITE FOR GRADUATE DEGREES IN ENGINEERING DESIGN. ALSO, THE ROTATION OF GRADUATE DESIGN ENGINEERS THROUGH INDUSTRY, RESEARCH, AND ACADEME AS A PLANNED COURSE OF PROFESSIONAL DEVELOPMENT, WILL PROVIDE THE FIELD WITH ENERGETIC, STATE-OF-THE-ART TALENT.

THE CREATION OF A "NATIONAL CONSORTIUM FOR ENGINEERING DESIGN" NEEDS TO BE APPROACHED WITH CAUTION. THE NEED TO ESTABLISH SEPARATE ORGANIZATIONS TO DEAL WITH SPECIFIC PROBLEMS MAY REPRESENT A KIND OF SOLUTION THAT IS BECOMING A PART OF OUR PAST. THE SOCIETY FEELS THAT THERE IS SUFFICIENT TALENT IN PROFESSIONAL SOCIETIES, GOVERNMENT AGENCIES, INDUSTRIAL ASSOCIATIONS, AND EDUCATIONAL INSTITUTIONS TO DEAL SUCCESSFULLY WITH THIS PROBLEM. WHAT NEEDS TO HAPPEN IS A COMING TOGETHER OF THIS TALENT IN ORDER TO FOCUS ON DEFINING SOLUTIONS AND IMPLEMENTING RESULTING ACTIVITIES LEADING TO SUCCESS. THE CURRENT STATE-OF-THE-ART IN INTEGRATED SYSTEMS TECHNOLOGIES AND THEIR APPLICATIONS MAKE THE ESTABLISHMENT OF VIRTUAL TEAMS TO DEAL WITH THESE KINDS OF ISSUES A REALITY. THE SOCIETY OF MANUFACTURING ENGINEERS IS READY TO WORK WITH OUR SISTER PROFESSIONAL SOCIETIES AND THE DESIGNATED STEWARD OF PUBLIC FUNDS TO PULL SUCH A TEAM TOGETHER.

OUR COMMENTS ON THE NATIONAL RESEARCH COUNCIL REPORT, "THE COMPETITIVE EDGE: RESEARCH PRIORITIES FOR MANUFACTURING" (NATIONAL ACADEMY PRESS: 1991), WILL BE LIMITED TO THE SUBJECT OF CHAPTER SIX: MANUFACTURING SKILLS IMPROVEMENT. THE REASON FOR DOING SO IS TO EMPHASIZE THE SOCIETY'S FOCUS ON WHAT IS THE ULTIMATE DETERMINANT AS TO THE SUCCESS OR FAILURE OF U.S. MANUFACTURING--IT'S PEOPLE.

THE SUBJECT MATTER OF THE PREVIOUS CHAPTERS, AS WELL AS LIKE MATERIAL IN OTHER PUBLICATIONS DEALING WITH THE NECESSITY TO REINVIGORATE THE U.S. INDUSTRIAL BASE, DEPENDS ENTIRELY ON THE ABILITY OF THE WORK FORCE TO IMPLEMENT STATED RECOMMENDATIONS FOR IMPROVEMENT. ADVANCED MANUFACTURING TECHNOLOGIES AND PROCESSES HAVE BEEN PROPOSED AND DISCUSSED. BUT, HOW QUALIFIED WILL THE WORK FORCE BE WHO HAS TO DEVELOP THEM AND IMPLEMENT THEM? WHERE WILL THE PEOPLE COME FROM WHO HAVE TO TEACH, WHO HAVE TO DO THE RESEARCH, WHO HAVE TO WORK WITH THE ADVANCED MANUFACTURING TECHNOLOGIES AND PROCESSES OF THE FUTURE?

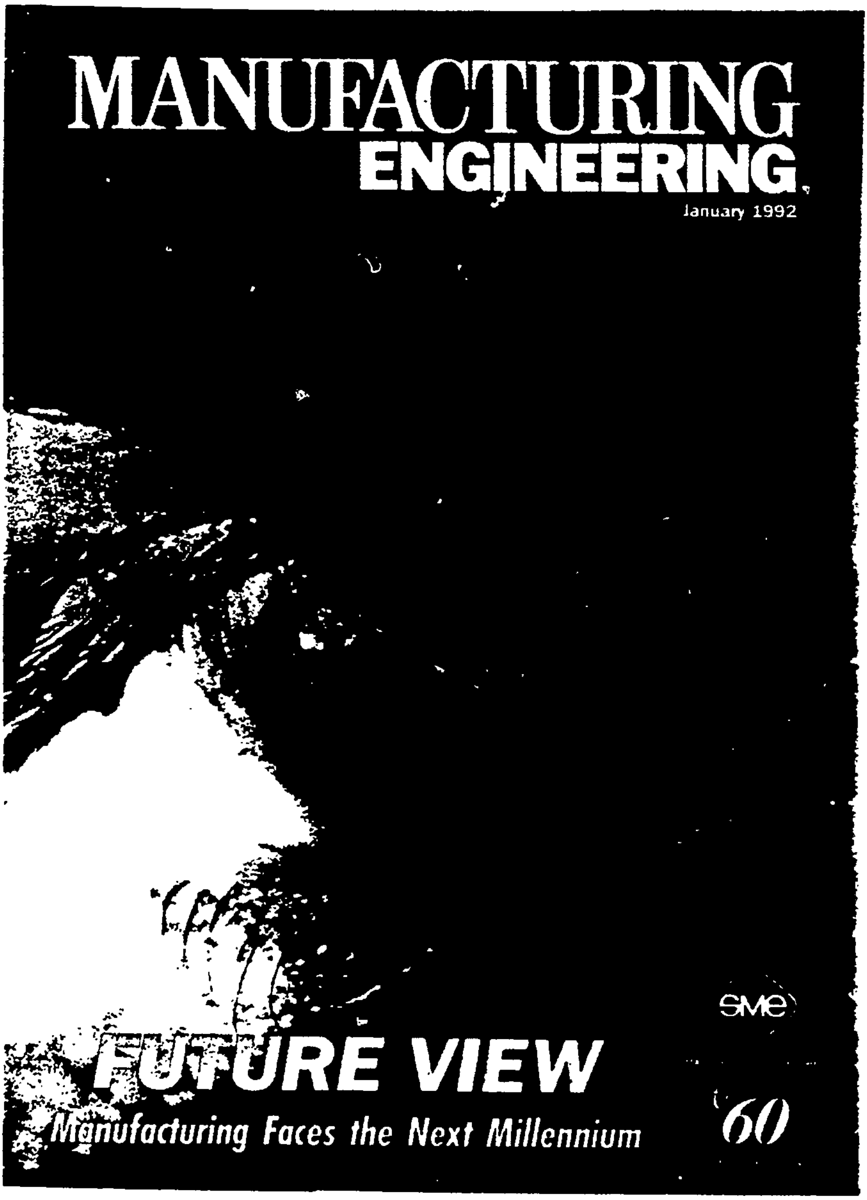
WITH A CAVEAT DEALING WITH THE CREATION OF NEW ORGANIZATIONS, WHICH WAS PREVIOUSLY EXPRESSED IN THIS TESTIMONY, THE SOCIETY ENDORSES CHAPTER SIX AS REFLECTIVE OF ITS POSITION ON MANUFACTURING SKILLS IMPROVEMENT. ALSO, AS PREVIOUSLY STATED, THE SOCIETY STANDS READY TO WORK COLLABORATIVELY TO ACHIEVE IMPROVEMENT IN THE AREAS IDENTIFIED.

THE STRATEGIC MANUFACTURING INITIATIVE ANNOUNCED BY THE NATIONAL SCIENCE FOUNDATION AND THE OFFICE OF THE SECRETARY OF DEFENSE IS AN EXAMPLE OF THE KIND OF ACTIVITY THAT COULD BE A PART OF ACHIEVING THE NATIONAL MANUFACTURING VISION, WERE THAT VISION DEFINED. THE ABSENCE OF THE TALENTS OF THE DEPARTMENT OF COMMERCE, THE DEPARTMENT OF ENERGY, AND THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION AS A PART OF THE GOVERNMENT TEAM IS QUESTIONED. WE NOTE THE ROLE OF "ASSISTANCE AND ADVICE OF THE RESEARCH COMMUNITY..." AND THE STRONG ENCOURAGEMENT TO INTERACT WITH INDUSTRY. MORE IS NEEDED. THE SOCIETY BELIEVES THAT THIS INITIATIVE IS BUILT FOR THE PARTICIPATION OF CROSS

FUNCTIONAL TEAMS INVOLVING, IN AN INTEGRATED FASHION, APPROPRIATE TALENTS FROM GOVERNMENT, INDUSTRY, ACADEMIA, AND THE RESEARCH COMMUNITY. ONCE AGAIN, WE OFFER TO HELP.

A FINAL NOTE. THE SOCIETY OF MANUFACTURING ENGINEERS HAS RECOGNIZED FOR SOME TIME THE VALUE OF THE NATION'S COMMUNITY COLLEGE SYSTEM TO DELIVER SERVICES AT THE GRASS ROOTS LEVEL OF SOCIETY--ACHIEVING INTIMATE CONTACT WITH A DISPERSED, RATHER ELUSIVE SET OF CLIENTS. THE MAJOR OBJECTIVE OF COMMUNITY COLLEGES IS TO EDUCATE AND/OR TRAIN PEOPLE WITH EMPHASIS ON LOCAL JOB OPPORTUNITIES AND CONTINUING EDUCATION. A COMMITTMENT TO COMMUNITY SERVICE IS CENTRAL TO THE VALUE SYSTEMS OF THE COMMUNITY COLLEGES. THE USE OF COMMUNITY COLLEGES AS DELIVERY AGENTS FOR THE PRODUCTS OF MANUFACTURING EDUCATION AND RESEARCH SHOULD BE AN INTEGRAL PART OF ANY MANUFACTURING RESEARCH AND EDUCATION PROGRAM.

MR CHAIRMAN, THE SOCIETY OF MANUFACTURING ENGINEERS APPRECIATES THE INTEREST OF YOUR SUBCOMMITTEE IN WHAT WE HAVE SAID TODAY. WE STAND READY TO PROVIDE ANY ADDITIONAL INPUT AND ASSISTANCE YOU DEEM APPROPRIATE. WE ARE FULLY COMMITTED TO DOING ALL THAT WE CAN TO RESTORE VITALITY TO AMERICA'S MANUFACTURING SECTOR. FOR AS IT IS SAID IN PROVERBS, 29:18 AND IN THE FINAL ARTICLE OF "FUTURE VIEW": "WHERE THERE IS NO VISION, THE PEOPLE PERISH...." I WILL NOW TRY TO ANSWER ANY QUESTIONS YOU MAY HAVE.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FUTURE VIEW
MANUFACTURING MANAGEMENT IN CRISIS

The war in the Persian Gulf a year ago was a dramatic example of why technology is critical to America's future. But Americans may have drawn the wrong conclusions from it. "It was not a demonstration of US technological preeminence," says George M.C Fisher, chairman of the Washington, DC-based Council on Competitiveness. "Much of the electronics in US weapons was several generations behind the most advanced commercial technologies, and in many of these technologies the US is no longer the leader."

Daniel Burstein, business consultant and author of *Yen!* and *Euroquake* (Simon & Schuster, New York) agrees "Americans became overconfident about the country's military success and what they saw as its overall global leadership. In American eyes, Japan and Germany failed the test " Short term, the war caused a decline in US interest in Europe It made Europe seem less important. Yet today's popular American notion that Europe is a nice place, a big but somewhat backward market, will be seriously challenged over the next decade, along the lines of the current challenge from Japan.

And Japan? "If you look 10 years out to 2002, Japan—which will still have only 50% of our population and even a sm . ler percentage of our total workforc. - will equal or surpass the US in terms of total manufacturing output. At best (for us), they'll outproduce us 2:1 on a per-capita basis. That's frightening."

What is going wrong? Our problem is our success, answers Burstein. "The system worked so well for so long few people want to tamper with it. We are at a crossroads, however. Other cultures are demonstrating that in some ways their systems are superior. We're still in the denial stage. We have a vested interest in believing we have the greatest system the world has ever seen."

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The Editors

Five Myths

According to John Young, president and CEO, Hewlett-Packard Co. (Palo Alto, CA), we comfort ourselves with five myths about America's technical leadership. "The first, which I call 'the sunrise industries' myth, goes like this: 'Sure, our traditional manufacturing industries are under siege, but we still lead in the new, high-growth, high-tech segments.' " The high-tech trade balance may have looked good in the early '80s, but that ended in 1986, when the US witnessed its first-ever trade deficit in the high-technology segments, Young explains. With technological innovation, the financial rewards are cumulative. If you lose one round, it's very hard to get back in the fight.

The second myth is about "the leading edge." It says even if the US

has trade problems in technology sectors, they're only at the low end, in consumer electronics. We're ahead in leading-edge technology.

Again, facts refute the myth. In terms of dollars, it's true our biggest trade problem in electronics involves TVs, audio equipment, and VCRs; however, America is also falling behind in several critical generic technologies, including integrated circuit fabrication, optical information storage, and robotics. And consumer electronics is not all "low-tech." "Many HP engineers," says Young, "feel the degree of sophistication in the design and packaging of today's home video camcorders is the most advanced of any product family they've seen."

Myth three—the "copy-cat"—says that though other countries have caught the US, they've done so by aping us. The Japanese, especially, are incapable of innovating on their own. This was true in the early years following World War II. "But today," says Young, "US patents tell a different story. In 1988, the most recent year for which we have data, 48% of the patents granted in the US went to foreign inventors, and many were for significant technologies."

The "Nobel Prize" myth says that the US leads the world in Nobel laureates, our research universities are the best, so we have the strongest technology infrastructure. "This is misleading in two ways," Young points out. "First, we must ask whether the breakthroughs that win Nobel Prizes actually help win a fight. We focus on the pursuit of basic knowledge but give little thought to its application. Second, our technology infrastructure is showing signs of strain. We've been living off the fat of the land, doing little to ensure future generations of technology and trained people."

In real terms, federal funding for university research facilities declined 95% over the past 20 years. The White House Science Council reports it will take a $10 billion investment to bring the facilities up to adequate condition, and no one is rushing to spend the money.

As to trained people, Young sees more bleak numbers. For many reasons, more than half the engineering doctoral degrees in this country are granted to foreign students. "We're also facing a shortage of university professors," he says. "We've got a situation in the human resources area that's similar to what we have in the fiscal area. We're living on borrowed money, talent, and even time."

The "Sputnik" myth refers to the jolt Americans felt when the Russians beat us into outer space. "It galvanized us into action," recalls Young. "So we invested and succeeded in being the first to land a man on the moon." According to the myth, all the US needs to shore up its technology base is another, similar event. "The Japanese haven't obliged us by launching a Toyota into space, however," notes Young. The real cure might involve a series of small, rather undramatic changes, not another megaproject like putting a man on the moon.

Burstein points out a particular shortcoming in America's view of foreign competitiveness that he calls "the Lexus factor." Shortly before the Lexus debuted, most US automotive experts had a low opinion about Japan's ability to compete at the high end of the automobile market. A few months ago, the Lexus surpassed Mercedes in unit sales in the US. A similar skepticism was evident for many years about the European Airbus consortium, which is now seriously beginning to challenge Boeing. "Why do we keep doubting?" Burstein asks. "I'd say it's doubtful they won't succeed."

The Lexus factor mentality may be changing, however. The US public is becoming seriously concerned about the country's economic future. "By virtually every benchmark," says Fisher, "Americans are increasingly worried about what is unfolding. More than 77% think Japan is ahead of the US in terms of its ability to compete economically, and 73% believe the worst is yet to come."

In response to a call from Congress that the Defense Department develop a strategic plan for spending manufacturing technology dollars, the DoD came to industry and asked it to describe the competitive manufacturing enterprise of the 21st century. The DoD also wanted a plan of action to make that competitive model a reality. Fifteen senior executives brought together by principal investigators Dr. Roger N. Nagel, Harvey E. Wagner Professor of Manufacturing Systems Engineering and operations director of the Iacocca Institute at Lehigh University (Bethlehem, PA), and Rick Dove, chairman, Paradigm Shift International (Oakland), held a series of meetings last summer to identify the characteristics of what they came to call "agile manufacturers." Nagel and Dove are taking the group's findings to industry leaders to build a consensus before what they hope will be a series of Congressional hearings on US industrial competitiveness.

According to Dove, there are

The Air Data/Inertial Reference System design/build team at Boeing's 777 Division includes representatives from Honeywell, the system supplier.

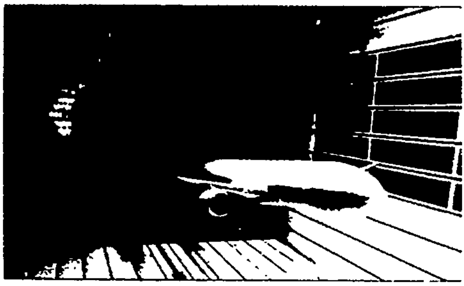
Survival in Aerospace

The aircraft industry is one area where US manufacturers have not lost their lead; however, those in the industry know they can't be complacent. The challenge from the European Airbus is real.

Dale Hougardy, VP of operations, Boeing Commercial Airplane Group—*777* Division, identifies several major competitive challenges facing his company over the coming decade. They include European subsidies, multiple certification requirements, the burden of health care costs, and the economic impact of environmental regulation.

Subsidies for Airbus. Boeing, being the country's leading exporter, is intensely concerned about maintaining open markets, good international trade rules, a strong GATT (General Agreement on Trade and Tariffs) system, and what Hougardy calls "a level playing field on government support."

Certification requirements. Imposition of airplane certification requirements by multiple countries affects the competitiveness of the entire aviation industry, he says. Certification by the Federal Aviation Administration (FAA) used to be accepted by other countries, but no longer. "To be sold in Europe, Boeing airplanes must be certified twice: in the US and again by the European Joint Airworthiness Authorities. In addition, the European country of registry adds national variants to certification. Our competitors are also subject to these multiple certification requirements."



A 3.7% scale model of the *777* twinjet at Boeing's Transonic Wind Tunnel, where aerodynamic efficiency is under study.

Hougardy claims there is no evidence that multiple certifications improve safety. "They only increase the cost of aviation products and services, making our entire industry less competitive," he says. "The industry must vigorously press toward a process of multilateral agreements or some other method that will result in only one certification process."

Health care. While industry should provide health care for employees and their families, Hougardy argues that rapidly rising costs are having a direct bearing on US manufacturers' ability to compete globally. Between 1987 and 1990, Boeing's costs for medical care for employees and their families increased 55%. In 1991, they rose another 21%. The problem can't be ignored, he says.

Environmental regulations. Environmental regulations have become extremely costly. "Boeing is investing heavily to solve problems such as chemical reduction and waste minimization," says Hougardy. "We have accepted the Environmental Protection Agency challenge to reduce emissions 50% by 1995. Soon we will see more efficient paint guns, water-based processes, and less toxic solvents in use throughout our factories. And we're providing extensive employee training on all environmental issues." But in two years, costs for record keeping, training, and reporting have risen more than 115%.

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three major descriptors of the successful manufacturing enterprise in the next century: continuous change, rapid response, and evolving quality standards.

Continuous Change

Technology is advancing so rapidly that the environment will be one of dramatic, continuous change. That means, says Dove, "the products you build today will compete with products a competitor will build two weeks from now—and they'll be made using technologies you didn't have. The processes installed in your factory six months ago must compete with those in factories equipped with technologies not available to you."

"There will be no fixed-plan operation," adds Nagel, "because products will change daily. We'll be forced into dynamic process planning, figuring out how to make things in the context of what else we're making and our configuration capability."

According to Dr. D. Bruce Merrifield, Walter Bladstrom Professor of Management, Wharton School of Business, University of Pennsylvania (Philadelphia), "Management of manufacturing will become the management of change. Survival will require major corporate restructuring to manage a combination of continuous incremental improvements and simultaneous development of next-generation technology designed to obsolete and leapfrog current systems before the competition does," he says. The hierarchical form of organization cannot manage such an environment.

Any company not involved in a process of continuous corporate renewal probably has made an unintentional decision not to be in business a few years from now. Continuous renewal involves the following five elements:

- A vision of where you must be in five years to survive
- Theoretical options for getting there

• A strategic plan comparing existing skills, resources, and capabilities against those required

• A business plan allocating resources needed and developing strategic alliances to fill the gaps

• A vigorous in-house program of workforce reskilling.

Rapid Response

Operations in a continuous-change environment climax with very short windows. Opportunities don't last long. "You must find how to get involved in that activity, master the technology, have the right production facilities available, and then get out of the business at the right time and move to something else," says Dove.

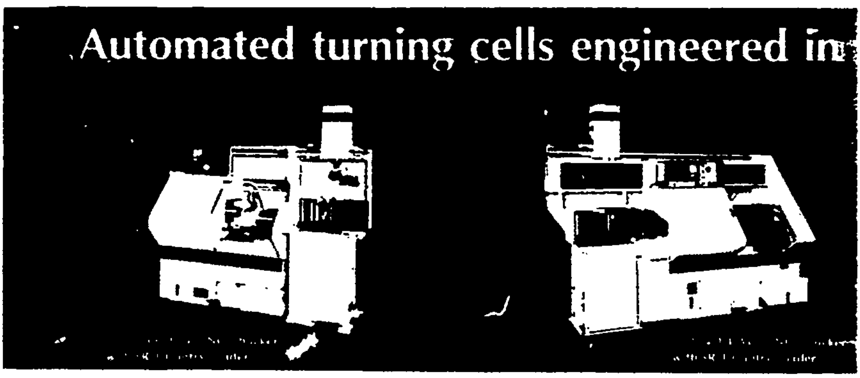
Rapid response will force much more interaction, cooperation, joint ventures, and teaming. There simply won't be time to grow all these capabilities in-house, however. Virtual corporations—made up of what you need from a number of disparate places, inside or outside the company, each contributing something unique but needing something just as unique from the others—will soon evolve. "In fact," notes Nagel, "because of the needs to put the right skill sets together, Wall Street will scrutinize how good a partner you are and what skill base you have when it ass---es the competitive health and future of your company.

"Of course, because agile manufacturing depends on sharing, teaming, and cooperation, it will highly emphasize trust. The idea of sharing information and behaving properly with respect to proprietary information will be a major ethical issue by the end of the decade."

Ed Miller, president of the National Center for Manufacturing Sciences (Ann Arbor, MI), sees a strong move among independent organizations to form collaborations. Some 208 consortia are registered with the Attorney General, often for simple projects between just two companies. Many occur on an ad hoc basis, however, and he encourages companies to seek partners outside of their normal sphere. He cites an example of companies in different industries—electronics and health care—that found they were doing parallel work in stereolithography. The electronics firm felt it had created an excellent system in the 18 months it had allowed itself, only to discover that the other firm had built a more advanced system within six months.

"Such partnerships will function in the early, precompetitive stages of technology development, allowing vigorous competition in the later stages of product development," Fisher adds.

Just as we share people, we will share processes, facilities, and the means to operate them. "Shared flexible computer-integrated facilities will be cloned around the world for remote satellite programming to make what you want, when you want it, and wherever it's needed for just-in-time delivery," says Merrifield. The modular facilities will provide rapid CAD/CAM prototyping, permitting immediate entry into a market for one, 10, or 1000-of-a-kind products at essentially the same cost, but with the precision and reproducibility required for global competition. They will be continually reprogrammable to make new or modified



products. Basically, these facilities will fulfill a service function, raising developing nations to manufacturing's leading edge while providing profitable opportunities for those who can generate the advanced systems that can be programmed into them.

About eight shared flexible computer-integrated facilities are now operating in the US, with another dozen due to open shortly. The Industrial Credit and Investment Bank of India plans to clone one soon.

Rapid response requires much-improved communication in the area of fundamental research, too. In November, a group of 60 academicians, government representatives, and industry leaders met to discuss enhancing the speed and effectiveness of transferring fundamental knowledge among their institutions. "Can we continue government support of academia when the output is students who never go into a factory and papers that the Japanese read so they can make new products?" asks Dr. Iva M. Wilson, president, Philips Display Components Co. (Ann Arbor).

"Some in the universities say the problem is with US industry—it doesn't want to accept the knowledge," responds Dr. Yoram Koren, chairman of the Department of Mechanical Engineering and Applied Mechanics, University of Michigan, and chair of the NSF-sponsored workshop. "Others say it's academia—it doesn't know how to deliver. And how should government agencies that fund research decide if research is good? Is a four-page equation a good one? Academia, industry, and government must communicate and collaborate to maximize the impact of basic research and education on manufacturing competitiveness."

Eight Agile Answers

How can a manufacturer measure its agility? Answer these questions, say Nagel and Dove:

- How quickly can you respond when you get an order for a customized product?
- How long does it take to build a new variety of something that's in your product line?
- How long did it take to negotiate parameters for real strategic relationships compared to how long it took to actually begin a strategic relationship? If the number is greater than one, something's wrong.
- How many joint ventures has your company formed this year?
- How many products do you introduce per year?
- What percentage of your new products are customized?
- What percentage are reconfigured?
- What percentage of your customers are repeat customers?

Evolving Quality

Over the next 10 years, the definition of quality will merge with the definition of customer satisfaction. "Eventually," says Dove, "we won't count defects because there won't be any. Today's standard of quality is 'defect-free.' This will be only the entry level for the next quality frontier, which will be the enjoyable emo-

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tional experience of interacting with the product."

Ed Kfoury, vice president, IBM (Armonk, NY), and president of its Industrial Sector Division, puts it another way: "Our focus is on more than the product. Quality encompasses every aspect of customer satisfaction. It means doing a better job of understanding our customers and rededicating ourselves to eliminating defects in everything we do."

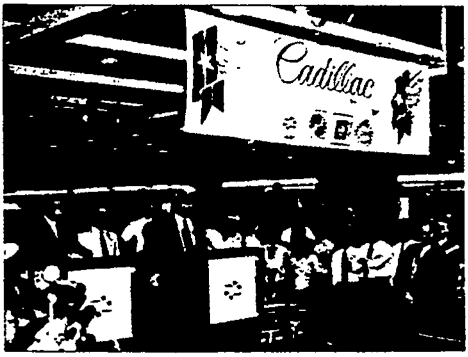
"There's a difference between quality and value," adds Leroy D "Pete" Peterson, worldwide director of Andersen Consulting's Products Industry practice (Chicago). "Most of this country's manufacturers are working to improve the quality of production, when they should focus on value—the customer's perception of how good a product is for the price.

"In the past, American consumers were all too willing to buy low-cost products of limited value. Low-cost mass production of reasonably durable goods will continue to be vitally important to some households." Nevertheless, US manufacturers must realize consumers are starting to appreciate value. Practicing statistical control is no longer acceptable. Processes now must make quality products the first time without inspection, rework, or scrap.

Dr. H. Thomas Johnson, Retzlaff Professor of Quality Management, Portland State University (Portland, OR), takes quality a step further. "Competition in the near future means adapting quickly to and even *instigating* change in customer expectations. That means empowering everyone in the company to listen to the voices of the customer and the

Best Management Practices

Twelve practices distinguish the makers of great products from average manufacturers, says Peter Marks, managing director of Design Insight (Los Gatos, CA), a consulting firm specializing in CAD/CAM and CAE. They are the following:



- *Vision*. Leading manufacturing companies have a compelling vision that is widely understood and believed. A clear vision helps recruit, motivate, and keep top technical people satisfied.
- *Attitude*. Top manufacturers have a can-do, will-do work ethic aimed at continuous innovation and improvement. They set, and often surpass, "impossible" stretch goals (see this month's "Quality Advisor" by HP CEO John Young).
- *Standards*. They have high performance expectations and devote special attention to measuring performance. They are careful to select appropriate measures.
- *Teamwork*. Leading manufacturing companies build strong functional teams and encourage cross-functional teaming. They indoctrinate new employees in the company's culture. They hire top people and place a high value on communication skills.
- *Reconfigurability*. Job and team assignments change to meet changing customer needs. Effective SWAT teams handle short-term problems. Product teams form and reform to bring out new products. Divisions form and close in response to market needs.
- *Efficiency, Effectiveness*. Great manufacturers balance local efficiency with overall company throughput and effectiveness. The key is knowing how to get results that show up in the product.
- *Shared Information*. Leading manufacturers communicate well, both internally and externally. Their people are articulate, their organizations are flatter, and they run effective meetings. Buildings and facilities are well-designed, and communication tools like E-mail, fax, and meeting rooms are widely available.
- *Ongoing Review*. World-class manufacturers continually measure progress against well-chosen milestones, benchmarks, and commitments. They know enough to make realistic promises, and they hate missing deadlines.
- *Urgency*. They have a sense of urgency—but not at the expense of getting the product right.
- *Resourcefulness*. In world-class manufacturing companies, people know what to do and where they're going—and they figure out the best, fastest, cheapest way to get there, even if it means adapting technologies from outside the organization.
- *Centers of Excellence*. Leading manufacturers understand no one can be best at everything. They create one or more centers of preeminence and rely on world-class suppliers for other technologies.
- *Early Warning Systems*. The best manufacturing companies have sophisticated early warning systems in such areas as changing customer needs, social environment, demographics, regulatory environment, evolutionary product and process technology, replacement technologies, competitors, suppliers, and distribution channels.

process. No more passing instructions down from the top to docile workers who will manipulate processes to achieve accounting targets. No more treating the customer like a sponge who will soak up companies' output to 'cover their costs.' "

How do you learn to focus on the customer? Start by focusing on your internal customer, recommends Wilson. "He's the guy down the line that you influence when you do your job. You can't implement customer orientation with your outside customers without practice."

The Human Touch

Achieving agile manufacturing requires changing how we manage people. "The process of business is mostly people," says Wilson. "If you want to be successful, you must integrate the people with the machines, processes, and products."

Human resources is an area where a competitive disadvantage is good, says HP's Young. "We don't want lower wages, because we don't want to compete on the basis of cheap labor. After all, the goal of competing is to raise our standard of living. That means Americans must be so productive and innovative they will earn more than their counterparts abroad without high unit labor costs."

In some ways we can learn from the Japanese in dealing with people, says Dr. Alan S. Blinder, Gordon S. Rentschler Memorial Professor of Economics, Princeton University (Princeton, NJ). "We could successfully import things like high training, high job security, workplace flexibility, relatively egalitarian workplaces, flexible workforces that aren't hamstrung by restrictive work rules, high employee involvement, and well-organized consultation procedures between labor and management."

According to Blinder, in a well-functioning Japanese enterprise, there's only a small distinction between some aspects of the personnel department and the labor union. Union leaders may well be management personnel on loan. "That sounds like a union that's a lackey to management," he says, and to some extent that may be true, but in Japan most managerial personnel began their careers as union members. Labor-management relations do not foster or promote the *us-versus-them* attitude so damaging in English-speaking countries. The whole system is geared to making it *us*.

"Of course," Blinder continues, "many US companies have excellent labor-management relations, and have for years. One could argue that a lot of these Japanese ideas came from us. What we must do is make this the majority of US companies, not the minority."

In 1990, the Indiana Labor and

Challenges Facing Manufacturing

MANUFACTURING ENGINEERING asked a select group from SME's College of Fellows and recipients of SME's Young Manufacturing Engineer Award to speculate on the issues facing manufacturing during the next decade. Here are excerpts from the comments of these industry leaders:

Q What challenges face manufacturing management during the next 10 years?

Donald G. Zook, assistant professor, manufacturing engineering, California State Polytechnic University, Pomona (past SME President, '86-87):

These are the critical issues for management:

Restoration of loyalty in the management workforce. Workforce reductions and elimination of middle management can only result in loss of loyalty. Fewer professionals will want a lifelong association with one employer. As companies recognize the damage done by short-term approaches, the correction effort will be formidable.

Education in linking cellular systems. Evolution from job-shop or line-flow arrangements to cells will be partially successful because of immediate payback in reduced inventory and material-handling costs. The really tough job will be educating the large number of people needed to link multiple cells, exchange information and materials, and achieve full integration.

Pacing the application of new technologies. With the accelerating development of new materials and processes, a major challenge will be selecting the appropriate tools and pacing their application to the workforce's ability to manage and use them.

Charles J. Klein*, engineering group manager, vehicle assembly, General Motors (Warren, MI):

The competitive factors of the '80s—cost and quality—have become givens. The next level of competition will include the following:

Style and product flexibility—the ability to produce a variety of differentiated products with minimum investment or setup. The current mismatch between market demand and mass-production philosophy requires a rapid transition to truly flexible, low-cost manufacturing systems.

Integration of manufacturing into design—bringing manufacturability requirements into the design process early. Significant progress has been made in design for assembly and expert systems, but even greater manufacturing knowledge must be integrated in the design process to develop robust, cost-effective products.

Social/environmental issues—a global issue for manufacturing in the next decade. New material technologies will present unique disposal and material-handling challenges.

Taylan Altan, professor and director, Engineering Research Center for Net Shape Manufacturing, Ohio State University (Columbus):

Overseas companies have three major ingredients for success: cash, technology, and a well-trained workforce. The critical issue facing US firms is training the present workforce, plus acquiring and keeping well-trained engineering and management talent.

In Germany (formerly West Germany), each year 5000–6000 students with post-high-school training in manufacturing technology enter the industrial workforce. Of these, 150 are PhD manufacturing

Management Council surveyed more than 300 Midwest manufacturers regarding their quality and productivity improvement strategies. They were asked about three classes of strategies—social system, technical system, and technology/equipment—and their impact on nine variables: domestic market share, foreign market share, overall sales, product quality, new and improved market introductions, productivity, organization costs, employee skill and knowledge, and profitability. Survey results indicate social system strategies have the most significant correlation with the outcomes, which suggests emphasizing the social aspects of performance improvement produces the greatest payback.

A potential customer's reaction to a prototype software project is observed and recorded visually and verbally at Hewlett-Packard.

Government's Role

Can US manufacturers become competitive without government assistance? No, responds Dr. Jacques S. Gansler, visiting scholar at the Kennedy School of Government at Harvard University (Cambridge, MA) and senior VP TASC (Arlington, VA). "Even a concerted effort by industry to take such actions as listening to the customer and cutting down on new-product realization cycles will be insufficient if the government continues resisting making changes that will let US industry compete.

"Industry must pressure government into initiatives like long-term, low-cost capital: an educated and

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engineers, 500–800 are on the master's level, and the rest come from two or four-year engineering-technology colleges. In Japan, the number of engineers graduated every year is larger than in the US (more than twice as many engineers per capita).

In the US, most manufacturing engineers, although extremely skilled and valuable, are not degreed and have limited openness to new technology. Similarly, in middle management, many MS and PhD-level engineers in Germany run manufacturing plants. Most US companies do not have that level of technical capability or training in their workforce.

To build a competitive manufacturing workforce in the next 10–15 years will require innovative compensation policies as already practiced by many high-tech companies in the chemical, electronics, and communications industries.

Allan Young, vice president & general manager, AYM Inc. (Albia, IA):

Here are the problems:

Shortage of trained or trainable people. It's difficult to convince the smartest people entering the workforce to go into manufacturing when the remuneration is low, challenges few, and growth too slow.

Lack of funds for updating facilities. Because we are in a mode of making money by buying and selling businesses—the business is always paying for itself—there's not enough to plow back into facilities and technology improvement.

Internal politics. With manufacturing increasingly controlled by lawyers, accountants, and marketing executives, required people skills are more political than technical, so manufacturing suffers.

Hans-Jorgen Warnecke, PhD, Fraunhofer Institute for Production Technology and Automation (Stuttgart, Germany):

To achieve cost and price leadership, innovation must be managed well, especially quality-function deployment, zero defects, and time compression. Conventional business structures must be overcome: the organization must be product and process-oriented rather than function-oriented—the vertical hierarchy must be changed to a more horizontal, product-oriented one. The bottleneck will be the thinking and attitudes of people at all levels.

The need for flexibility will grow, along with the investment in computer-controlled systems that adapt. The factory will no longer be determinate—a machine where changes and disturbances must be avoided. Instead, it will be structured to be continuously changed and "disturbed" by markets and customers. Manufacturing will be a service.

Mickey Love*, engineering manager, chassis product plant, Dana Corp. (Oklahoma City, OK):

These are the most critical issues:

Educating our workforce. We must nurture employees—provide all the things they need to grow, prosper, excel, and become outstanding employees and well-rounded individuals.

Empowering our workforce. For an "empowered" and accountable workforce, we must push the decision-making process to the lowest level. This removes the need for managers. People will take pride in all they do, and they will do a tremendous job.

**Recent recipient of SME's Young Manufacturing Engineer of the Year award.*

continuously trained workforce: incentives for R&D and capital investment; and adequate support for the necessary infrastructure (including communications and transportation). Current government policies have the perverse effect of forcing industry to focus on short-term investment, encouraging many critical industries to move offshore and separating the military and civilian sectors of the industrial base."

Many think it's primarily government's attitude that must change. "Our policymakers tend to believe computer chips and potato chips are the same," says Clyde V. Prestowitz, president, Economic Strategy Institute (Washington, DC). "When other countries target the computer, auto, or semiconductor business and execute industrial policies aimed at gaining leadership in them, our policymakers think it's a positive thing because Americans are getting good, inexpensive products. If you respond, 'But it's driving US manufacturers out of business,' they say, 'Let them make potato chips.' All chips don't have the same economic implications. We are systematically eliminating ourselves from the high-value-added industries of the future.

"The President, in particular, must make it the highest national priority to achieve and maintain industrial and technological leadership," Prestowitz stresses. "He now gives that attention to geopolitics. We subordinate our economic interests to get votes in the UN or allies in the Middle East. We're constantly trading away tangible economic assets for intangible political gain."

"Change in the government is essential," Gansler agrees. "Not

Relationships among Sociotechnical System Variables and Outcome Variables

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0.1172 [illegible]
[illegible]	[illegible]	[illegible]	[illegible]
PRODUCT QUALITY	[illegible]	[illegible]	[illegible]
NEW AND IMPROVED MARKET INTRODUCTIONS	[illegible]	[illegible]	[illegible] 0.372
PRODUCTIVITY	[illegible]	[illegible]	[illegible] 0.041
ORGANIZATION COSTS *	-0.1241 [illegible]	[illegible] 0.422	-0.0879 0.121
EMPLOYEE SKILL AND KNOWLEDGE	[illegible]	[illegible]	0.2786 0.000
PROFITABILITY	0.1072 [illegible]	[illegible]	[illegible]

* Survey of Midwest manufacturers indicates social system strategies have higher impact on outcome variables than technical system and technology strategies. Top entry is the correlation coefficient; lower entry, the level of significance. Correlation with a significance below 0.05 shows a relationship between the two variables.

Sociotechnical System Factors and their Component Strategies

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

SOURCE: [illegible] CENTER FOR QUALITY & PRODUCTIVITY IMPROVEMENT

only must it shift toward a far longer term perspective, but it must begin recognizing that (a) there is a problem and (b) government has a significant role to play in correcting it. I suggest far more emphasis in the government 'mission agencies' on long-range technology investments, with departments like Transportation, Education, and Environment mirroring the investments of the Defense Advanced Research Projects Agency [DARPA]. The Office of Science and Technology Policy could coordinate these investments.

"Applied technology is the key to future competitiveness," he continues, "in both military and economic spheres. A technology-based strategy emphasizing a balance between process and product technologies (typical in Japan) and focusing on their rapid application to new, improved—but less expensive, more reliable—products is clearly the way to go. Government must assure industry has all the incentives to move in this direction...but it first must remove the barriers."

What about a national industrial policy, with specific technologies targeted by the government for support? It's a hotly debated topic, and Dan Burstein favors it: "Of course, we'd have to set it up carefully. I call it a postindustrial policy, where government money—but not much—is pumped into supporting industry, coupled with aggressive use of tax credits.

"The decisions about which industries to favor would be made in a forum of representatives from private-sector business, economists, consultants, and academics who can model industries of the future. I believe we can pick winners and losers, but I don't think Congress should do it. It wasn't the Diet that developed Japan's industrial policy; it was an elite body of the Ministry of International Trade and Industry [MITI], dedicated civil servants who tapped the best economic minds and resources in their country."

Dr. Richard K. Lester, professor of nuclear engineering, Massachusetts Institute of Technology (Cambridge), and director of MIT's Industrial Performance Center, agrees the US needs a national industrial policy. "We must develop better capability in the federal government regarding industry or technology policymaking. Whoever shouts the loudest now gets attention—for a few months, until the next loud voice comes along. That's how it was with HDTV and semiconductors. It's an ad hoc process. We must create a sustainable body of knowledge and expertise within government or available to it that can evaluate industry needs.

"On the other hand, I'm lukewarm about what targeting will actually accomplish. There are so many areas such as health and education and savings and investment in which government policy could produce a significantly greater impact on our ability to compete."

Lester recommends a variation of the RAND Corp. as a Federal technology policy resource. "RAND was established when the nation faced serious national security problems. It provided objective analyses for the defense sector. Even conservatives in the current debate would find an equivalent organization operating in the industrial area acceptable. Of course, at the other end of the spectrum is a Department of Industry

Message from a Friend

In the life of any industry, many a disadvantage can be turned into an edge over a competitor. The Japanese have become grand masters at this game, and the rest of the world is trying to catch up.

But less thought is devoted to how advantages can quickly slide into liabilities. During the heyday of the "American century," the US made efficient use of its conspicuous advantages: an abundance of raw materials, great talent, and an enormous home market. Now the last and greatest advantage—the size and vigor of the domestic US market—is actually harming US ability to compete against Japan and Germany.

In the cutting tool industry, the questions asked about Japanese and German success are like those asked in other industries. How do they create products that are slightly better and slightly cheaper? How do they market them so effectively? Both countries have the same basic approach to world markets, market share, and product line selection. It's not a question of lower labor costs, since ours is not a labor-intensive industry, or of raw materials, since similar materials are used to make cutting tools throughout the world. Nor is it a question of infrastructure; Japan, Germany, and the US have roughly equivalent economies.

You could cover the globe with paper describing and analyzing Japanese and German industrial success. But there is one central factor: the two countries have exalted industry almost into a religion. This "religion" helped restore their pride after World War II and reinforced itself by giving workers an extremely attractive set of incentives: an intangible patriotic goal, the emotional satisfaction of becoming number one in their particular industry, and the very real benefits of a substantially higher standard of living.

While Japan and Germany were busy honing this process, the US was spending a lot of money playing policeman to the world. Even more important, the sheer size and dynamic character of the US capital market created the illusion that investments and moving money around were more important than industry and exports.

The size of the US market created other distortions. Lester Thurow from MIT's Sloan School of Management makes two relevant observations. One is about Japanese success in bypassing the pitfalls of monopolies through the keiretsu system. In the US, antimonopoly legislation kills the incentive to be number one. In the evolving free world market, the reasoning behind this legislation is no longer relevant. An astute foreign corporation will always be there to challenge a US monopolist. Current legislation creates an incentive to be second best.

Thurow's second point has by now become a common battle cry: the need for laws encouraging "patient money" that would make capital markets less a lottery and more an instrument of solid growth that's competitive through-within the executive branch."

That's on the mind of William J. Fife, Jr., chairman and CEO, Giddings & Lewis (Fond du Lac, WI), one of the country's largest machine tool builders. "Look at agriculture," he says. "The government always supports it strongly. It put low-cost land into the hands of farmers; it established land-grant colleges; wheat, peanuts, milk, corn, and other goods are protected through price regulation; and agriculture even has Cabinet status. All this effort goes into a portion of the economy that accounts for only 2.9% of our gross domestic product today. I don't want to downplay the importance of agriculture, but manufacturing is *the* largest sector within our gross domestic product."

Princeton's Blinder has a different view on a national industrial policy. "I can't imagine a government structure less likely to succeed with such a policy than ours," he says. "Here's the kind of country in which it *could* work.

"First, there should be a rough national consensus about what must be done, the direction the nation should go. We don't have that yet. Second, there should be a political mechanism able to promulgate such a consensus, translate it into laws and institutions. We don't have that. Third, the political institutions should be nationally rather than locally oriented; politicians should believe their job is to further the national interest, not the interest of the 13th district of Texas. We certainly don't have that. Fourth, we should have an effective, independent, smart professional government agency free of political interference to translate this broad mandate into specifics. We don't have that, either. Finally, there must be a tradition of cooperation between government and industry, so industry doesn't view government as either a nuisance that it must get rid of or a feeding trough. Does this sound like reality in the US?"

Sunrise or Sunset?

The future of US manufacturing? Burstein sees two scenarios. "The better case is the decision makers will hear the wake-up call and get moving. There will be new capital investment in plants and equipment and new human resources policies that bring in highly qualified factory-floor specialists, and these professionals will participate substantially in product design. Ironically, perhaps, the biggest saving grace will be that Japanese companies will continue shifting their manufacturing to this country, together with their management and process/equipment approaches. Japanese transplants and Japanese-American joint ventures will significantly renovate facilities and adopt new ways of coping with industrial challenges. I hope they'll bring more of their better stuff here than they have so far.

"The worse case is we don't respond and there's a continuing erosion of competitiveness. It won't be apocalyptic; manufacturing won't disappear in America. This country is too big, the manufacturing base too large, and the domestic market too great for it to be lost completely. Nevertheless, we could see a significant deepening of the curve of lost competitiveness."

"We're not going to drop into the abyss," adds Lester, "but I have little hope for the short term because too many US policymakers don't yet perceive the situation as a full-fledged crisis. The problem is insidious." ■

out the world, not just in the US.

The size of the American financial world is still beguiling. The size of the American market is still confusing: why sell to a foreigner who speaks a different language when there is a customer next door? Japan and Germany never had these dilemmas. For them it was always clear that exports were the key to survival.

Things have changed in the last decade, but American insularity is still a powerful and impeding factor. The words that describe the debate over industrial policy are a giveaway. People talk of the need for a national policy, while what they really need is an international policy. We have proof of the higher survival value of export-driven economies. Any manufacturer with a stake in the blossoming East Asian markets is now enjoying a helpful cushion against the doldrums in the US and Europe.

Another popular misconception is a strong educational system from kindergarten through university is a key to a nation's ability to survive in the new world of export industries. Real quality of life derives from exports, not schools; knowing is no substitute for doing.

The casualties are your children, who are growing up with the gloom of lower expectations, facing less work in manufacturing and more in services. When people talk about the changeover to a service economy, they gloss over the fact that there has been hardly any rise in productivity in services during the past 30 years. In a service economy, expectations are inherently limited. In brutal terms, it means selling fewer cars than the Japanese while trying to make more money out of the Japanese tourists visiting New York.

With the misconceptions about service industries and education, plus the union approach of getting higher wages without waiting for more cars to be sold, it is not surprising that America thinks it has hit hard times. If size and wealth have become a disadvantage, however, they can be turned around again. The vast market and general acceptance as the world's leader are powerful aids. All you need is a few simple conceptual tools and goals on which to focus your tremendous energy.

The US leads in aerospace, chemicals, and many other industries. You must make further progress to strengthen positions in which you are already strong, focusing on exports and making better products at a cheaper price.

Nobody can compete with Americans in the sports they really like. Make exports a sporting game and world competition a rival team. When the top exporter gets Superbowl attention, you will have won the game. This means a poorer government and richer people who, like a winning team, have the strength and agility to adapt quickly to changing situations. It is also a basic condition of freedom and democracy.

Stef Wertheimer
Chairman
Iscar Ltd
Tefen, Israel

FUTURE VIEW

When the Hudson Institute published a book over five years ago called *Workforce 2000*, a study done for the US Department of Labor, researchers, pundits, and after-dinner speakers made its title a buzzword for trouble ahead. The book offered three visions of the economy at the turn of the century: the surprise-free scenario, in which the economy and labor force grows slowly, with unemployment at just over 7%; the world-deflation or global-recession scenario, with over 9% unemployment; and the technology-boom scenario, where growth rebounds to post-World War II levels and unemployment drops to 5.9%.

Whichever view you chose, you saw the manufacturing labor force shrinking both absolutely and relatively, though productivity could rise through new technologies and manufacturing systems that improve quality, cut costs, and raise output. This prediction was based on what Hudson called the Five Demographic Facts.

- *The Shrinking Pool.* By 2000, the population will probably be only 15% greater than in 1985. US Bureau of Labor Statistics estimates range from a conservative 7% growth (based on low fertility, high death rates, and few immigrants) to 18% (based on the return of large families, lower death rates through advances in cancer and AIDS treatment, and many immigrants). "Throughout the '70s and early '80s, the US managed to sustain a rising standard of living by increasing the number of people at work and by borrowing from abroad and from the future," says the report. "These props under the nation's consumption will reach their limits at the turn of the century."
- *More Older Workers.* As the population (and workforce) average age rises, the pool of young workers shrinks. In 1986–2000, 38% more people will be in age group 35–47, 67% more will join age group 48–53. At the turn of the century, only 13% of the population will be young (20–29 years). Workers' ages track these trends closely. In 1985, 38% of the workforce was in age group 35–54; 25 million workers, half the pie in the standard chart, will join this group by 2000.
- *More Women.* There will be more women workers, though the rate at which they join the workforce will taper off.
- *More Minorities.* Minorities will make up a larger proportion of workers than in the past.
- *More Immigrants.* More new workers will be immigrants than at any time since World War I.

The Skills Gap

What will it cost to train these new workers—the "nontraditional" ones? What will it cost to retrain those now on the job? Nobody knows. We don't even know how much industry spends on training today. The National Association of Manufacturers (NAM) says $30 billion annually; the American Society for Training and Development says $50 billion.

Though the federal government has no reliable figures, the President's Council on Competitiveness does estimate the cost of closing the "skills gap." The private sector's training efforts, which now affect one of every 10 workers, would have to reach three of every 10. The price tag: $88 billion.

Why is the bill so high? The statistics are familiar but still horrendous. The Bureau of the Census tells us that one out of four births in the US in 1990 was illegitimate. Broken down by race, 57% of births to black women, 23% of births to Hispanic women, and 17% of births to white women were illegitimate. Over two-thirds of births to teenage mothers were illegitimate, and 90% of births to black teenagers were illegitimate. Babies born out of wedlock are likely to be poor and disadvantaged, but babies born to teenagers are at the greatest risk, so these figures are benchmarks for trouble in the workforce of 2010.

As for people on the job today, with one of eight employees reading

at no better than fourth-grade level and one in five reading at eighth-grade level, the picture isn't rosy. There could be as many as 27 million illiterate and semiliterate adults and four million with under 5 years of school. The NAM expects US employers will soon be hiring a million workers a year who can't read, write, or count adequately. Those already at work will have to be retrained—all 30 million of them.

It won't get better. The NAM pointed out in a 1990 report, *America's Workforce in the 1990s*, that "as jobs grow more demanding, education and training deficiencies will continue to cause a fundamental mismatch between jobs and workers that will necessitate a substantial expansion in corporate training."

Managing the Shrinking Pool

Manufacturers are showing growing concern over workforce management because of the skills gap. Two-thirds of NAM members surveyed by Towers Perrin last November reported "some current difficulty"

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WILL THE WORKFORCE WORK?

filling professional jobs: 57% reported difficulty filling technical jobs, and 52% reported some difficulty finding skilled craftspeople. NAM members expect these shortages to ease in five years: the percentages drop to 47%, 39%, and 33%, respectively.

Asked what workforce issue was most important in corporate planning, members indicated powerful concern for the kind of worker hired. That issue outranked even labor shortage. Why? "Although the growing number of women, minorities, and immigrants in the workforce was not the subject of this survey, it is an issue that casts its shadow on the problems of labor shortages and skills gaps." Yet it is extremely important to tap these nontraditional groups in times of shortage. There are "self-interested reasons," says the NAM. It sounds as though we'll hear a lot about managing diversity in the next decade.

If you work in California for a high-tech company like TRW Space and Defense (Space Park, CA), however, diversity is a fact of life, and William Izabal is the diversity manager. As such, he told the National Action Council for Minorities in Engineering (NACME) recently, he deals in facts, not feelings. Facts mean demographics.

"There are some nonbelievers in the company," he says, "so I give them demographics for the Los Angeles labor pool that we draw on: 30% of the population Hispanic, 11% Asian, 11.2% black, 39.7% white." The K–12 school population is 58% Hispanic. "That's the workforce coming up today, not years away," he says. TRW's own demographics reflect the change: on the technical staff today 45.6% are minorities; in the overall space/defense workforce at TRW, a third are minorities. "You don't ignore numbers like that," Izabal tells managers.

Over in Palo Alto, at Hewlett-Packard, John Lynch has the title of corporate manager for Equal Employment Opportunity/Affirmative Action/Diversity, which nicely reflects changing concerns of employers over the decade. Diversity management is a priority matter at HP: CEO John Young put it on his list of top 10 strategic objectives in 1989.

"Diversity is a business issue," Lynch told his NACME audience. "It takes $50,000–$100,000 to get a new engineer up to speed. You invest six to seven years in training and development. Without opportunities, that person will leave, probably in the sixth to tenth year of employment—those are the crucial years." HP finds the most vulnerable group to be women and minorities with advanced degrees.

In high-tech companies all over the US, diversity managers face a major obstacle, however: workforce downsizing and flattening of management layers. It's not enough to hire someone and give him or her a paycheck every month, Lynch says. "Diversity management means retaining, developing, and promoting. It means an action program in which all managers play a role."

What's the solution? Every corporation has a culture. Find out how it works, and then make it work for these nontraditional employees. "The most frequent reason female professionals and managers give for leaving is exclusion from the old-boy network," says Izabal. His studies of TRW produced an interesting fact: employees central to social networks in an organization tend to be seen as influential and get more promotions than others. So it follows that engineers and scientists who become part of that network are more likely to stay with the company and be promoted.

"At certain levels, in companies like ours," says Lynch, "the technical skills are there." What's missing for women and minorities are nontechnical, "soft" things like visibility, relationships with key senior managers, support systems, good advice about when to move to another job. "You have to measure these soft things," says Izabal, "because they determine whether an employer is preferred by this new workforce." When good technical people are in short supply, employers like TRW and HP want to be preferred.

Chaos on the Training Scene

We don't have a national industrial policy (except by default) to guide a monumental effort to educate and train the workforce of the next century. We don't have a national education system, a national apprenticeship system, a national curriculum. Given these facts, it's probably just as well that we don't have a national competence test to tell us how bad things are.

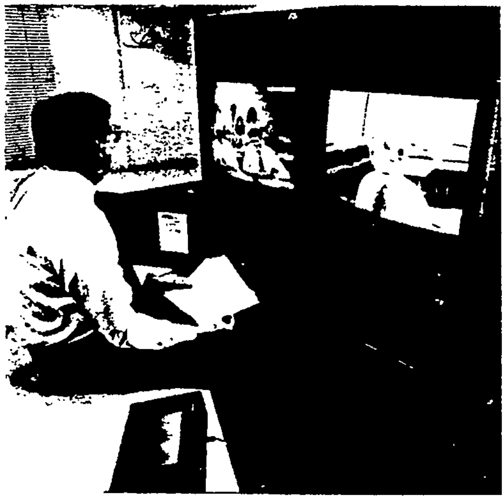
Billions are spent and no one is satisfied. John W. Sinn, professor of manufacturing technology and associate dean of the College of Technology at Bowling Green State University (Bowling Green, OH), describes the chaos:

- Little or no coordination among primary and secondary schools, two and four-year colleges and universities, and graduate schools
- Little connection between educators and business, though business is education's customer
- No linkage of math, science, and technology in technical programs
- Obsolete equipment and obsolete instructors on campus
- Inflexible bureaucratized and politicized educational structures from state to local levels
- Overlapping and conflicting technical and professional groups, all busy with turf battles rather than useful agendas.

The result, says Sinn, is "much technical education is isolated, disjointed, out of date, and irrelevant to the needs of a technological culture."

Jerry L. Monson has a name for what Sinn describes. He says there's been a "paradigm shift" in manufacturing that neither educators nor manufacturers yet understand (see tables, pp. 52, 54). He's been pondering these issues since he left a metal fabricating company to become vice president for customized training at Minnesota Riverland Technical College in Owatonna.

From the perspective of three decades of manufacturing experience, he looks out over the campus and sees flux. "The distance between management and shop floor is shrinking fast. The skills once specific to each group are beginning to blur and meld." Shop floor workers now need to read, write, communicate verbally with each other and in groups, collaborate, handle statistics, and use computers.



Professor Peter Bulkeley lectures his graduate class in manufacturing engineering, shows charts and tables on the classroom screen, discusses points, answers questions. So what's new? Bulkeley is in Boston and the students are in the Hamilton Standard plant in Windsor Locks, CT. It's all happening in real time, thanks to interactive video. They see him; he sees them; for closeups of faces he uses his zoom button. "After a while the screen disappears," says Bulkeley. "I become merged with the class."

The pressure on educators to meet these new demands is intense and will only increase, yet schools resist. "The typical educator on the front line," Monson concludes, "has not yet realized that his competitor is not at the college or university next door but across the ocean."

Chicken or Egg?

One such competitor in the high-tech area is Walter Ebersheim, who occupies the chair for manufacturing engineering at WZL (Laboratory for Machine Tools and Manufacturing Engineering), Aachen University of Technology (Germany). Ebersheim has been watching the US system at work over several decades and is still astounded. In the mid and late '60s, when groups from the US came to look at the German educational system, professors would complain to him that in the States they couldn't get research contracts from industry because industry said they had no reputation. How could they gain industry's confidence if they never got a chance to show what they could do? Ebersheim calls this the "chicken-or-egg" problem.

Though Ebersheim has been listening to these complaints for 20 years, he is still amazed at the results of the deadlock. He remembers coming to the US in the '80s to work with MIT and looking into the teaching lab. "I found a machine tool museum!" A few years ago on a California visit he discovered that the lab at Stanford University had just acquired its first NC machine tools.

At the time of his Stanford visit, by contrast, Ebersheim and his colleagues back in Germany were hard at work on a CIM curriculum to be taught in a university-run CIM factory. Students would conduct industrial projects as they were trained in advanced technologies, designing a part, creating a program to make it, measure it and test it, order materials, schedule, and assemble.

Because CIM demands flexibility above all (and humans are the most flexible resource), and lifelong learning is part of Germany's industrial policy the new CIM factory provides for workforce upgrading. Workers will hit the campus during school vacations in groups, work in the factory for a week or two, return to their companies, and come back again as needed.

Even in Germany, where the industrial policy gives priority to CIM and lifelong learning, college professors can't create such projects by decree. Ebersheim says an intense lobbying effort at federal ministries of economics was needed. (Note that in Germany creation of workforce skills is an economic matter, not an educational one.) In the end, the most sympathetic officials were in Hannover, and the factory is rising there. Hannover worked out the curriculum jointly with Aachen and the technical university in Geneva, Switzerland, where Ebersheim holds a teaching post.

Partnerships, says Ebersheim, can get away from the paralyzing question, "Who takes the first step?" In 1975 WZL sent experts to Colombia and Brazil to establish such a

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[illegible]

[illegible]

[illegible] Miller decided to go to the source, Japan, and offered himself as an apprentice to several Japanese firms. Only Fujitsu Ltd. took him seriously. Once [illegible] management recovered from its astonishment that an American tenured professor at a famous school wanted to work in a factory, things moved fast. The company decided [illegible] Miller even more than he asked: a 2½-year [illegible]ceship in Japan and a permanent job in a [illegible] up plant at the end of the process.

S[illegible] 88, with nine weeks of Japanese-lan[illegible] der his belt, Miller and family left for [illegible] seeing manufacturing engineering and [illegible] the Fujitsu way—learning new things while doing familiar and necessary things. When he comes home this year he'll be heading to Richardson, TX, to help set up Fujitsu America's new '80-million telecommunications manufacturing plant.

MANUFACTURING ENGINEERING asked Miller to share his inside view of this high-tech Japanese firm.

ME: *What kind of engineers does Fujitsu hire?*

Miller: Almost all manufacturing engineers here come right from school, with no knowledge of our products or production methods. Most graduated from the specialty high schools, very few from four-year-college programs. Advanced degrees are rare. In a manufacturing engineering department of 300, you probably won't find one person with a graduate degree, though you might find a few in product engineering.

ME: *What about the plant floor?*

Miller: Most production workers come out of the standard high schools. A small percentage come from the specialty high schools, and a few support staffers come from four-year college programs.

ME: *Then what's the career path?*

Miller: A college graduate might move into quality control, manufacturing engineering, or a fast-track section within a production department. A high-school graduate might go right to the plant floor, perhaps moving up to group leader or even supervisor.

ME: *How selective is the company in hiring?*

Miller: [illegible] so [illegible] take what they can get. They [illegible] a small percentage of new hires will become [illegible] it to the managerial level, and the rest [illegible] acquire the skills and experience to [illegible] well.

ME: *What about training programs?*

Miller: The attitude is knowledge and skills aren't [illegible] the schools; [illegible] in-plant classes [illegible] are as rare as advanced degrees. If you ask a supervisor what his job is, he'll say he runs the shop. Really, other people do that. We'd call him a full-time trainer. Supervisors spend most of the day critiquing, guiding, planning, reading—things that transfer expertise in their departments. The training department is incidental.

ME: *How do people learn on the job?*

Miller: Learning is a four-step process. I see it going on in every department all the time. (1) Each department systematically identifies technologies and technical knowledge that must be mastered to support new manufacturing systems; (2) certain staff members are assigned the job of acquiring the new knowledge in depth; (3) once that's done, the entire staff begins to practice creating, installing, debugging, and supporting the new systems; (4) the department now begins a series of technical collaborations with machine and instrument makers, other related hardware and software vendors, or the company's own research labs when they are the source of new machines or methods. Vendors and staff engineers are sitting at tables poring over specifications and design details all the time in our department, bringing in expertise.

For example, one person—or a small number of people—in the manufacturing engineering department might focus on a hardware or software development project for several months or longer, all low key, while other people in the section busy with their own work pay little attention. If it's clear six months later that this small development effort will let the staff do something new or make an improvement, more people get involved, and the effort intensifies.

ME: *Are there lessons here?*

Miller: Yes. When development work goes on in the factory side by side with everyday production, when learning new things on the job is part of the normal work routine, and when people are given time to learn those things, you get amazing results. People who came into the company with no special education

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partnership. The Aachen people set up a manufacturing engineering program, installed equipment bought with a multimillion-mark donation from the German government, and told their partners to say, when the chicken-or-egg problem came up, "We don't have the expertise to do your project alone, but our partner in Aachen does." In the process of selling your partner's expertise, he says, you acquire what you lacked at the beginning.

In short, it's time for Monson's new paradigm to show itself—for US educators to stop blaming each other and start talking to industry, and for US industry to stop blaming educators for workforce deficits and start talking to the schools. Even if you give up on the kids, educating adults on a lifelong basis for changing technology means the two will have to get together sooner or later. Are we going to keep asking who's going to go first?

Industry-Education Alliances

Don't hold your breath waiting for a national education agenda. Don't expect President Bush's Thousand Points of Light to wink on in time to light up manufacturing's needs. Henry P. Conn, who heads A.T Kearney's Total Quality Management consulting practice and has

[illegible]

ME: *How does the [illegible] philosophy look close up?*

Miller: It's everywhere. The 4000 employees in this plant formally submit about 35,000 suggestions a year. That may impress visitors, but not me. What does impress me is the company's infrastructure of small-group improvement projects, constantly generating suggestions for product or process improvement or cost reduction, with support staff constantly evaluating and following up. At the plant-floor level, the staff can pursue any suggestion it wants. That's what turns ideas into improvements. Our manufacturing group is no different: our job is to build products, meet delivery dates, and make improvements.

ME: *Any tips about working in teams?*

Miller: Not one. I discovered that no one talks about teams here. No one has philosophic arguments about who should be involved in a group. If you assume no one human ever has all the information needed to solve a problem, you know the process will take place in a group. If the work group doesn't have the expertise, you look outside it and pull the right specialties across the boundaries. Group activity itself doesn't strengthen expertise or generate it.

ME: *If US companies start borrowing from Japanese work styles, will the ME's role become more important?*

Miller: I think that's wishful thinking. The manufacturing engineer becomes more important in a company only when everyone in that company, from the CEO down, believes manufacturing power is important. The pecking order here is not so different from plants at home: the top executives all come from design. What's different is the people in manufacturing aren't on a track—fast or slow—to anywhere else. Power builds through expertise, the company says, so the engineer with 15 years' experience is more powerful than one with five.

ME: *Speaking of power, how about financial power in the company?*

Steve Miller is working in Oyama, Japan.

Miller: The manufacturing managers are the financial heavyweights. Everyone does budgets, cost accounting for activities in the group, planning for machine investment and depreciation. They funnel those data to the central accounting group in the plant, which keeps a low profile. All the executives understand that when you're constantly pushing the performance envelope, you must get new automation. Sophisticated cost accounting doesn't build better products. People here keep cost justification simple, so design and manufacturing staff can focus on reducing cost, time, and defects.

ME: *Fujitsu invested in you. Is the company worried about it?*

Miller: Our markets are down now, and cost-cutting pressure is intense, but I'm not affected. The company said I'd be here for 2½ years, so I'll be here for 2½ years.

I'm finding out how this company keeps things moving through organizational and individual willpower and commitment. That's enough for Fujitsu. But remember—I'm a college professor. I'm sure reality will hit me on the head when I arrive at the plant in Texas.

recorded a somewhat apocalyptic vision in a book called *Workplace 2000*, believes that would be a waste of time. "Our educational system has always been parochial, fragmented, and selfish," he says. It's up to local businesses to get together, take on a few kids apiece, and try something new.

Solutions have been percolating up from communities, regions, and even state capitols, not down from the federal government. Local alliances are being forged; community resources—however unsatisfactory they may look at first glance—are being tapped; regional coalitions of economic development groups, businesses, and schools are forming; industry is bankrolling high-tech training centers on campus; pay-for-skills or pay-for-knowledge programs are blossoming. That's the American way: 240 schooldays a year, as in Japan, is definitely not the American way.

Companies with skills crises on their hands, like Will-Burt Co. (Orrville, OH), a fabricator of machined parts for Volvo, Mack, and Raytheon's Patriot Missile, must act. They have no time to blame the schools that didn't teach Johnny to read. Will-Burt, facing liquidation because of product liability suits, took a close look at its workforce. Like many manufacturers with quality problems, the company hadn't realized the size of its skills gap. It found workers using blueprints who couldn't read them and workers using scales who couldn't understand the readings. The company teamed up with the University of Akron to develop a math-literate workforce. It now has a premium-quality product.

Not everyone turns to the schools first in a crisis. Another auto parts manufacturer, Plumley Companies (Paris, TN), knew how poor the general education system was around its plants in western Tennessee and northern Mississippi, so it led the assault on educational problems inside and outside the plant. Management began with the basics: teaching workers reading, writing, and math. Now there's a plant staff of teachers who prepare workers for certification as quality engineers and technicians and give courses for the GED. At the same time, the company is highly visible in the education system, with a flock of employee-volunteers acting as substitute teachers in the local schools and serving on school boards. In fact, it's one of only 16 companies to win the US Department of Labor's award LIFT (for "Labor Investing for Tomorrow").

Bill Lewis, who heads the machine tool technology department at Northern Kentucky State Technical School (Covington), firmly believes in strategic alliances with industry. The trick is to get a core group of the right people to work with you. Then they can recruit others. He set up an advisory committee for his program composed of people from four key Cincinnati-area companies: Kennametal, GE Aircraft Engines, Mazak, and Cincinnati Milacron.

The group now numbers 18 and represents a cross-section of the greater Cincinnati precision metalworking industry. It incorporated as a nonprofit organization (to bypass educational bureaucracies) and started offering courses in skills area workers needed that were convenient and cheap: 20 hours of statistical process control training for $100, 25 hours of geometric dimensioning and tolerancing for $200. Courses were up to date: the GD&T teacher was a General Electric employee, the SPC teacher worked for Ford, a trainer from American Society for Quality Control taught the quality course.

Manufacturing 2002

OLD PARADIGM	NEW PARADIGM
INSPECTORS RESPONSIBLE FOR QUALITY	WORKERS RESPONSIBLE FOR QUALITY
ONE WORKER AT ONE MACHINE	SELF-DIRECTED WORK TEAMS AT MACHINES
STATIC JOB ASSIGNMENTS	WORKER EMPOWERMENT
"MANAGEMENT THINKS, YOU DO"	"MANAGEMENT AND WORKERS THINK AND DO"
QUANTITY OVER QUALITY	QUALITY OVER QUANTITY
PRICE AND SUPPLY	QUALITY AND CUSTOMER SERVICE
COMPETITION	COLLABORATION
COLLUSION/ANTITRUST	MANUFACTURER NETWORKING
INDIVIDUAL INCENTIVES	GROUP INCENTIVES
"LET THE BUYER BEWARE"	EXTERNAL AND INTERNAL CUSTOMERS
LOCAL ORIENTATION	GLOBAL ORIENTATION
SINGLE JOB SKILLS	JOB CLUSTERS/SKILL FAMILIES
MUSCLE POWER	SMART MACHINERY
INDIVIDUAL EFFORTS	PARTNERSHIPS
SPORADIC TRAINING	CONSTANT TRAINING
"DEGREE" EDUCATION	LIFELONG OR COMPETENCY-BASED LEARNING

With all this tuition money in hand, the committee put on a recruiting blitz, producing a flock of glossy brochures, media ads for the program, and a fat, impressive ring binder with color photos of trainees at work on shiny high-tech equipment, lists of precision metalworking job requirements and pay scales, answers to questions about careers—even a video bound into the cover. Every high school counselor in northern Kentucky got a binder; every high school graduate in northern Kentucky got a set of slick recruiting brochures; everybody who visited the Cincinnati convention center for a sports, boat, travel, even a home and garden show saw the committee's booth.

John Sinn, who has a similar successful advisory group at the college level at Bowling Green State, says you don't need a board of overworked and uninterested executives performing a "community service." You need a working board that meets once a month or so, with almost every member in attendance, that really works for your program all the time, even traveling to the state capitol—or Washington—to lobby.

The Integrated Engineer

"I don't think the universities or industry have yet come to grips with what the manufacturing discipline will be in the '90s, much less in the first two decades of the next century," says James Duderstadt, president of the University of Michigan (Ann Arbor) and an engineer. "In the '90s we'll find out more about what the manufacturing engineer really is."

Duderstadt's advice? "Get the broadest possible education now. I don't mean taking more science and math. I mean liberal education. Avoid specialization as much as you can. The technology is moving too fast to keep up without constantly upgrading skills. Our engineers shift out of engineering in about five years if they don't. They migrate to marketing, management, or elsewhere."

Future factories will rely on sophisticated skills. Competition for craftspeople like this one, molding a complex composite part at LTV Aerospace and Defense Co., will be fierce.

Kearney's Conn agrees. "Being an engineer is not good enough. When I was in engineering school we took engineering English, engineering economics, engineering ethics. Why not? We were engineers, after all. The ME of the future won't focus on machine utilization and labor content. We don't need narrow skills: we need multifunctional people."

There's another factor here that makes Conn's and Duderstadt's advice even more meaningful: recruitment. Students are being driven away from engineering by the fragmentary and repetitive approach schools favor. Dean Emeritus Joe Bordogna of the University of Pennsylvania (Philadelphia) told the National Society of Professional Engineers board last year. They are repelled by curricula that promise a steady diet of the same subjects they studied in high school. Only at the end of the engineering education process, if at all, do students finally see the interconnections among specialized areas of knowledge.

The result? Engineering graduates with no experience in mak-

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[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	FLEXIBLE STRUCTURE
[illegible]	KNOWLEDGE MODULES, FOCUS ON MASTERY
KNOWLEDGE BY LECTURE	KNOWLEDGE BY INTERACTIVE ELECTRONICS
TEACHERS ASSIGNED TO CLASSES	TEACHERS TUTORING INDIVIDUALS
SCHEDULES DRIVEN BY SCHOOLS AND SPACE	SCHEDULES DRIVEN BY STUDENTS
GROUP SETS THE LEARNING PACE	INDIVIDUAL SETS THE LEARNING PACE
BOOKS MAJOR TOOL	COMPUTER MAJOR TOOL
INDIVIDUAL COMPETITION	GROUP COLLABORATION
LEARNING FACTS	LEARNING TO LEARN AND REASON
GROUP TEACHING, INDIVIDUAL RATING	INDIVIDUAL TEACHING, GROUP RATING
CHILD-ORIENTED EDUCATION	CHILD AND ADULT-ORIENTED EDUCATION
6-HR DAY, 5-DAY WEEK	24-HR DAY, 7-DAY WEEK
FOCUS ON PAST	FOCUS ON FUTURE
DISCIPLINE/ROTE MEMORY ORIENTATION	CREATIVITY AND INNOVATION ORIENTATION
[illegible] 12-YR EDUCATION	SHORT-CYCLE LEARN-AND-DO EDUCATION
SINGLE-CULTURE FOCUS	MULTICULTURAL FOCUS

ing connections among seemingly different discoveries, events, and trends—with no synthetic skills. Even more serious, said Bordogna, is the effect these graduates have on US manufacturing competitiveness. "The inability to look at technological development as a whole is the prime reason why US manufacturers can't get competitive goods out the factory door."

How would this new curriculum work? Students would be confronted with hands-on activities right from the start, said Bordogna. They would learn to define problems, consider alternative solutions, and experience "the excitement and frustration caused by creative design, limited knowledge, and open-endedness in creating a new product or system."

There's another advantage of the approach, said Bordogna: "The tough courses in science and math that would follow these hands-on experiences, the ones that drive many an engineering student away, would no longer be taught in a vacuum." By the time they came along, students would see the connections between these fundamentals and the goal—they'd see the relationship of process and principles he feels is so crucial for engineers in the next decades.

The ME in Ford's Future

Ford Motor Co. seems to be on Bordogna's wavelength. The company describes the manufacturing engineer it needs to handle its future factories in one word: "integrated" (its report is titled "The Need for an Integrated Engineer in the 1990s"). This conclusion doesn't represent a consultant's vision. Ford decided to go out to the plants and ask the workers doing its jobs today what skills they needed now and what skills they would need in five years.

People from plant manager and chief engineer down to entry-level engineers and production and maintenance supervisors gave interviewers their skills lists. If at least half the employees doing a job said a skill was mandatory, it went on the official list. The skill categories for Ford's MEs now form a blueprint for the company: basic engineering, material handling, finance/business, quality, plant engineering, personal computers, safety, supervision, interpersonal, maintenance and production practices. Out of these Ford picked three key categories. That basic engineering was one is no surprise, but look at the other two: quality and interpersonal.

How will Ford of the future be different? The manufacturing engineer will work much more closely with product design engineers and communicate with them on the same technical level, like it or not. The goal, says Ford, is not to make a designer out of the ME but to make the product the highest quality and the lowest cost. That means talking the design people's language well enough to exert strong influence at the point when most product cost is established.

Ford anticipates the shift in the ME's role on the plant floor that others mention, with technologists

Learning To Learn: Tomorrow's Survival Skill

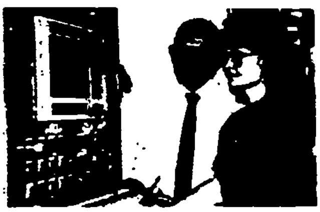
US Department of Labor/American Society for Training and Development researchers expected a long wish list of technical skills in the late '80s when they began a major study called *Workplace Basics: The Skills Employers Want*. They got a surprise. The most basic skill employers needed was "learning to learn." James F. Barcus, Jr., in a president's message to SME members last fall, called it "the lifeblood of manufacturing, possibly manufacturing's No. 1 priority." It's certainly tomorrow's survival skill. Here's a look at some survivors.

Henry Martin has worked at Procter & Gamble's plant in St. Bernard, OH, for 25 years. He was a loader when a maintenance machinist job opened up—a good job, an interesting job, more money. He had the seniority but not the training. P&G, which had recently restructured its plant around teams and technicians, decided to help Martin, a high-school graduate, get up to speed.

P&G staff and people from Northern Kentucky State Technical School, nearby in Covington, collapsed a two-year program into one, building on the skills Martin had. In '89 Martin became a full-time student in a tailor-made program, while P&G paid his tuition and supplies and sent him his paycheck every Friday.

Martin hadn't done homework in 25 years. The kids in his welding class were his own kid's age. Trigonometry almost killed him. Worst of all, his son, who had just gone off to college, started coming home on weekends to give him advice. "When I fell asleep on the bed doing homework," says Martin, "he'd wake me up and tell me to sit at the desk to do it—just what I used to tell him. It was comic!" Meanwhile, he had chores to do along with that trigonometry—he raises beef cattle on his farm out in the country. Now that he's back at P&G in that machinist job he wanted, he's thinking about going back to school on his own. Whether he does or not, he's learned how to learn.

Teresa A. Browning has two grown children, two horses, a 3.8 GPA, and a Myrtle and Earl Walker scholarship from SME. After auditing tax returns for the State of Indiana Department of Revenue for 20 years, "I had a job, not a career. I didn't know what career goals were. So I took a chance." She quit her job, took her retirement money, and invested it in herself.



Teresa Browning: They call us the new majority.

In May '93 she'll graduate from the CIM Manufacturing Technology program at Indiana University-Purdue University at Indianapolis. Why CIM? It promised variety and hands-on, she says, and it's delivered (the photo shows her at her co-op job at Allison Gas Turbine with designer Madhu

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coming to the forefront as supervisors. MEs will need a four-year degree in engineering or technology. The name of the degree—manufacturing engineering or mechanical engineering or technology—is not the issue. Skills are the issue.

Ford's "generic profile" of the ME of the future is summed up in a word, "flexibility." Achieving that profile will mean self-improvement: "Continuous lifelong learning has become an essential ingredient for the ME's personal and professional development," says the profile. "Future MEs must be flexible enough in temperament and skill acquisition to adapt to rapid changes in technology and business conditions."

Could this describe the "manufacturing systems engineer" we keep hearing about? As Dr. John B. Yasinsky, executive VP for Power Systems, Westinghouse Electric Corp. (Pittsburgh), described this new breed at the University of Pittsburgh last year, the MSE will understand the role manufacturing plays in the overall business, lead the quality drive, understand how to customize products to meet the needs and suit the tastes of users around the world, and know how to make and deliver the product competitively.

In 1987 Westinghouse Electric Corp. helped Pitt create its MSE program to serve a global market. Global, high-tech companies seem to prefer broad-based programs like these over more traditional curricula focused on mastery of leading-edge technology and product-specific skills. Giants like Boeing, General Motors, and Eastman Kodak heavily support MIT's Leaders for Manufacturing master's program, for example. To get multiskilled managers they are willing to provide internships and loans of executives.

Engineering Education: Four Years? Seven? A Lifetime?

How can the new skills be crammed into the classical engineering program? Many observers say engineering programs must be expanded. "I don't think you can produce an engineer in four years," says the University of Michigan's Duderstadt. "I expect the MS to be the entry-level degree for the engineering profession in the '90s, and I expect it will take five years to get it. Four-year programs will be for people who don't want to be engineers—people preparing for something else, like medicine or law." Henry Conn expects to see seven-year engineering programs take off.

Some, like Marcus A. Clarke, Jr., process manager, manufacturing strategy and planning, Ford Motor Co., who prepared Ford's analysis of the integrated engineer of the future, suggest adding a year but giving graduates an MS at the end, as schools like Rensselaer Polytechnic Institute (Troy, NY) do. The extra year would allow time for summer internships and co-op programs.

Most educators don't like the idea. At academic and society meetings every year there's talk about revising the curriculum to reflect systems engineering, TQM, design for manufacturing, communications skills, or other priorities-of-the-month. Still, according to Neil A. Norman, presi-

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Chatterjee at the controls of his new heat-treat equipment). Unlike Henry Martin, Browning found others like her in class. "They call us 'new majority' students at IUP," she says. "We're older, we have work experience, and we have been unhappy."

What happens next? She'll begin an MBA program in August '93, after that, an MS, "now that I've learned to be a student again."

Jim Shellaberger: In life, no guarantees.

Henry Conn joined Ford Motor Co.'s Louisville, KY, Heavy Truck Assembly Plant first as a student trainee, then in 1964 as a manufacturing engineer. Like many ambitious MEs, he started working on an MBA at night. It took him five years; along the way he got a second master's and studied languages.

When he became manufacturing engineering manager at the plant, the largest of its type in the world, he was ready for corporate management, but management wasn't ready for him. Coming from manufacturing as he did, he was told, he'd have to serve another 8–10-year apprenticeship at the corporate level to move up the ladder.

Conn had the skills and decided not to play the game. He quit, and took a job as as corporate director of manufacturing for Allis-Chalmers' Siemens division, and then moved to TRW as a corporate officer in charge of change and quality. Now at A.T. Kearney, he thinks about a future where jobs depend on skills and performance, not longevity. What skills? The ME must know how to "listen, write, negotiate, cajole, facilitate."

James Shellaberger was a machine operator and job setter for 15 years in Dana Corp.'s U-Joint Division plant in Lima, OH. For 10 of those years he went to school at night, ending up with a handful of associate's degrees—business administration, marketing, and production management. Meanwhile, he moved around the plant every chance he got and made no secret of his ambition: to be a manager and an engineer.

In the hard times of the '70s, nobody heard him except his boss, who took time to tell him straight out that his chances were nil. That made Shellaberger mad.

"I was going to prove them wrong," he says. "I was going to make it here, or make it somewhere else."

While he was biding his time, he bought a PC and kept busy teaching himself computer language. When he saw an ad in the local paper for NC/CNC programming, he signed up. "At this point, total computer power in our plant was one PC-XT and one CNC machine," he remembers. After that class, he signed up for an

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dent of the American Society of Professional Engineers, who keeps his ear to the ground on such matters, no engineering educator involved with accreditation will commit to a five or six-year requirement, nor will the chief engineers of major corporations support such a move.

Opposition is both philosophical and practical. On the philosophical front, opponents say it's ridiculous to ask schools to prepare students completely for tomorrow's factory: cram their heads with all the engineering basics and all the leading-edge technology, and then stuff in the communication skills, financial and management techniques, international insights, ergonomics, TQM, and conflict resolution techniques, and then maybe shake it all into place with hands-on experiences—co-ops and internships.

Where will you find students willing to spend seven years in school to learn technology that's only good for five? These critics also want to know who will pay the bill for more faculty, classrooms and labs, scholarship funds, housing.

Gregg Bruce, who teaches manufacturing technology at Purdue University (Lafayette, IN), is one of these cynics. University graduate programs in engineering and science emphasize mathematical theory because they are tailored to the needs of doctoral candidates, he says. What's needed are programs that are better, not just longer. He suggests that, instead of more theory, a graduate program focused on one technology or one industry would give students a good grasp of relevant business issues while exploring the technology's engineering issues. Clarke also likes the idea of longer programs in which students study key technologies like control theory or computer system development on a graduate level after mastering the basics.

As the Pyramid Collapses, the Technologists Ascend

Debates over curricula must reflect the fact that the technical workforce of the '90s will no longer be a pyramid, with one person at the top, below that field engineers and technologists, and then a herd of unskilled workers making up the base. Duderstadt expects the pyramid to be replaced by a structure more like a rectangle made up of four groups of about the same size.

At the upper level, people with advanced degrees in engineering and business will manage and oversee manufacturing operations. "MBA and finance types will disappear rapidly from this level of management," says Duderstadt. "It's unthinkable that anyone without a strong technology background—and that probably means an engineering degree—will be put in charge of a manufacturing enterprise."

At the next level, we find MEs responsible for designing and integrating the manufacturing process. Reporting to them are the engineering technologists (a relatively new specialty) responsible for the machines themselves. At the fourth

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Learning To Learn: Tomorrow's Survival Skill

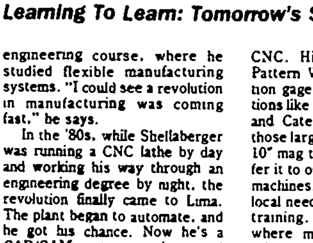
engineering course, where he studied flexible manufacturing systems. "I could see a revolution in manufacturing was coming fast," he says.

In the '80s, while Shellaberger was running a CNC lathe by day and working his way through an engineering degree by night, the revolution finally came to Lima. The plant began to automate, and he got his chance. Now he's a CAD/CAM systems engineer and a key member of the Lima CIM team that won CASA/SME's LEAD award last October.

How did Shellaberger know all those courses would pay off? He didn't. "Life is full of risk for people who want to better themselves," he says. "There are no guarantees that if you go to school and work hard you'll get ahead. For me, it's a matter of interest in life. When I'm in my '60s, if I don't feel I'm learning something new every day I'm at work, I'll stop right then and there."

Leo Potts, an Indianapolis pattern maker, was worried about CNC. His employer, Jacobson Pattern Works, supplies production gages and molds to corporations like Navistar, Chrysler, GM, and Caterpillar. "The data from those large companies comes in on 10" mag tape, and we must transfer it to our system and out to the machines. All of us in our union local needed CAD/CAM and CNC training, but the small shops, where most of us work, can't afford it. They pay for apprentice training, but that's it."

So Potts got an okay from his boss to see about CNC training, and went on to Hurco Manufacturing to get some advice. Hurco, known in the area for good training on its high-tech machines, got involved right away. One obstacle Potts saw was academic credits: most employers wouldn't pay for training apprentices and others without them. No problem: Hurco had an educational partner, Ivy Tech (Indiana Vocational Technical College). If he could find the students, Ivy Tech would create the courses they wanted, and the pattern makers would be on their way to computer literacy (and Ivy Tech credits).



Leo Potts: Alone in a room with CAD/CAM.

Potts did. Courses take up a good chunk of time—eight hours a week for 16 weeks. Students often bring in a part from the shop as an exercise for the night class. Potts' boss and 29 other people have taken CNC, and can choose introductory or

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level we find the technicians and operators. The "herd" of unskilled will keep shrinking as we approach the factory of the future.

Purdue's Bruce has worked out a four-level arrangement similar to Duderstadt's and Ford's vision. MEs will give over their production support and supervisory role to technicians. Jobs such as maintenance and production supervision, requiring high levels of technical competence, will be filled by people with technology or engineering degrees, by technical school graduates, or by graduates of advanced apprentice training programs. Technicians will be much more sophisticated than they are today. Duderstadt predicts, and machine maintenance will require four-year technology training.

What about the herd of hourlies? If Ford has its way (and whether it does depends on the supply of labor), all such workers will have two-year associates' degrees in technology, as they do in Japanese auto plants. Duderstadt goes farther: such degrees will be requirements, not goals. "It's hard to imagine a manufacturer in the late '90s not requiring two-year degrees so all workers are up to speed in math and statistics."

advanced CAD/CAM, MasterCAM, and CadKey.

How do you keep up when your skills are ahead of your job? Potts bought a 386-based PC to work on CAD/CAM programs at home. At age 36 one of the youngest members of his craft union, he's going for the long term: "Ten years down the line I see myself in a room with a CAD/CAM system, a milling machine and maybe a lathe behind me, and my toolbox."

Peg Torzewski: The floor is where the action is.

Margaret A. Torzewski was at college studying to be a music teacher when she got married, had four kids, and left the labor force. When she divorced and needed a job to support the family (the youngest is five, the oldest 12), she knew teaching wouldn't do it. So she went to the public library and took out a book of occupations. Industrial engineering caught her eye, she says, because it had computers and a lot of contact with people.

Now she's in the CIM Manufacturing Technology program at IUP along with Teresa Browning. Like Browning, she's a Myrtle and Earl Walker SME scholar. Working in plants as a student has been very important to her: "It's one thing to read about manufacturing, another to see it working. I'm amazed at how much I've learned in two months as a co-op at Allison Transmission."

Any advantages to being a "new majority" member? Her age gives her more confidence and experience in dealing with people, she says: "I don't pretend I know everything, like some supervisors fresh out of school. I take everyone's ideas seriously, and let them know I do." When conflicts occur in her workcell, she says, she can draw on experience: "When you have kids, you become a mediator."

The MT degree gives choices. "When I graduate I could hire in as a manufacturing engineer or an industrial engineer or a quality control engineer." But she's not looking for the fast track. She'd like to work her way up the engineering levels and then think about management. "I've heard that technology and the MBA make a good combination," she says. "But I don't want to lose touch with the floor. I'm not a paper pusher. Some women students say they're hired to use their brains, not fix machines. I'm different. If there's a problem, I want to get my hands in it. The floor is where the action is, and that's where I want to be."

Engineering Shortage: Crisis or Con?

Readers watching the public handwringing over the shortage of engineers may conclude, "Not to worry." Engineers are so scarce they'll have a job as long as they want, skills or no skills. These know-it-alls are in for a shock in the next decade.

"I wish there were a shortage of engineers," says Joseph Coates, who studies future trends in technology from Washington, DC, for several engineering and professional groups. "If there were, employers would have to give the engineers they have now all the technology and education they need to upgrade their skills and effectiveness. And that, in turn, would mean corporations were in the process of retooling to get in competitive shape."

Unfortunately, says Coates, there's no evidence this is happening. The laws of supply and demand have not been repealed. The flat salaries of engineers over the last decade mean the commodity is plentiful. There's another indicator too. A shortage would mean the best and brightest technical personnel from around the world, especially from eastern Europe and the Soviet Union, would flow into the US. "Their economic expectations will be unmet over the next five to seven years, and they'll move," Coates predicts. "If they see a shortage here, the US will become their preferred first stop."

When you hear talk about shortages, he says, look at who's talking. Are they "people with a direct or indirect interest in a shortage" — staff at the National Science Foundation or the National Academy of Sciences, the engineering faculties, the professional societies? We don't hear talk about shortage from one group — the unemployed engineers."

Shortage talk is most troublesome, says Coates, because it "diverts groups like the engineering societies from serving their members on what everyone agrees is the most

important issue that exists today: technological obsolescence."

Lawrence P. Grayson, acting director, postsecondary staff, US Department of Education, told NACME last summer that when starting salaries for engineers haven't gone up in 30 years, and companies are hiring fewer of them, it would be sensible to conclude industry is not concerned about shortage. He, like Coates, thinks the shortage talk distracts attention from important problems like making better use of the engineers we have.

When the Subcommittee on Science, Space, and Technology of the US House of Representatives held hearings on the supply of engineers and scientists last July, R.A. Ellis, director of manpower studies at the Engineering Manpower Commission, testified there were serious problems with the numbers. Neither the federal government nor agencies like his really know much about supply and demand for technical professionals, he said.

The data from the Bureau of Labor Statistics conflict with the data from the National Science Foundation. When numbers for all groups of engineers are presented together, or numbers for some subgroup are presented as though they represent a general pattern, journalists report "shortages of science and engineering faculty, surpluses of older workers in industry, spot shortages of new graduates in hot fields like environmental or manufacturing engineering, and surpluses of graduates in other fields." One group shouts "Shortage!" while another screams "Surplus!" Both may be right in a given case, says Ellis, but they're not talking about the same things.

He, like Coates and Grayson, prefers to rely on the laws of supply and demand. Real shortages should make the cost of engineering services rise. Instead, engineering salaries reached their peak in the late '60s. Ellis finished demolishing the shortage notion by reminding subcommittee members that mainstream economic thought assumes the equilibrium of supply and demand. Thus shortages and surpluses of technical workers are nonsensical concepts.

In short, if you're short on skills, don't count on the shortage! ■

B-Schools Stress Manufacturing

A recent survey of the top 25 US business schools, conducted by Fujitsu America Inc. (San Jose, CA), disclosed a renewed emphasis on manufacturing on the part of MBA students. "Dramatic changes in manufacturing have occurred on the academic side," says Professor Steven Wheelwright, UCLA. "The number of schools interested in production or operations is increasing significantly, along with student enrollment and academic staffing."

The study found business schools adding manufacturing courses in response to student interest. Some 83% of the respondents offer a manufacturing curriculum in '91-92, compared to 43% five years ago. Sixty-one percent offer a manufacturing/operations management concentration or major, compared to 48% five years ago. The number of faculty teaching manufacturing courses increased at 48% of the schools.

Eighty-three percent reported increased student enrollment in manufacturing/operations management. And in 56% of the schools, recruitment of MBAs into manufacturing increased while it dropped in many other fields. Eighty-seven percent of the schools report more students finding jobs in manufacturing than they did five years ago.

Respondents see the following manufacturing trends in the '90s:

- *Joint Global Developments.* Larger companies will acquire and work with smaller, specialty shops worldwide to enter and capture niche markets. Engineering know-how will diffuse rapidly across national borders.
- *Flexibility.* Large-volume products will continue giving way to customized products.
- *Advanced Automation.* Large and small factories will automate to satisfy customer requirements.
- *Short-Cycle Production.* Redneed design-to-delivery cycles will allow gearing production to customer demand for less surplus and overhead.
- *Management Style Changes.* Multifunctional teams will reduce bureaucracy and increase worker responsibility.
- *Customized Logistics.* Technology will allow greater coordination and efficiency throughout the logistics chain, from order to delivery.
- *Design for Manufacturing.* Knowledge of manufacturing system capabilities and limitations will continue to be systematized and incorporated into decision making during product design.
- *Quality Management and Control.* Competitiveness will be determined by instituting total quality control management in every step of the organization.

FUTURE VIEW
WHO NEEDS GOVERNMENT?

Since the US has no national industrial policy, manufacturers are taking matters into their own hands by participating in not-for-profit consortia for collaborative research to cut R&D costs. And now, at the urging of the Department of Commerce, they are taking their efforts a step further by forming a consortium of consortia called the International Center for Manufacturing Sciences (Ann Arbor, MI).

"While there are unique aspects to each consortium's R&D agenda, there is also a great deal of overlap, which you might expect since automotive, aerospace, and semiconductor manufacturers run into some of the same problems," explains Stephen Ricketts, ICMS vice president of research. "Members like General Motors participate in several research consortia and are repeating projects four or five times."

ICMS began as a partnership between the National Center for Manufacturing Sciences (Ann Arbor, MI) and the Microelectronics Computer Technology Consortium (MCC in Austin, TX), but organizers hope to attract more partners, such as Sematech, CAM-I, and the Industrial Technology Institute. The umbrella organization will coordinate the domestic and international agendas of its members. Talks are currently under way.

The CEOs and executive vice presidents of these consortia have agreed in principle to eliminate redundant projects by leveraging their resources. For example, MCC, NCMS, CAM-I, and Sematech all had enterprise integration activities. "Rather than each continuing on its individual path," offers Ricketts, "MCC won a large contract from the Air Force, and all of the consortia will work under MCC in that effort." He estimates a savings of approximately $3–5 million in '92.

Another reason the DoC encouraged forming ICMS is to create an industry-based organization that can orchestrate the US share of research into the international Intelligent Manufacturing System (IMS) project and commercialize the results. Japan's Ministry of International Trade and Industry (MITI) proposed IMS to DoC in 1990. Originally, MITI had budgeted $1 billion over 10 years to split among Japan, US, and Europe to do collaborative research. After a series of trilateral meetings, however, Europe and the US decided to fund their own activities to preclude ownership disputes.

Now there are six participants: the European Community (EC), the

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European Free Trade Association, Canada, Australia, the US, and Japan. Each participating region will select five members for each of the three committees governing IMS: the international steering, technical, and intellectual property rights committees. As the US secretariat, DoC will appoint three representatives from industry, one from academia, and one from government to each committee to fill the US seats. It hopes to launch the US effort sometime next month.

While other groups organize, Japan's IMS Promotion Center is proceeding with projects it hopes will entice foreign companies to get involved. There are snags in many countries, however. Some US companies have concerns about entanglements with government bureaucrats who do not understand manufacturing's needs. "IMS comes with rules and regulations," says Ricketts. "Many members want to participate in international research but not necessarily under those same terms. Europeans are concerned about getting involved in precision machining with the Japanese. They feel they have some of the best machine technology available anywhere and don't want to give away their competitive edge."

The parties also disagree on how to focus the project. The Japanese want to standardize the key manufacturing processes and systematize them, which means dividing those processes into autonomous machine components that can organize themselves to do a task. The Europeans, however, have taken a shorter-term, different view and want to add more automation to today's technology. In fact, they call the project the Future Generation Manufacturing System program. "Americans are somewhere in the middle, knowing that there are many autonomous artificially intelligent machines and systems that must be developed," notes Ricketts, "but we don't quite have the clarity the Japanese have."

Military Taps Private Funds

The private sector is not the only beneficiary of research consortia. For example, the US Army Missile Command (MICOM)—its Research, Development, and Engineering Center's Manufacturing Technology Division—recently joined the Fuller E. Callaway, Jr., Manufacturing Research Center (MARC) at the Georgia Institute of Technology (Atlanta). Born in 1987, MARC specializes in developing advanced manufacturing processes for the electronics industry.

Director Kelly welcomes Georgia Tech's Manufacturing Research Center's newest member, the Army's Missile Command. With support from member companies and a $15 million grant from the State of Georgia, the R&D consortium recently built a 120,000-ft² laboratory and office building.

"With money so tight now in the Department of Defense, we must take advantage of every opportunity to get more for our money," explains John Davis, chief, MICOM Manufacturing Technology Division. His operation will leverage its research funds with those from four other consortia members: Motorola, IBM, Digital Equipment Corp., and Ford Motor Co.'s Electronics Division. Besides more access to related Georgia Tech programs, MICOM now has a $1 million resource, which is five times its own investment.

MICOM wants better flexible manufacturing systems for missile electronics, which includes sensor-component fabrication and assembly. "What they are doing at MARC is directly related to our interests," says Davis. "They're involved not just in basic research but also in developing new manufacturing processes and equipment. Being a consortium member will greatly enhance our work in microelectronics and photonics and will help reduce future Army weapon production costs. It will also provide another opportunity for rapidly inserting new technology into military systems."

When MARC demonstrates a new technology in its pilot factory, member companies—and the graduate students working on the project—can see how to put that proven technology into production. From this collaboration, Davis also hopes private industry will learn how to make military and commercial products on the same line. Transferring new technology and creating capacity for military projects on private-sector production lines will broaden the defense production base and, ultimately, reduce weapons cost.

Dr Michael J Kelly, MARC's new director, says the center encourages cooperation and interaction across a range of disciplines at Georgia Tech and industry. By providing a neutral environment open to all the applicable disciplines, the center can foster the cooperation necessary to tackle tough problems. While research is one of the Center's primary goals, Kelly believes the program can also aid industry by educating a new generation of broadly based engineers and scientists who can take a "systems approach" to manufacturing.

Call Your Extension Agent

Most university-industry activities involve Fortune 500 companies.

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Even community colleges chase big companies to balance their budgets. No one bothered training a few people in small local machine shops. But shops like these fabricate the products that Fortune 500 firms design, assemble, distribute, and service. These 350,000 small US manufacturers supply about 60% of the domestic components and employ about 50% of manufacturing workers. And 85% of those manufacturers have less than 50 employees.

To infuse advanced technology into these firms that constitute the infrastructure of US manufacturing, the DoC sponsors five manufacturing technology centers through the National Institute of Standards and Technology (Gaithersburg, MD). These centers help small to medium manufacturers improve competitiveness by providing technical assistance and training. NIST hopes to start three more later this year.

Rensselaer Polytechnic Institute (Troy, NY) was one of the first universities to establish a cooperative program with manufacturing companies. In 1979, it opened its Center for Manufacturing Productivity and Technology Transfer to bring large companies together to deal with common technology problems. Now the center also runs the Northeast Manufacturing Technology Center (NEMTC), which became one of the original three NIST manufacturing technology centers in January 1988.

From a building that houses six other manufacturing research centers on campus, NEMTC typically services the New England states plus New York, New Jersey, and Pennsylvania. "NEMTC concentrates on systems integration problems in small to medium manufacturers that cut, bend, or mold materials to make parts," says Gene R. Simons, NEMTC director. "So other [NIST] centers refer companies to us if we have the expertise."

NEMTC also gets referrals from state industrial extension agents, who work much like the old agricultural extension agents. New York, for example, runs its extension service through the New York State Science and Technology Foundation. "In New York and, to a limited extent, in some other states, industrial extension agents visit local companies to determine their needs and steer them to the right programs," says Simons. "If it's a technical problem, they usually refer them to us. If the company doesn't have CAD, we help them get it. If it has CAD, we help them link it to NC equipment."

One NEMTC client (in Buffalo) controls 60% of the small market supplying automobile wheel locks to the Big Three and the Japanese transplants. The locks are round lug nuts with a clover leaf pattern cut on the faces. The nuts foil thieves who do not have the matching wrench that fits the pattern. But the nuts caused problems for more than potential thieves.

The firm sends batches of nuts with mixed patterns to its in-house

A Glimpse at Collaborative Manufacturing R&D in the EC

The European Community (EC) has not been idle as Japanese and US firms team up with universities to leverage research funds. Eureka-Famos, the EC's R&D program, is spending 6.8 million pounds on an integrated flexible assembly cell technology, called InFACT. It has organized 10 participants in Austria, France, Italy, and the UK, including Bristol Polytechnic in western England.

The approach is based on the concept of generic assembly. Up to 80% of all assembly operations are common to all assembly tasks, while only 20% are product specific. By merging these common processes into one system, InFACT can quickly change over to accommodate many families of assemblies, alleviating worries about high investment costs and fluctuating demand.

In the past, traditional robot technology has been too expensive or too inflexible. Researchers hope to overcome that problem with a transputer, a British-designed computer on a chip. Linked together to form a powerful parallel processing controller, transputers can do many functions simultaneously, which is necessary for integrating materials handling, parts presentation, and parts manipulation. Conventional controllers with such functionality would be three times more costly.

A pilot plant (photo) is assembling a variety of demonstration products, ranging from electrical connectors to model railway wagons. The machine has two gantry robot manipulators mounted above work zones and uses a common palletized material handling system. Linear vibratory feeders deliver small components or piece parts into the work zones. Users wanting to assemble new products simply fabricate product-specific tooling and fixtures (only 5–10% of the machine cost) and modify assembly instructions with a menu-driven package.

plating and heat-treating operations because volume of any one pattern was too small to justify processing segregated lots. Afterward, the tedious task of sorting four identical nuts and packing them in an envelope with the correct wrench wasted one of the firm's most scarce resources, skilled employees. The alternative, sorting with machine vision, was expensive because the pattern had no reference point and required a factorial sort, which is a lengthy comparison. Quotes for such systems ran between $250,000 and $300,000.

Through NEMTC, however, the firm got a simpler and much less expensive option based on a $1100 high-resolution camera and a 386-based PC. "A graduate student working on a similar problem developed an algorithm for a PC rather than a high-speed computer, which was much of the cost," recalls Simons. "When they finish, their investment in the vision system will be less than $25,000 and the material handling system another $50,000, which is roughly a third of what they would have otherwise spent."

Student Power

To provide services, NEMTC uses 18 students for field projects and work in the demonstration facility and relies on a pool of faculty members to provide technical assistance. "Some of the most successful projects put students in a company for three to six months," says Simons. "Students love these projects because they get far more authority than they would on typical co-op assignments, and small companies are much more receptive to student help than large manufacturers. In most cases, it's the first time a small company has had [input from] a trained engineer (a junior or senior)."

At one New York company using its second intern, the student is helping staff bring in a product formerly made in the firm's small German subsidiary. Originally, his job was to convert CAD drawings, but he quickly found himself writing manufacturing instructions and helping set up the line.

Besides placing "traditional" engineering students, NEMTC tries spreading more trained students througbout industry by training employees of small companies through a network of 17 community colleges in its service region. It established this network because local training in a reasonable travel distance is the cheapest, most practical way to operate. NEMTC provides the courseware and trains the community college faculty to use it.

On typical projects, NEMTC funds half the training and implementation costs; recipients fund the other half and must buy the hardware themselves. Of NEMTC's 1991 $6 million budget, half came from the federal government and a quarter from various state programs. The remainder came from fees and large-company contributions. "There is no standard formula for funding a project," says Simons. "If we're working with a group of suppliers to a large company, for example, that company may subsidize the activities with its suppliers. If we're working with a company in New York, the state might provide part of the funding."

Simons believes the program's future depends on Fortune 500 companies adopting supplier develop-

Shopping for Manufacturing R&D

Here's a way to get more for your research dollar or help with advanced manufacturing technology. Call one of the following institutions for details.

R&D Consortia

CAM-I, Arlington, TX (817) 860-1654

Manufacturing Research Center, Georgia Institute of Technology, Atlanta (404) 894-3444

Microelectronics Computer Technology Consortium, Austin, TX (512) 343-0978

National Center for Manufacturing Sciences, Ann Arbor, MI (313) 995-0300

[illegible] dards and Technology (NIST)

Northeast Manufacturing Technology Center, Rensselaer Polytechnic Institute, Troy, NY (518) 276-2905

Southeast Manufacturing Technology Center, University of South Carolina, Columbia, SC (803) 777-7053

Great Lakes Manufacturing Technology Center, Cleveland Advanced Manufacturing Program, Cleveland (216) 987-3200

Midwest Manufacturing Technology Center, Industrial Technology Institute, Ann Arbor, MI (313) 769-4000

Mid-America Manufacturing Technology Center, Kansas Technology Enterprise Corp., Topeka, KS (913) 296-5272

Other Sources

Delaware Valley Industrial Resource Center, Philadelphia (215) 464-8550

Illinois Institute of Technology Research Institute, Chicago (312) 567-4384

Institute of Advanced Manufacturing Sciences, Cincinnati (513) 948-2000

Oregon Advanced Technology Center, Wilsonville, OR (503) 657-6958 Ext. 4609

ment strategies rather than adhering to vendor certification practices. In vendor certification, firms demand a certain amount of compliance to a quality standard and base their contracts accordingly. Supplier development means large companies get to know their suppliers' process capabilities and finances—not just the parts they ship—so they can help strengthen them. "Firms like Motorola, Xerox, IBM, and Digital are developing relationships much like those that most Japanese manufacturers have with their suppliers," he notes.

He also points out that defining a US company is becoming increasingly difficult for consortia and industry-university cooperatives. "Many foreign-owned firms in the US want to participate in these programs," he says. "A few key Japanese companies are making noises about getting involved in major university programs in the US, and some already have. There will be many interesting decisions over the coming years, with some programs getting involved in international ownership." ■

FUTURE VIEW
A GAME OF MUSICAL FACTORIES

Imagine working for a large Midwestern job shop in 2002, when concurrent engineering is not a buzzword but the lifeblood of the organization. A Japanese design engineering firm you frequently do business with has just landed a lucrative project from a European marketing consulting group and is shopping electronically for production capacity. Since you can deliver that capacity at the right price, you win the contract and the race is on to bring to market what promises to be the next rage in the US.

Engineers from the design firm and job shop begin working together immediately, but without leaving the workstations in their offices. By simply dialing the phone, they can talk to each other and share the same computer screen in real time. During their discussions, they point at critical load points with arrows and circle a section of a complex 3-D surface that needs modification. Electronic mail messages containing color images and voice also expedite communications over time zones.

The concurrent-engineering effort is not limited to engineers, however. The marketing group offers its input after reviewing a 3-D, tangible prototype it received by fax. Once the product reaches the end of its life cycle, the partners dissolve their "virtual factory" and move on to new projects with other partners. Virtual connections are electronic linkages rather than face-to-face meetings or paper drawings.

This is how the International Center for Manufacturing Sciences (Ann Arbor, MI) and Lehigh University (Bethlehem, PA) see manufacturing in the next millennium. "The process of manufacturing will become a commodity with a lot of fairly standard manufacturing capability scattered all over the world," predicts Stephen Ricketts, vice president of research, ICMS. Traditional factories with engineering, manufacturing, and marketing departments will become less important and might eventually fade away. Outsourcing taken to the extreme will allow specialty companies to flourish and replace those departments.

"Product will be built to order more than shipped from inventory," Ricketts continues. "Products will have a standard component, but much will be built to the purchaser's unique tastes. The emphasis will be on anticipating market trends because the value of manufactured goods will come more from design and marketing—the hard-to-hold parts of manufacturing. If indeed manufacturing evolves that way, the US may be in

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a good position to exploit it, more so than any other country."

John Mazzola—president, Unigraphics Division, Electronic Data Systems (St. Louis)—agrees, pointing out that the President's Council on Competitiveness says the US still leads many critical tec' nologies and processes to make t it happen.

Virtual Factories on the Rise

"In the future," Mazzola predicts, "human networks of many people will collaborate in a global enterprise, which is the company and its suppliers, customers, and partners. Projects will be defined digitally. For example, the design will be a digital model, and the analysis will be on that digital representation. The model will also drive manufacturing and the logistic support network."

He admits industry is a long way from virtual factories but notes it is beginning to lay the necessary foundation. "Manufacturing is already becoming international," he says. "When building an airplane, for example, you might make the wings in Taiwan and the landing gear in Canada. The design work might be in the US and France. Physical separation is less of a consideration because of the economic incentives to use a particular distant supplier. Boeing on its 777, McDonnell Douglas on the MD-12, and the automotive manufacturers are doing more of this collaborative work and embracing concepts like concurrent engineering."

But worldwide electronic collaboration is on a small portion of product and on a pilot basis. The barrier to widespread practice is suppliers cannot connect electronically to the digital model. "After 30–40 years, we can't even get people networked on alphanumeric data, let alone on a digital model," Mazzola points out.

The digital models shared in tomorrow's virtual factories must define an assembled product, not just one part. They will represent and manage all parts in an automobile or airplane and be robust enough to combine many parts from several sources into the product. More than 3-D graphics, these models will be mathematically correct for heat, structural, and other analyses and for manufacturing.

Imagine an airplane company building an electronic model of a whole airplane and watching it perform in an electronic wind tunnel. Such dynamic simulations are more complex than static simulations like structural dynamics. As software becomes more sophisticated and hardware becomes faster, however, the more practical it becomes to simulate for immediate feedback without having to build prototypes and test them. Simulations will compress time to market and create more reliable designs.

Rapid prototyping devices, which make faxing physical models possible, are one way industry already exploits digital models (on single parts, not complex assemblies). These machines divide the model into layers and use that data to build a polymer part layer by layer. "Once

Challenges Facing Manufacturing

MANUFACTURING ENGINEERING asked a select group from SME's College of Fellows and recipients of SME's Young Manufacturing E. ·er Award to speculate on the issues facing manufacturing during the next decade. Here are excerpts from the comments of these industry leaders:

Q What will the manufacturing enterprise look like in 2002?

Seiuemon Inaba, PhD, president and CEO, Fanuc Ltd. (Yamahashi, Japan):

Today, we have FMSs (flexible manufacturing systems) that started as FA (factory automation) and are in the process of evolving into CIM (computer-integrated manufacturing). In 2002, I believe the IMS (intelligent manufacturing system) will be realized. With its harmony of machines and human beings, IMS enables the integration of manufacturing

Jack L. Ferrell, manufacturing vice president (retired), TRW:

We will see networks of alliances among suppliers, producers, customers, and competitors. Entities will form cooperative links to transfer information and data, and use one another's facilities, production equipment, and proprietary knowledge to bring products to market efficiently. This may lead to "virtual companies," quickly formed to implement a particular marketing strategy. Increased computerized process modeling will mitigate the need for pilot plants, lengthy process trials, and redesign and debugging of new processes and equipment.

The following is more a wish than a prophecy: Manufacturing engineers will be absolutely certain that their processes can meet design specifications all the time. Product designers will comprehend the real consequences (scrap, rework, customer dissatisfaction) incurred when tolerances are wishes rather than true requirements. Furthermore, both parties will continually work toward a process that does not vary from the mean dimension of a tolerance. Dr Taguchi will be proven correct: Society as a whole benefits from the reduction of variation.

Edward S. Roth, president, Productivity Services Inc. (Albuquerque, NM):

Only smaller, entrepreneurial companies that simultaneously design products, production processes, and quality systems using CAE will be in manufacturing in 2002. They will consist of teams of career-path interdisciplinary specialists (engineers, fixture designers, machinists, technicians, purchasing agents) who will design product, process, and quality systems to ANSI Y14.5, ISO/TC 10, and ISO 9000 International standards. These teams will identify and remove all sources of process variation by concurrently designing parts and fixtures as sets of functionally interrelated products. Engineering changes and middle managers will cease to interfere with the fast-tracking of new product. Both will disappear in the successful, European-Community-oriented manufacturing enterprise of the year 2002.

you create a digital model," observes Mazzola, "you're in the position to transmit it any place in the world for review and manufacturing. Imagine what that will mean for a company's flexibility. If a machine goes down, you fax the definition someplace else and make it there. You compete not on location but on cost."

To make that vision a reality, computers will need more parallel processing, high I/O capacities, and large MIPS (millions of instructions per second) ratings, more than what we can imagine today. "These digital models will bring even 70–80-MIPS workstations to their knees," explains Mazzola. "Remember, just rotating an exact mathematical definition takes tremendous capacity. That—and handling all the part configurations—is an awesome data-management and computing problem."

A glimpse of a control center for tomorrow's virtual factories? It just might be if manufacturing capacity becomes a commodity as some experts predict.

Experts believe tomorrow's computers will be up to the challenge, though. In fact, many predict manufacturers will be able to afford whatever computing power they need. "Simulating a factory on a supercomputer, for example, is affordable now," claims Dan L. Shunk, PhD, who is both chairman, Computer and Automated Systems Association of SME, and director, CIM Systems Research Center, Arizona State University (Tempe). "To run our detailed factory simulation, w[e c]all our campus Cray from workstations in our offices, where we've modeled the factory, loaded the data, and vectorized the program. The Cray does the number crunching."

The price-performance ratings of RISC workstations have doubled approximately every year and a half. A manufacturing task requiring a $10 million Cray supercomputer 10 years ago would have had difficulty showing a return on investment. Today, that same task might run on a $100,000 RISC multiprocessing box, and in two or three years, it might run on a $15,000 desktop.

"Because computer power will become so cheap, optimization will not be something kept in the back room for industrial engineers to do once a year," predicts Robert Clifford, CIM manager, Sun Microsystems Computer Corp. (Mountain View, CA). "Companies will optimize their manufacturing lines minute by minute, reoptimizing schedules every time machines go down. And rather than evaluating alternatives in the production schedule weekly, they can run it 20–30 times in the last couple of hours of the day to find the best schedule. They might even ship another 10,000 units and make the company more money."

Phones: The Backbone

The infrastructure for transmitting information dynamically from one functional unit to another will be the virtual factory's spinal cord. "If you're working in a dynamic world, your communications must also be dynamic," says Michael Galane, director, strategic consulting, Hewlett-Packard Co. (Palo Alto, CA). "You can't afford to have dedicated wiring to every place you might be doing business. Proprietary networks use coaxial cable, which has a high bandwidth for carrying much information. The trouble is, you can't use coax to link the world because it's too expensive and switching is inconvenient."

Galane believes manufacturers will adopt the most popular and prevalent communications network in the world: the telephone system. In fact, many site-to-site transmissions already travel by phone. "Phone lines are just about everywhere and are continuing to grow," he says. "Once you connect to the telephone network (that is, get a phone number), you can reach anywhere the phone system goes. We will not see as many dedicated or proprietary communication lines in the future because of the incredible flexibility that phone lines will offer."

Most long-distance carriers have been investing heavily in fiber-optic lines as they convert to digital technology. Like traditional coaxial cable, the bandwidth of fiber-optic lines is high enough to transmit large amounts of digital multimedia information, such as voice, alphanumeric, image and video data. As fiber optics come on-line, the phone system's reliability will continue to increase.

To explain the impact of plugging computers or controllers into a telephone system, Galane offers this analogy: Imagine a reasonably large house with cable television in several rooms. Moving the cable service to different rooms requires stringing dedicated wire and means leaving or removing an unused line. Contrast that with the convenience of having a phone jack in each room and plugging into one when you need it. In fact, many firms already use phones to link their PCs to other computers, whether in the same building or across the country.

"Real-time control applications obviously will need dedicated lines because they cannot wait the seconds required to dial up a line," Galane admits. "But for a line with much less utilization, a dynamic network like the phone system, which allows dialing other devices and transmitting information as required, is an attractive, inexpensive way to network."

For this reason he doubts whether the Manufacturing Automation Protocol (MAP) will survive. "Sure, MAP will be around awhile; so will baud bus and the Allen-Bradley data highway," he says. "But in 10 years, if MAP doesn't grow to include much faster information transfer (such as for video), it will become less important. As we approach the year 2002 why would a standard developed in the early '80s be more pervasive than a standard that is much more dynamic with ever-increasing bandwidth? Why would users string dedicated

lines when they could just plug devices into a phone jack?"

"MAP has 5% of the factory networking market," adds Sun's Clifford, "and forecasts say it will have 5% throughout its life. It never took off partially because it is difficult and expensive to implement. Expensive technology might be okay for General Motors, but most of the world can't afford it. In the real world, most people use DECnet or TCP/IP (the Unix standard) on Ethernet. Many users run MMS (manufacturing messaging service), the key part of MAP, on Ethernet to cut costs." He also sees proprietary networks dying because they lock users into one vendor's hardware, which cannot work in an open systems world.

CASA's Shunk disagrees with the proposition that MAP is failing. "MAP isn't withering away," he insists. "Rather, people are migrating back to simple layer one and layer two (Ethernet and TCP/IP) in the seven-layer OSI communications. Elements of MAP—MMS, for example—will become a national, maybe even an international, standard for communications."

He notes that the Japanese have modified some layers within the MAP architecture and are aggressively pursuing it. "They've gone with a simple layer one and layer two," he says, "but they believe in the rigor. MAP is not dead; it's just another option for supporting your overall business strategy."

Computers Mimic the Brain

No matter what the virtual communications network looks like, the computers it connects will bombard people with much more information than they can digest. Many experts predict that neural networks could sift out the important information and help those people make recommendations.

"In the early years of artificial intelligence, people laughed at fuzzy logic and neural networks because of their probabilistic natures," notes Shunk. "But there's been a quiet revolution. We realize that the world is not black and white, it has shades of gray. Fuzzy logic and neural networks are suddenly now of major interest.

"The human mind is a probabilistic neural network, not a deterministic expert system. Just as the eye and brain work together, neural networks can make decisions from sensory perception." That means a neural-network-based computer does not resemble today's digital computers. Digital computers can simulate them, but they work very differently.

Conventional logical (parametric) programming requires engineers to define finite responses for every kind of input, which requires a tremendous amount of detailed testing. Logical processes are very procedural and sequential. Neural networks are different in that they mimic the cognitive capabilities of the brain. "Recognizing your mother, for example, is a cognitive operation and different from a logical process of executing sequential steps," says HP's Galane. "You look and recognize her within fractions of a second."

Cognitive activities require much parallel processing to come to a conclusion rapidly. To do so, neural networks can have thousands and even millions of building-block components. Like the brain's neurons, how these building blocks connect to each other determines the system's response. Users "train" neural networks instead of programming them in the traditional sense. They feed the networks some sort of sensory input and tell them what the appropriate response should be. The networks make the appropriate connections to deliver the proper response.

Much of today's work has been in software and tends to be slow. Several companies, many Japanese, are developing hardware chips that contain large neural networks, which will speed them up tremendously. For example, 50 building blocks yield decisions of a certain quality. But 50,000 offer much better cognitive capability. The amount of refinement required for a decision determines the number of neurons, or building blocks, needed.

"Digital computers are good at sequential processing and will continue to get faster," says Galane. "In the next 10 years, advances in cognitive chips will make neural networks large enough to be useful in the factory."

Such networks can help people make nonparametric quality decisions. Visual inspection, for example, is difficult without a human inspector looking at a part and deciding whether it is aesthetically pleasing and blemishless. An inspector, however, can show a neural network connected to machine vision 5000 good and bad parts. After adjusting its internal connections, it can then recognize minor variations and respond to a situation it has never encountered, much like the human mind does. The more cases

Faxing 3-D parts is not sci-fi and will soon be as commonplace as faxing 2-D documents. Once a digital model of the part exists, engineers can transmit a facsimile file to a rapid prototype device, like this 3D Modeler from Stratasys Inc. (Minneapolis).

fed into the neural network, the better it performs cognitive functions.

If a neural network checking quality on a production line incorrectly assesses two parts out of 100,000, a human inspector can show it those parts and tell it the correct response. It will then adjust its connections and "learn" from its mistakes. "As the computer gets older, it actually improves," notes Galane. "Conventional programming can't do anything like that. If it isn't programmed to handle a condition, it's useless."

Will Digital Computers Survive?

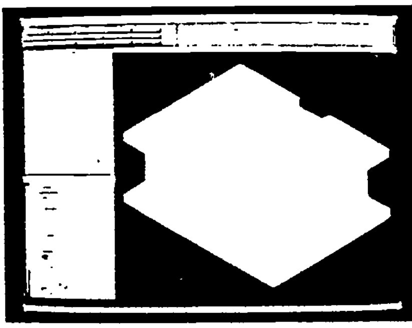
Despite that limitation, Galane does not expect traditional logical computing to disappear. "If we view mimicking the human mind as an objective of computing technology, marrying the logical and cognitive parts will be key because that is how the brain works. The brain performs both parametric (logical) and cognitive processes—the classic left brain and right brain model."

Parametric and cognitive tasks will just be marshalled to the appropriate parts of the system. In quality control, for instance, counting good and bad parts would not be relegated to the neural network. This belongs to conventional computing.

Sun's Clifford, however, is not convinced neural networks will catch on by 2002. "Many companies bought special LISP machines like the TI Explorer for AI applications," he recalls. "You can run those applications today on a workstation at nearly the same speed without buying new hardware. Perhaps very high-performance RISC processors will be able to emulate this new [neural network] computing technology too." For dedicated use, though, he admits specialized processors may be necessary.

He also points to a tremendous untapped capacity for improving conventional digital computers. "There are many things you can do with easier-to-use expert systems, especially for diagnostics and quality control," he says. Because expert systems are an extension of conventional programming, they rely on a knowledge engineer to be good at interviewing a human expert and rendering that knowledge into rules of thumb. Because of that tedious task, the proliferation of expert systems has been disappointing, but Clifford expects a breakthrough to automate acquiring data, organizing it and programming the expert system.

Galane argues, however, that neural networks are that breakthrough. "The system is only as good as the programmer is at extracting the knowledge from the expert and putting it into rules," he points out. "Programming a neural network is dramatically different. An expert shows it what is good and bad, and the network programs itself based on the expert's assessment."



A neural network helps the Rapid Design System automatically generate a process plan for a part. The system associates certain machining processes to part features like flat surfaces, slots, and holes. The US Air Force, the sponsoring organization, is collaborating with industry and academia to compress the time to manufacture.

Galane and Clifford agree, though, that fuzzy logic represents untapped potential for conventional programming. "Fuzzy logic seems to be heading into the mainstream for special-purpose processing much quicker, especially in various types of vision systems that monitor quality," says Clifford.

Fuzzy logic saves time in applications that can accept close-to-optimum solutions rather than a 100% solution, which could require orders of magnitude more programming. "Fuzzy logic is a misnomer because the mathematics behind it is very precise," notes Galane. "The programmer defines how much 'inexactness' you can live with in that precise mathematical model. It greatly simplifies the mathematics for arriving at a decision."

Whether to change a tool, for example, is based on cutting time, ambient temperature, and work material. Except for breakage, there is no specific point when the tool absolutely needs changing. Instead, there is an acceptable window for changing it. "In applications with windows, fuzzy logic works very well," offers Galane. He stresses, though, that these applications are "much different from controlling alarms in a nuclear power plant."

Clifford also sees object-oriented technology replacing the more prevalent parametric software and relational databases. Definitions for conventional software and databases have little leeway. "In MRP systems, for example, you can use one or more levels in a bill of materials," he explains, "but you have a bill of materials that links with other parts of the system in a predetermined way. Suppose you wanted to automate scheduling in such a way that you need a new class of information about parts. To make a fundamental change, even something relatively simple like adding another set of codes to a part number, you change the software everywhere in two or three million lines of code."

In object-oriented technology, modules "inherit" the capabilities of other modules, so modifying the module that defines part numbers changes it in the rest of the system automatically. "A two or three man-year modification might become a two man-day effort," reports Clifford. "That fundamental capability allows building and modifying systems faster, and will change the way people deal with computer systems." ■

FUTURE VIEW

Consider the contrary computer HAL in *2001, A Space Odyssey*, or the self-replicating micromachines that eat computer memory in *Star Trek: The Next Generation*. Intelligent processing systems such as these never seem to do what their manufacturers want them to. The cyborg in the sci-fi classic *The Terminator* is another example. Just when you start to hate the iron man, a sequel turns him into a nice guy. Unfortunately, by this time, he's over the hill. The creators just introduced newer (and nastier) technology.

Woven through these visions of the future are bits of reality. For instance, with the current pace of technological change, it can take less than six months for a state-of-the-art computer to become old technology. And software viruses can gobble up monthly production reports in seconds.

Now for the good news. By 2002, microrobots may crawl through intelligent machining systems, performing preventive maintenance in areas previously inaccessible. Smart cars using mechatronic systems may automatically adjust for driving conditions, road surfaces, and passenger preferences. Solar power could become the cost-effective, environmentally safe way to fuel many advanced manufacturing processes, such as laser welding.

Traditional methods of design and manufacture will give way to concurrent engineering (CE) strategies that target improved communications between design and manufacturing. Automakers, aircraft manufacturers, and even job shops will design for manufacturability. These strategies will strongly influence development and deployment of advanced manufacturing technology well into the next millennium.

As more manufacturers promote concurrent engineering, Charles Hull, president, 3D Systems Inc (Valencia, CA) predicts rapid prototyping technology will play a key role in helping them see a product before committing hard tooling. He adds that it matches well with the need for US manufacturers to shorten design cycles and improve design quality. "This broad class of technology, which I call free-form manufacturing, allows a wide range of arbitrary shapes to be quickly formed using part information generated in CAD systems."

Itzchak Pomerantz, president, Cubital Ltd. (Raanana, Israel), sees the technology used for rapid small-scale production within five years. When speaking of rapid production, he notes you must distinguish between direct and indirect. The first method produces parts by toolless rapid prototyping technology. The second entails part production using conventional casting or molding, but relies on patterns or tools made by toolless rapid prototyping. Sand-casting foundries may take advantage of indirect rapid production this year. Commercialization of direct rapid production is not far off, with the first applications showing up in packaging.

Currently, manufacturers wishing to implement wide-scale rapid production face several hurdles. First, rapid prototyping equipment vendors must improve part life expectancy since photopolymer aging and photodegradation are more severe reactions in production than in prototyping. Increasing equipment uptime also is critical. In all, Pomerantz expects another one or two years of experience, and a couple of generations of system reengineering must take place to boost uptime of rapid prototyping technology to that demanded by production.

In addition, while current prototyping machines are universal, manufacturers will want to tailor production systems to specific applications. Even when we solve these problems, Pomerantz stresses that companies will never make parts by rapid production techniques if parts aren't designed for manufacture by the processes. This entails training design engineers about rapid manufacturing technology. He estimates it will take two to three years for universities to create this next generation of rapid designers, but this is only possible if the institutions have access to the rapid production technology.

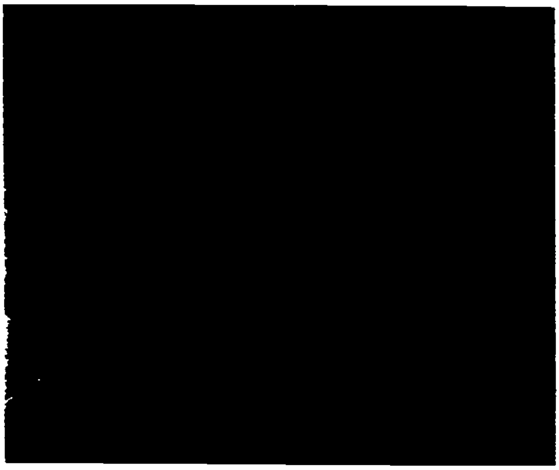
By Design Intent

For companies planning a move to concurrent engineering, recent advances in CAD/CAM, such as feature-based programming, show promise. Brent Burns, senior manager of manufacturing applications Intergraph Corp. (Huntsville, AL), explains that today's typical CAD data file contains graphic entities describing geometric attributes of a part or an assembly. CAD/CAM systems of the future will also include a large amount of nongeometric part information, such as part tolerances and required surface finishes, providing complete product models that will feed downstream manufacturing processes. Designers also will be able to see the impact on manufacturing cost when they add specific features to a part.

George Hess, vice president, systems and planning, Ingersoll Milling Machine Co. (Rockford, IL), sees

The Editors

TOMORROW'S MANUFACTURING TECHNOLOGIES



"Where there is no vision, the people perish . . ."
Proverbs, 29:18

feature-based programming as a critical enabling technology in the computer-integrated manufacturing (CIM) environment of the '90s. In 1987, reports Hess, the firm's management began the transition from computer-integrated to optimized manufacturing. This initiative entails extending CIM to the suppliers and improving productivity of support functions such as accounting. It also targets use of a feature-based solids modeling system from Cimplex Corp. (Campbell, CA) that will allow defining both construction and machined features, such as holes and surfaces. When operational, the technology will be the core of an advanced routing, generative process planning, and NC programming system.

By 2002, operator interfaces to CAD/CAM systems will extend beyond graphics-based user interfaces to virtual-reality systems. In the report *Forecast of Manufacturing Technologies for the '90s*, A.J. Vitale, a consultant with the Automation & Productivity Institute (Stow, MA), predicts interfaces will no longer be bound by fingertip inputs or screen dimensions. Instead, the computer will work with the mind and senses of the user to create a virtual reality. People will buy mindware, not just hardware and software.

The virtual-interface system will take in sensory input, such as head, hand, or eye motion, and feed back sensory output, such as sight and sound. Using a bodysuit interface, complete with eye, ear, nose, and mouth input/output devices, the operators will have total sensory contact with the computer, including capability to change the virtual environment by interacting with the system.

One benefit of virtual interfaces, notes Burns, is that designers and manufacturing engineers on CE teams will be able to hold a part electronically. "This edge is too sharp," "I didn't think the part would be this light," and "Look, I can snap this handle off" are phrases that will be heard before anyone produces a physical prototype.

Vitale reports virtual-interface technology already used in applications such as fire control systems in some military helicopters. In these situations, the pilot's helmet and goggles connect to the virtual interface system, which aims the guns wherever that person looks. A company in England is even selling video arcade games with virtual interfaces.

Virtual-reality systems in manufacturing will feed off NC simulation systems that include full machine and tooling data, predicts Burns. As a result, manufacturing engineers will be able to move an electronic version of a partially completed product from one virtual machine to another.

Simulation tools, key to any concurrent engineering program, also will help reduce the risks associated with introducing new technology to the shop floor. Mark Contesti, engineering manager for CSI (Troy, MI), which provides manufacturing consulting and simulation services, reports the tool is already used to prove new processing lines. The next step is to add simultaneous ergonomic analysis.

Current simulations analyze operator sequences using industrial engineering estimates. According to Contesti, true ergonomic analysis will evaluate issues such as part weight, how far the operator must reach to load a specific tool, and tool weight. Once processing lines are operational, line operators or manufacturing engineers will be able to use the developed simulation models in shop-floor systems to evaluate how processing changes will impact throughput.

"Simulation will also validate using robots in manufacturing cells," says Contesti. "Feedback from the simulation model will provide the basis for the robot control programming."

Ingersoll Milling extends the benefits of simulation beyond its factory. The firm is using the technology to

help the customer use advanced manufacturing technology. Hess reports the firm offers graphics training simulators that will help train operators, programmers, and maintenance personnel in use of its advanced manufacturing technology. The systems substitute color graphics terminals for the machines, yet they still depict all machine motions in real time in response to the NC part program or manual data input commands. So far, results indicate simulation can reduce training time by half.

Hess also sees the firm exploring enabling technologies such as expert systems to automatically develop NC programs and solve manufacturing processing problems. Other artificial intelligence (AI) will be implemented as the technologies mature.

Adding Intelligence

Vitale at the Automation & Productivity Institute sees AI techniques used in manufacturing emulating human performance in areas such as decision-making, natural language processing, vision, and robotics. AI-based approaches that will aid concurrent engineering efforts in the future factory will include knowledge-based systems, fuzzy logic, and neural networks. Each will have its strengths in problem reasoning. Solving some problems may require hybrid systems.

Knowledge-based systems, often called expert systems, capture expert human knowledge as symbols or rules to provide users with insight on how to react to situations. According to Vitale, these systems work best on well-understood, nondynamic problems that require precise calculations.

In one example, manufacturers troubled by fabrication cracking in heavy constructions can get help from a diagnostic system called Weldcrack Expert. This microcomputer software package from TWI (Cambridge, England) uses stored knowledge from leading welding engineers and metallurgists to guide the user through a series of questions about a crack's appearance and location. From the answers, the system diagnoses the probable cause.

TWI reports the expert welding program works well in applications examining hydrogen, solidification, reheat, and liquation cracks, in addition to lamellar tears. It can display photographs and schematics of weld microsections and provide operators with more than 30 digitally scanned, metallurgical photographs of classic fabrication cracks. Questions, responses, and results from each session can be stored on disk or printed. This allows building a library of case studies for future reference when tackling similar problems.

Nevertheless, life isn't always so simple that manufacturers can solve all problems using fixed rules. Sometimes, fuzzy logic is necessary, says Vitale. This AI technique relies on fuzzy sets, rather than strict, precise modeling methods, to deal with uncertainty. The system differs from knowledge-based systems in that it may prioritize some rules and disregard others during optimization. Since output tends to be smooth and continuous, this AI technique becomes a good approach for control of continuously variable systems.

Omron Electronics (Schaumburg, IL), US subsidiary of Omron Corp (Japan), is already marketing fuzzy logic modules for programmable logic controllers. Expecting the concept to significantly affect industrial controls through the decade, the firm made the concept a high R&D priority. As a result, it projects that at least 20% of its products will use fuzzy logic within three years.

During the next 10 years, Vitale sees fuzzy logic embedded in many software products without fanfare. Neural networks, however, still won't see widespread use. These are based on biological or mathematical models that loosely imitate the way the brain functions. The dynamic self-adapting systems can modify responses to external forces by relying on prior experience. In other words, neural nets learn from the past, says Vitale. Each network has several interconnected processing

Concurrent engineering, where designers work closely with manufacturing engineers, will have strong impact on both development and deployment of advanced manufacturing technology of the future.

elements functioning in parallel. Since information storage is distributed throughout, the network has no memory. Rather, it stores information as patterns and weights of connections between processing elements, evoking this information when necessary.

Most neural networks are software implementations on current computer hardware. Neurocomputers, of which there are few, are neural nets implemented in hardware. This computing method demonstrates significant capabilities in solving problems that are highly variable, data intensive, dynamic, and complex. In addition, its neural network is tolerant of ambiguous, incomplete, and conflicting data. Based on these features, neurocomputing may become an alternative computational approach for complex applications involving robotics, vision, industrial control, and modeling.

Vitale forecasts that neurocomputers based on multiprocessor designs will be available as off-the-shelf items by '95. Aggressive manufacturing users will have practical systems on line by decade's end.

Mechatronics and Smart Materials

Brock Hinzmann, program manager at Stanford Research Institute International's Business Intelligence Center (Menlo Park, CA), predicts mechatronic systems will also radically alter product design and development. These integrate sensors, actuators, and control functions in one intelligent system to improve precision, performance, efficiency, and ease of use. Technology advances underpinning system development include the following:

- *Sensors.* Size and weight of traditional sensors preclude their use for many applications. Look for microsensors, including semiconductor, fiber-optic, and biosensors to open up new application areas.
- *Integrated circuits.* Price/performance continues to improve to the point where 32-bit microprocessors costing less than $5 are likely to be standard technology by 95. Working in concert with the systems, reduced-instruction-set architectures will improve real-time processing of large volumes of information.
- *Smart power.* ICs that combine power-control switches and logic circuits on the same chip will allow designers to reduce system size and weight, in addition to improving its reliability.

Complementing and enhancing these technologies are smart materials that change shape, color, form, phase, electric fields, magnetic fields, optical properties, and other physical characteristics in a preselected response to stimuli in the environment. Hinzmann sees these materials leading to new mechanical concepts—actuators and motors that operate without traditional mechanical components, such as gears and pulleys. This will help manufacturers respond to important trends like dematerialization (doing tasks with less material).

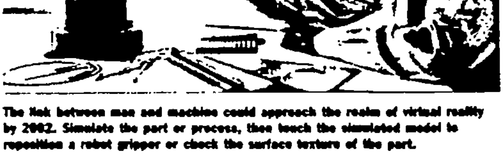
"Smart materials help bridge the gap between the ability to manipulate information and capability to use that information to direct mechanical action," says Hinzmann. "Designers will be able to use the materials to simplify products, add features, reduce material use, or reduce the expense and complexity of providing product variations for market niches."

The concept of smart structures (assemblies built with smart materials) grew out of the special requirements of the space program. For instance, there is no natural damping in space, according to Professor Sathyanarayana Hanagud at Georgia Institute of Technology (Atlanta). To maintain proper shape, a structure such as a boom must have sensors that detect deformations in real time and actuators that autonomously counteract those deformations.

Building on this concept, Hanagud recently completed an engineering study for the Army Research Office where he bonded piezoelectric sensors and actuators to slender beam models of helicopter rotor blades in a successful attempt to damp vibrations. He plans further research on use of special electrostatic films and shape memory alloys to produce the same effect.

The current generation of smart materials and structures remains devoid of any adaptive learning capacity, reports Professor Mukesh V. Gandhi at Michigan State University (East Lansing). He believes manufacturing engineers should characterize the smart materials for structural applications by their ability to respond in real time to changes in external stimuli, to interface with modern microprocessors and solid-state electronics, and to exploit modern control systems.

Gandhi adds that manufacturers will achieve these characteristics through coherent integration of the following: a structural material, a network of sensors, a network of actuators, microprocessor-based computation capabilities, and real-time control capabilities. The network of actuators will provide the muscle to make things happen, the network of sensors will be the nervous system; structural materials will make up the skeleton, and the microprocessor-based computational capabilities will add the brains that



The link between man and machine could approach the realm of virtual reality by 2002. Simulate the part or process, then touch the simulated model to reposition a robot gripper or check the surface texture of the part.

ensure good system performance.

Take advanced composites, for example. Gandhi and other MSU researchers are studying smart systems based on these materials that use electrorheological fluids embedded in macroscopic voids in the laminates. The fluids include micron-sized hydrophilic particles suspended in suitable hydrophobic carrier liquids. When subjected to electric fields, they undergo instantaneous reversible changes in material characteristics. As a result, the composite structures can dynamically tune their vibrational characteristics in real time by imposing specific electrical fields on the fluid domains. The voltages required to promote phase change are typically in the order of one to four kV per mm of fluid thickness, but because current densities are in the order of 10 μA per square centimeter, the total power required to trigger the reaction is very low. Fluids typically take less than a millisecond to respond to the electrical stimuli.

Future smart materials will be capable of self-diagnosis, repair, and learning, notes Gandhi. They also could have capability to anticipate problems. An attack helicopter would then be capable of in-flight structural surveillance if its rotor is a smart composite structure. On detection and measurement of changes in the rotor's vibrational response characteristics, the sensing network would begin a qualitative and quantitative damage assessment. It could then initiate a corrective action, such as redistributing loads around highly stressed regions of the rotor structure to control damage, or even instruct the helicopter to abort its mission.

Micromachines

Also critical for future mechatronic systems is micromachining technology. Techniques exist for producing functional devices or mechanical parts smaller in diameter than a human hair. This size allows placing sensors directly on ICs and using gears, motors, and a variety of actuators in micromachines or microrobots. A recent *Micromachines* technology impact report from Frost & Sullivan (New York) defines micromachinery as that consisting of gears, shafts, and other components that function in the same general way as full-scale machinery. One example is the electric motor developed at the Berkeley Sensor and Actuator Center at the University of California (Berkeley). The rotor of the device measures 60 μm, whereas a human hair measures 70-100 μm.

Louis Pasteur once said "...the part played by the infinitely small seems to be infinitely great." This becomes more apparent as manufacturers explore use of micromachines that work in the world of individual atoms. One atom is 1/10,000 the size of a bacterium. A bacterium is 1/10,000 the size of a mosquito. Elements the size of bacteria are in the microworld, measured in microns

The laws of physics give micromachines some advantages over their full-scale cousins, according to Hong Li, PhD, research engineer, Panasonic Technologies Inc (Cambridge, MA). Microrobots, for example, will have capability to move only a few micrometers at a time Therefore, they will be significantly more accurate than their full-scale cousins.

Virtual-reality systems will feed off NC simulations that include full machine and tooling data

Micromachines also gain advantages when you consider Newton's second law—force is the product of mass and acceleration. Since mass is very small, acceleration will be enormous for a given force. For example, a microscopic silicon air turbine recently developed rotates at 24,000 rpm using simple silicon bearings

The technologies used to machine microrobot components will vary reports Li, with each having specific advantages over the others For example, unlike etching techniques that can machine only silicon material, micro electrical discharge machining (EDMing) can process any conductive material, including metals, ceramics, and silicon

Micro EDMing also produces a surface finish around 0 1μm R_{max}, a value Li says is much higher than attainable with a laser machine The process offers better part accuracy than laser-beam, electron-beam, and laser-chemical machining In addition, roundness of 0.1 μm is possible and straightness of EDMed micro shafts approaches 0 5 μm

According to Frost & Sullivan, industrial applications being explored for microcomponents are exact alignment of lasers, light detectors, fibers used in fiber-optic communication, accelerometers in robotic control, and force-balanced transducers These components will also form the basis of micromachines and microrobots

To study microrobot feasibility, the Artificial Intelligence Lab at the Massachusetts Institute of Technology (Cambridge) developed a robot

Ergonomics simulation will play a key role in the design of the future manufacturing cell.

one cubic inch in volume that hides in the dark listening for sounds. When all is quiet, it ventures out in the direction of the last sound heard. It then finds a new hiding place, and the process repeats. Although large by micromachine standards, the robot reportedly uses techniques that may extend to the microrange.

Another MIT robot, called Genghis, weighs in at 2 lb (0.9 kg) and looks like an artificial ant. It also was designed to test the sensing and intelligence capabilities of microrobots. The six forward-looking, cone-shaped, passive infrared sensors are one part of the robot's sensor package. Of four onboard microprocessors, two interact with the motors, one monitors the sensors, and one runs the

[illegible]

Rapid prototyping—photolithography [illegible] systems that produce a part directly from CAD data.

Three-dimensional sensing—the ability to digitize [illegible] models, compare prototypes to CAD, and verify dimensions [illegible] or finished products in minutes.

Expert-system-based design aids—although not necessarily full artificial intelligence, the more interactive tools from past experts

Smart, real-time controllers—the ability to adjust the machine as it operates, compensating for material, wear, or alignment to produce a good part every time (simple neural-net operations are expected to be in use in the next 10 years)

Nontraditional machining—laser processing, waterjet, and EDM technologies are past the garage-shop stage and becoming fully industrialized. They may make plastics and composites the materials of choice in some applications because of the ease of manufacturability they provide. For example, because waterjets and lasers don't get dull, they can produce finish cuts in complex and difficult materials.

Dr. V.C. Venkatesh, Center for Manufacturing Research and Technology Utilization, Tennessee Technical University (Cookeville):

Material-"incress" manufacturing by rapid prototyping. The word "incress" (from "increscent," meaning becoming gradually greater), encompasses the use of powders, liquids, and solids as source materials. Powders are used in selective laser sintering and 3-D printing. Liquids are key components for shape melting, fused deposition, ballistic-particle manufacturing, and liquid polymerization. Solids are used in melting to remove excess material, gluing of sheets, and polymerization.

Plastics and new processing techniques. Gas injection molding for improved finish and fusible-core injection molding for weight reduction will gain recognition.

[illegible] edge angles, [illegible] reliable [illegible], and increased productivity.

In-process [illegible] surface integrity, and [illegible] will come from the development of piezoelectric sensors, acoustic emission, and digital image processing. Machine tools will have built-in diagnostic capabilities.

Fifth-generation controls. CNC controllers with process-monitoring capabilities will automatically generate NC codes based on part features. They will also perform adaptive-control machining and process monitoring, be able to do some process planning, and have the intelligence to make on-line decisions.

LaRoux K. Gillespie, senior project engineer, Allied-Signal Aerospace Co. (Kansas City, MO):

Nanotechnology in discrete parts—the ability to build parts from atoms mechanically placed together to make materials denser, more crystalline, stronger, and more electrically conductive. Few manufacturing engineers are even aware of this technology.

Desktop manufacturing—prototype parts finished overnight. This will save millions as the range of materials expands significantly. The processes will probably never get much faster than today, but tolerances will improve.

Process characterization—understanding minute process details and resultant capability. We're still trying to catch the Japanese on this—in-depth process knowledge is being lost in US industry that we must recapture. Even specialty shops do not have the expertise to answer customer questions about their own equipment or processes.

Deterministic manufacturing—monitoring process characteristics, not part characteristics. This is the ability to detect when one process variable changes before a single bad part is produced, instead of relying on statistical

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subsumption architecture that gives the robot its intelligence. Three batteries fit between the legs, making the robot self-contained and giving it more flexibility to roam.

Flexible Iron Men

Should full-scale iron men also walk through manufacturing cells? Researchers at Auburn University (Auburn, AL), including graduate research assistant T.Y. Wang and Assistant Professor G.J. Wiens, think so. J.T. Black, PhD, PE, director of Auburn's Advanced Manufacturing Technology Center, reports that cell size is constrained by the working envelope of conventional stationary robots. Robot process capability (RPC) also is key. This is basically a function of robot-arm extension length—the further the robot reaches, the worse its accuracy and repeatability. Making the robot

[illegible] Creep-feed grinding with diamond and cubic boron nitride abrasives can machine materials with ease, having exceptionally good surface integrity. Today's creep-feed machines are significantly different from yesterday's conventional grinding machines, and there have to be some dramatic changes in grinder design, both structure and controls, to machine technically sound and economically viable workpieces. Grinding is exciting again!

Our industry lacks education, however. Nonexistent apprenticeship programs and an aging workforce leave us fumbling and grasping at what little we know about past or existing technologies. In the panic to produce, there is little time to contemplate new technologies. The tried and true seems to be the safe path for most industries. Within 10 years, there will be no path for those industries. They will have disappeared in the cracks.

Q What have been the biggest manufacturing technology disappointments in achieving the factory of the future?

Joseph J. Baran, director of operations, Watervliet Arsenal (Watervliet, NY):

With the repeatability and reliability of CNC machine tools improving (but still with a long way to go), variability results primarily from materials and tooling. The biggest disappointment has been the lack of integration of sensors, adaptive controls, chip control, and tool monitoring/management capabilities with machine tools. These technologies are critical to reducing variability and moving to limited or untended workstation environments

Sanjay Joshi*, PhD, assistant professor, Department of Industrial & Management Systems Engineer-

[illegible] Part [illegible] but the software [illegible] hardware in the [illegible] flexibility. Software [illegible] integration. Systems [illegible] much attention, yet [illegible] components interfacing to enable this [illegible] not currently in the [illegible] because it requires [illegible] Mfrs need to be more [illegible] factory-control software. [illegible] engineering (CASE) technology [illegible] manufacturing environment. Software development tools—generic tools that can be widely used—must be developed to allow Mfrs to focus on tasks critical to making the factory run properly, instead of on programming details.

Joseph F. Engelberger, chairman, Transitions Research Corp. (Danbury, CT):

My field is robotics, and I was there at the beginning. For me, the biggest manufacturing technology disappointment is the failure of robotics to permeate production. Even the irresponsible forecasts of media sensationalists and financial pundits should have come to pass by now.

What happened? In the heat of the chase, the giant latecomers bought in and treated robotics like a commodity. After losing prodigious amounts fighting for market share, GE, Westinghouse, United Technology, IBM, and such quit, leaving the little guys in disarray. Japan, with incremental advances, took—and now dominates—the industrial robot market. Meanwhile, no one was fundamentally advancing the state of the art. When I was asked to update my 1980 book, *Robotics in Practice*, I downheartedly demurred on the grounds nothing much had changed in a decade.

If we had made our robots autonomously mobile, sensate, articulate, and imbued with artificial intelligence, the stand-alone robot worker could have become reality.

But, not to worry. To perform in service activities, robots must be more humanlike. That is where the action is today, and the smarts are right here in the US. Ten years from now, we in service robotics will magnanimously share robotic intelligence with manufacturing folks who have relegated robots to being just another automation subset.

*Recent recipient of SME's Young Manufacturing Engineer of the Year award

mobile allows bringing tasks into a better RPC region of the workspace by moving the robot closer to each machine. Designers have more flexibility to reprogram robot paths and reconfigure cells.

It is relatively easy to find a mechanism, such as wheels, tracks, rails, legs, and air pallets, to make robots mobile. In the manufacturing environment, however, Black stresses the mobile mechanism must be effective, flexible, and low-cost. Furthermore, the chosen mechanism can't interfere with existing manufacturing activities. For this reason, the Auburn team is using air pallet technology to help a robot move.

The Auburn mobile robot uses an air pallet that also has vacuum seals and is connected to a vacuum pump. These provide the chucking force between the robot base and floor when the unit is stationary. When the robot must move to a new location, it grabs a post, turns the air pallet on and the vacuum off, and pulls itself to that location. The project, still in its infancy, is exploring use of vision technology to aid in location.

Emerging Technologies: A US Report Card

	JAPAN		EUROPEAN COMMUNITY	
	R&D	PRODUCT INTRODUCTION	R&D	PRODUCT INTRODUCTION
ADVANCED MATERIALS	○ •	− •	+ —	○ —
ARTIFICIAL INTELLIGENCE	+ —	+ —	+ •	+ —
DIGITAL IMAGING TECHNOLOGY	· •	− •	○ •	− •
FLEXIBLE COMPUTER-INTEGRATED MANUFACTURING	+ —	○ —	+ •	− •
HIGH-DENSITY DATA STORAGE	—	− •	+ —	○ —
HIGH PERFORMANCE COMPUTING	+ —	+ •	+ •	+ •
OPTOELECTRONICS	○ —	− •	○ —	+ —
SENSOR TECHNOLOGY	+ •	○ —	+ —	○ —

CURRENT STATUS: + US AHEAD ○ US EVEN − US BEHIND
TREND: • US GAINING — US HOLDING ↓ US LOSING
SOURCE: DOC

Expert systems, such as Weldarusk from the English firm TWI, will increasingly lend a hand in factories by the year 2000.

Robotics also plays a critical role in a high-power, nonvacuum electron-beam welding process just developed by a United Kingdom-based venture. The partners in Cambridge Power Beams (CPB), Bristol, England, were originally brought together by the EC Eureka EU83 project to develop a 25-kW laser. They joined forces to develop the high-power nonvacuum electron-beam welding process under Eureka project EU86.

Current arc and laser methods are incapable of penetrating much beyond 20 mm into steel. They also waste a lot of heat that can distort the surrounding metal. CPB reports conventional systems use a beam of electrons that penetrates up to 300 mm in steel but require use of a vacuum chamber. This not only limits the size and configuration of components, it increases process costs. The firm's nonvacuum machine will weld up to 100-mm-thick steel at 500 mm/min in one pass with no distortion. It also welds complex alloys and dissimilar metals. To prevent oxidation, the system shields the workpiece with helium, which produces less beam scatter than other inert gases. An electron-beam welding bay, a simple concrete structure, will shield hard X-rays.

To take full advantage of the lack of distortion caused by electron-beam welding, the robot head carrying the beam will mount on rails to give stability. Leadscrew drives used in maneuvering will allow weld accuracy of 0.1 mm.

Future applications for the high-power, nonvacuum electron-beam machine could include cutting, heat treatment, and chemical processing, according to partners in the project. These include the British firms AEA Technology, International Transformers, and TWI, in addition to Denmark's Force Institutes, International Electronics and Manuel Torres Disenos Industriales of Spain, and Messer Griesheim of Germany.

Manufacturing with the Sun

In the near future, concentrated solar radiation may power many of the high-powered radiative processes and impact their design. Researchers at the National Renewable Energy Laboratory [Golden, CO; telephone: (303) 231-1449] recently demonstrated the feasibility of processes such as solar-induced surface transformation

of materials, solar-powered manufacturing, and solar-pumped lasers. Sunlight also can provide an alternative method of detoxifying hazardous waste.

The advanced solar manufacturing research is managed through NREL's Mechanical and Industrial Technology Division, which is dedicated to bringing American industry practical renewable alternatives that reduce or replace fossil-fuel-based energy sources. John Anderson, program manager for the solar industrial program, reports researchers are exploring new techniques for manufacturing advanced materials that use NREL's solar furnace. The furnace, which began operating in 1990, allows researchers to study the properties and applications of very high solar flux. The facility currently can produce solar flux densities of up to 50 000 suns (5000 W/cm²).

The solar furnace consists of a heliostat that tracks the sun and reflects incoming solar energy onto the stationary primary concentrator, which consists of 23 individual, curved facets. These collectively focus the solar flux at a point in the test facility that is just off the primary axis. The long focal length of the primary concentrator produces a 10-cm-diam concentrated beam of approximately 2500 suns at the center of the target area. When a secondary concentrator is placed at the beam's focus, the solar flux can be increased 10–20 times.

These performance characteristics put the solar furnace at the cutting edge of solar industrial process research, says Allan Lewandowski, project manager, advanced materials. One advantage the furnace has over conventional power generation methods is the capability to produce very high temperature directly from the sun. For example, researchers melted through a 2" (51-mm) alumina fire brick—which has a melting point of 1800°C—in less than 1 min. Another benefit is the extremely high rate of heating made possible by high solar flux. Very thin layers of the illuminated surfaces can then be driven to remarkably high temperatures in fractions of a second. The third characteristic is the furnace's ability to deliver the entire solar spectrum (from 300 to 2500 nm). This allows researchers to study applications requiring either broad spectrum radiation or a particular frequency, ranging from the infrared to the near ultraviolet.

The key to solar-induced surface transformation of materials is the rapid, controlled heating that alters the surface of a workpiece without affecting its base properties. NREL researchers are refining ways to use solar energy to produce surface modifications critical to a number of materials technologies including hardening, cladding, chemical vapor deposition (CVD) for applications such as cutting tools, and the manufacture of electronic components and circuitry. Preliminary economic analyses indicate concentrated solar flux, when used in large-scale production applications, could produce these materials at one-half to one-quarter the cost of production associated with the conventional radiant methods.

Solar transformation hardening of steel, for example, is reportedly competitive with laser-based techniques. Using solar radiation to clad applied powders to steel substrates also is generating considerable industrial interest. According to Lewandowski, this is because of the excellent metallurgical bonds produced between the melted powder and substrate. Manufacturers can obtain desirable properties of an expensive material such as a superalloy by cladding relatively small amounts to a less-expensive substrate base such as mild steel.

Solar furnace technology is well-suited to CVD because the surface heating can be closely controlled, eliminating the formation of solid product on surfaces other than the material of interest. NREL is investigating the CVD process for production of coatings such as titanium nitride and silicon carbide, in addition to thin hard-carbon films.

Micro EDM technology developed by Panasonic Technologies researchers can make metal gears so small they fit on this match head.

Solar-pumped lasers have been studied for more than two decades, but low beam concentrations limited the conversion efficiencies to approximately 1%. With the upper bounds of attainable concentration now near 50,000 suns, conversion efficiencies approach 5%. According to Anderson, there is potential to provide both high power and high efficiency for several types of lasers. To prove this, NREL will demonstrate a small-scale, 5%-efficient system midyear at the University of Chicago.

Systems such as this will also have advantages in space and lunar-surface manufacturing because the concentrated solar radiation technology would produce greater efficiencies than attainable on earth. Available solar radiation increases by 70% outside the earth's atmosphere and the ultraviolet portion of the spectrum expands down to 200 nm, providing more energy for photolytic interactions. Also, the direct use of solar radiation would employ a much smaller solar-collecting system because of the high efficiencies inherent in the technology.

In addition to surface modification applications, Lewandowski reports manufacturers in space would be able to use applications such as materials joining, welding, fabricating, repairing, and surface cleaning. He stresses the long-term success of NREL's R&D projects is tied to its close working relationships with industry and other outside research organizations. The National Renewable Energy Laboratory works with industrial partners through a variety of arrangements, including cost-shared demonstrations, joint research projects, and cooperative R&D agreements. ■

BIOGRAPHICAL SKETCH

James E. De Zutter, COL USAF(RET), is the Manager, Manufacturing Strategic Programs-Government for Digital Equipment Corporation. He represents the company in its strategic collaboration activities with the government which deal with manufacturing technology and improvements to the industrial base. Prior to this, Jim was Digital's Manager of Marketing Operations for Department of Defense Research and Development Programs. He joined Digital in 1981 upon completing a 27 year career in the United States Air Force. During the last ten years of his Air Force career he managed USAF command and control system development and acquisition activities.

Jim holds an undergraduate degree in electrical engineering from Arizona State University and a Master of Science Degree in Research and Development Systems Management from the University of Southern California. He completed additional post graduate work in Liberal Arts and Public Administration at Clark University. His academic honors include membership in Tau Beta Pi, Eta Kappa Nu, and Beta Gamma Sigma.

Jim is Digital's Corporate Representative to the National Security Industrial Association. He serves on its Manufacturing Management Executive Committee and is the vice chairman of its Industrial Base Subcommittee. Jim is a member of the Society of Manufacturing Engineers and serves on its International Government Relations Committee. Also, he is an active member of the Armed Forces Communications and Electronics Association and a Life Member of the Air Force Association.

Mr. BOUCHER. Thank you very much.
The gentleman from California, Mr. Packard.
Mr. PACKARD. Thank you, Mr. Chairman.
Dr. Agogino, do you have contact with other engineering education coalitions where you can share some of your findings relative to the engineering design and education program?
Dr. AGOGINO. We've collaborated on a number of projects with the second coalition out of the first round. The second round of coalition awards I think are just too recent. We haven't established any collaboration with them yet.
Mr. PACKARD. You mean with other universities that are involved in the Synthesis Coalition?
Dr. AGOGINO. Well, certainly within our own Coalition we're quite active. We make a point of meeting at each other's institutions and at some common location that may be involved with conferences associated with engineering education like ASEE.
Mr. PACKARD. Have other universities shown an interest in what your Coalition is doing?
Dr. AGOGINO. Absolutely. I've spent a lot of time traveling to other universities and conferences to make presentations at their request.
Mr. PACKARD. What do you do to disseminate the information that you are gathering?
Dr. AGOGINO. Well, we certainly published a number of papers. The goal of our Coalition is to create a national computer network as well, called NEEDS (the National Engineering Education Delivery System), and that is to be a mechanism for mass transportation at least of the computer-based curricular materials. But we also have put a lot of effort into the publications, conferences, links to professional societies and other linkage activities.
Mr. PACKARD. Thank you very much.
Dr. Bordogna, what does the NSF—what are their plans to implement the recommendations of the NRC report?
Dr. BORDOGNA. Let me answer that in two ways. I commented that there are five portions of their report, and Mr. Markovits, this morning, detailed them, for example, intelligent manufacturing control. We have programs in each of these and I'll mention a few. But the purpose is to integrate all of these. We are very concerned about there being separate efforts and pieces, and the idea is to try to collect all of this and have an impact in some way.
For example, in intelligent manufacturing control, which is one of the five real important parts of the "Competitive Edge" report, we have an intelligent control systems initiative, which is funded, development of new sensor technologies, which is not funded as much as it should. This happens to be what I personally think is an important technology not being attended to properly. For example, we don't have an ERC in that yet, and that's one reason why we should have more ERCs. It is a very specific focus. If you talk to manufacturing people, this is a great need.
To put that in a little more context—sensors are important to use intelligent machines. Unless you can get the information in the machine, can't really use its intelligence to make a decision. The Engineering Research Centers and the Industry–University Cooper-

ative Research Centers both deal with intelligent manufacturing control.

Let me just mention a few more. Manufacturing of and with advanced materials, that's important. There is a material synthesis and processing program underway now in fiscal 1992 which is new, sort of as a precursor to the proposed AMP program, the FCCSET program for next year. And we have a very interesting new announcement—in manufacturing which deals with chemical manufacturing. You know, there's assembly manufacturing and also chemical manufacturing, which has a lot to do with messing up the environment.

So we have a new announcement called "Environmentally Benign Manufacturing Processes." And that's important also from the viewpoint of—well, two things. The design—the idea is not to create an environmental engineering initiative in NSF, but to have the environment considered at the front of every design of any product. The second important part of that is the front cover of this announcement—has both the NSF logo and also the Chemical Research Council, which deals—which is an industry group which deals with chemical engineering departments. And inside this announcement, as a way to try to force more interconnection with industry, a researcher at the university who would submit a proposal cannot do so unless there's an intellectual connection, as opposed to a fiscal connection, with someone in industry.

So, in summary, all these five portions of that report have programs under them.

Mr. PACKARD. Thank you very, very much.

Mr. BOUCHER. Thank you, Mr. Packard.

Dr. Bordogna, let me inquire a little bit about the additional ways that the NSF intends to meet the challenges that have been outlined here this morning and are reflected in the two National Research Council reports. One of the things the report suggests is that we encourage what it refers to as a new architecture for learning in these important fields, and it suggests that maybe what we ought to have is teaching factories that would be modeled along the teaching hospitals in which doctors are trained today. In any event, it's clear that a new architecture of some kind is called for.

Can you tell us a little bit about how your NSF programs are geared to produce that new architecture, and generally what level of resources do you intend to devote to that mission?

Dr. BORDOGNA. Well, the enabling work force is a very, very important component of getting the job done, as well as the enabling technology and enabling management ideas. So it's a focus.

And you have to realize, which I'm sure you do, that everything at NSF that's done in research must be done in an educational mode. The two are connected, and that's a very, very important distinction of NSF's effort. So we must pay due attention to that.

You've heard about the Engineering Education Coalitions. It's very, very important that those Coalitions involve industry up at the front end. This is another paradigm shift. We generally in this country in academe have developed some nice ideas about research and education. They've been developed by the faculty in-house. And then afterwards, after a few years of endeavor they go out to our industrial colleagues and say, "Please join us." And this is a thing we have to change.

All these efforts now bring industry up at the front end, at the beginning of development of the idea, the program, so they become party to it. And this may seem like a simple thing, but it's very, very important to have—for the purpose of having industry involved up at the front end.

The ERCs have this, and the Coalitions have this, and it's not accidental. This is an important part of what is going on. So the ERCs and the Coalitions have two important facets: the industry connection on the front end of developing programs and therefore being total party to it, and also being available so that the students have access to industry. This is the way the flow is going. And a second important facet is both the Coalitions' programs, Education Coalitions and the Research Centers have the concept of integration, and I want to bring in and make a forceful point about this.

The real problem as we see it, and I think collectively too—I have a personal, a strong feeling about this, but I think collectively in the Nation the reason the ERCs were developed and the reason the Coalitions program was developed is that we don't in academe teach integration. We spend our time in academe in this country—it's the great strength—in picking apart topics and teaching very focused efforts, so people incisively and deeply study something. And the quintessential end of that is a Ph.D., which is very important, leads to Nobel Prizes and should be nurtured. So that, as Dr. Agogino implied, that all undergraduate curricula, not just engineering, are a collection of courses each of which is disconnected from the other.

So an important part of this whole process is to integrate all of that. And, for an engineer, the reason for being is to construct the whole—to make things out of something. So engineering science has been not quite the only thing to do. We've done that very well. But it's science and it's analysis and it's focused.

So how do you do this integration? Well, one way, as the previous panel mentioned a couple of times, is in the freshman year—Dr. Agogino's doing this too—is to start the engineering process up front. Have the students involved in how you put things together, not just in how you take things apart and study pieces of it. This is not possible to do without a lot of help from industry.

Now, you asked a specific question about this architecture of having the engineering students do something like the medical students do, where they go out and do clinical practice. And interestingly, about 6 or 7 years ago the medical schools began to have their freshmen, first-year students do clinical practice. They used to wait till the back end too. Like in engineering we still do. We wait until the senior year to do a design project. It's much too late because the whole idea of design and putting things together is the essence of engineering.

So we need a turnaround here. In all these programs, and undergraduate in particular, are to start this process at the front end. We're going to need a lot of help from industry to make that pragmatic because there's no teaching hospital at an engineering school, for example. And there should be no intention to develop such. But we have to go out to industry and make connections.

We're not quite sure how to do this, but the flow is that way. And the most important piece of this is in both the Engineering Research Centers and the Engineering Education Coalitions. For example, industry is party to the whole thing at the front end. So you develop these intellectual connections, and then it's very smooth and easy and comfortable to go through that interface between industry and academe.

Mr. BOUCHER. Okay. We are learning, I think, from your prepared testimony today and also suggestions we had received earlier that this broad and important subject is going to become a part of the FCCSET process next year. How definite is that? Give us some sense of how that FCCSET initiative is going to be structured. What agencies will participate? What specific subjects will they be inquiring into? And what level of resources will be devoted to it?

Dr. BORDOGNA. Well, I'll give you my personal rendition of what's going on. I'm in it. I chair a committee right now, the so-called Taxonomy Development, which is becoming a very generic committee. So daily there's interaction. And on Thursday we're having a meeting in which we hope to have some kind of draft context of the whole thing.

There's a vision being developed, and I think the vision is pretty much what I used to prepare my testimony today. The vision I described to you is pretty much the same vision that will be the basis of the FCCSET initiative.

In brief, the idea is to bring to bear the Industrial Revolution success of enhancement of muscle power. We've made machines. We've been able to leverage our physical strength. Now let's leverage our mental strength with the Computer Age. So the connection there is very important.

That is a difficult thing to do because you may drift off and say that information is the most important thing or software is the most important thing. But you have to keep in mind that the ultimate objective, and it's going to be of the FCCSET initiative, that something has to come out the door and be salable. So that's a very, very important focus on what we're doing.

The FCCSET has as its broad vision, now in the context of what we do by fiscal 1994 is a bit difficult. So there's a focus now, and the focus has two parts to it. One is—we don't know the name of it yet exactly, but something like software technology for manufacturing. We have great strength there vis-a-vis our international competitors. We should take advantage of that.

Can we use that strength to vault us ahead a bit, to make some kind of jump and bring our national production system into a more competitive position? So that's a piece of it. But along with that is something—we don't have the title for it, but something like intelligent machines and intelligent equipment, and the process of putting those together on the factory floor. So you might call this taking the Industrial Revolution capacity for doing things with machines and coupling it with the Modern Age capacity, which we have in great strength, of the Computer Age. That's a focus on what we're—it's a general focus, but now what do we do specially?

We've so far developed a taxonomy, which is a collection of all the pieces, again, of what we're doing and what should be done. There will be an inventory taken, the usual kind of procedure. I think we're almost there on what that should be. That's a bit of a complicated process.

We're not sure at all yet what specifically is going to come out of this in terms of a specific list of programs, but they'll be very similar to the kind of thing that you see in the fiscal 1993 NSF extra $25 million. Because these are precursors to what everybody is thinking about in terms of the FCCSET.

You asked about who's participating. And from the NSF point of view, it's very critical that we all team together on this. So in this committee of about 10 or 12 people is DOD, is NASA, is NIST. Incidentally, NIST has been mentioned a couple times this morning with the first panel. I think it's critical to look carefully at what NIST has started with these advanced manufacturing centers out there in regions, in the country. This is the beginning of an idea which I think can be very, very valuable.

Let me say just vis-a-vis NSF, if you look at NIST and NSF and other agencies—let's take NSF and NIST as an example—NSF is really a research arm. It's also an educational arm of an agency of the government and it looks a bit out further. It looks more in the long view. Now, in the FCCSET initiative, we have to see something in the short view too. It's got to be some more quickening of how it's—it's timely now and the time is running out. So we have a short view and a long view here.

In that context, NIST has these centers out there which take what we know right now, extant technologies, manufacturing technologies, and the intent is to get them into the marketplace, especially with small companies, so that the interface between government and industry can be made more permeable with these centers. People liken that somewhat to an agricultural extension. That's being talked about now. That has some merit in the sense of getting knowledge out quickly to where most of the jobs are being created, and NIST is positioned for that. And I think that's a nice evolving program.

If that's connected, for example, with the rest of us—for example, with NSF—to make a continuum from where a discovery is made—we talk of concurrency, by the way. Concurrent manufacturing is making sure design and manufacturing is sort of done together. Now we're expanding that view to what this Nation does best—discovery. So there's concurrency all the way from discovery to getting some applied research done, the prototype, design, manufacturing, production, getting it out the door, recycling it back, don't mess up the environment—closed-loop manufacturing kind of idea, but all done concurrently. And so in that sense having what NIST is doing, NSF is doing, make a concurrent link—that can be a great kind of impact on how we can move ahead more quickly.

And DOD, NASA and so on have all these talents. So anyway the FCCSET is moving along, I think, very nicely with a consensus, a lot of argument among the agencies as to what to do.

Mr. Boucher. I heard you refer to some of the individual components of it, and you were talking about the advanced software for manufacturing and some other things. Do I take it that the broad title of this, the scope of it, is going to be along the lines of what we're discussing this morning? And that is, better engineering design and manufacturing technology generally?

Dr. BORDOGNA. Yes, I think—let me say something a little more detailed about that. I think—again, everything that's been said this morning I agree with fully. I think everybody—there's a team here—these reports have been out , and these reports all sort of have the same idea in them; and the competitive edge is just one of them. I think there's general consensus on what to do, but I think there's a larger envelope around this that has a lot to do with making an enabling work force, not just getting something done on the factory floor, which is imperative, and that's the idea of integration. I'll bring that back again.

I think the psyche of the country is such that from the time you go to school until you get out of school and go to work we're training all and educating all our young people to be reductionists, to take things apart and investigate them very, very carefully. The system is set up that way. And very rarely in high school anywhere is any connection made among the pieces of this.

So that we see the FCCSET initiative—the effort to make the country more competitive in manufacturing, which is critical to our national wealth creation—as a way, also as a vehicle for beginning a new kind of mode of balancing education in the country. Besides being good analytically, which we are, let's develop an integrative mode.

Now, there's a lot of—I use the word "psyche" because our country dwells a lot on individual performance. There is very little group or team reward in the country. And this is a difficult thing to change.

I should—there's a lot of connections here. Let me give you one more connection because it relates to this. The Presidential Young Investigator Award which, I don't know—Alice, you're one of these, and there are about 1400 of them? Something like that. There's over a thousand of these young people out there who've been given this Presidential Young Investigator Award, and it has been interesting to see how that's developed over the first 8 years of it.

In the beginning it was a way, in the context of—Dr. Dieter was here answering about academe is like. In the context of the classical academe, that program was started to make the new young faculty the best, very proficient in research only. Get them up to speed fast, in a tenure period of 6 years or so, by giving them enough resources and a distinction, a label which is very prestigious. That's changed a lot, and now we have two events happening. The new Presidential Faculty Fellows and a new NSF Young Investigator Award, which is the same kind of program. A little different label on it, same number of people. You can't get one of those now without being equally proficient and have promise for teaching and education as well as research. The teaching and research and education has a lot to do with integration, again. So that there's a plot here of trying to develop a different way of changing the way we educate in this country where we're going to use different vehicles to do it, and the manufacturing initiative is one of those.

Mr. BOUCHER. I'm encouraged to hear the early plans that you have for this FCCSET initiative, and I would certainly add my endorsement to the idea of this being one of the areas for focus by the FCCSET process.

First of all, in further questions along that line, does the administration generally support this? Have you—does OSTP add its imprimatur to this effort?

Dr. BORDOGNA. I'll say it personally. Dr. Gene Wong is on us everyday.

Mr. BOUCHER. Okay.

Dr. BORDOGNA. There is a—OMB, OSTP—everyone is pressing very hard.

Mr. BOUCHER. Good. And what level of resources do you think will be applied for this FCCSET initiative? Do you have any estimate of what the total budget number will be?

Dr. BORDOGNA. No, I don't know. It's totally premature for me especially to make a guess of that because it's going to be a collective kind of thing. But the inventory will start soon, and we're going to try to do this quickly, get a—we're going to have a rough cut inventory first, so we can get into the 1994 budget with some kind of focused initiative.

Mr. BOUCHER. Well, your own program is $104 million for fiscal year 1993. Assuming you get that level appropriated—that's what you asked for—I would assume that bringing all these other agencies in would increase that number significantly. So do you care to give us just a ballpark estimate?

Dr. BORDOGNA. You know I—well, some have said that the manufacturing base in R&D in the Federal Government is somewhere around $1.2 or $1.3 billion. It's a—that's been tossed around. I'm not quite sure it's come from. People were giving some thought to this last year because there had been some work going on, and it's very interesting—it's very similar to the advanced materials initiative. It was about 1.3 billion.

And I—another part of the FCCSET—I want to answer your question, but I want to put another piece to this. A very, very important part of the FCCSET which may in the end—in the long run be more important than just next year's budget is the fact that the lines are being blurred between the agencies. There's a lot of collectivity. People are getting to know each other, and we're getting a good way to look at a collective integrative way of doing this.

I don't know what the investment should be. I—certainly we could—NSF started off this year with a $75 million request for an advanced intelligent manufacturing initiative which I think in the end was too broad-based to start immediately. Let me give you a context now. So it was throttled down to 25 million, which I think was correct. So I think, you know, a doubling kind of money—if you play out rationally all the programs that are needed, you end up with something like doubling. But then you have to worry about starting this, gearing this up for next year.

So, in the NSF thing, the reason it was scaled back was to be more rational in getting the base going, then advancing from there.

Mr. BOUCHER. We'll look forward to following with interest that progress, and I'm encouraged to hear that so much progress is being made on that front.

Let me get you to respond to two suggestions made on the previous panel. The first of those came from Dr. Jones, and that is that in your ongoing advanced manufacturing initiative you are not placing enough emphasis on engineering design. That that needs to be highlighted more and that, I guess—I guess additional resources need to be applied to it.

What response do you have to that? And what intentions, if you agree with Dr. Jones observation, do you have to remedy it?

Dr. BORDOGNA. I'll give you two answers to that. One is yes, I think we don't put enough emphasis on design. But you have to be very careful that the design in and of itself has pieces to it. One is the research piece and one is the education piece, which Dr. Agogino very capably described as to what we have to do in undergraduate education. So, if you collect those two things, you get a different kind of answer of how much is being spent.

So we certainly need new Education Coalitions, which I would add in as the design money we need, because I can't separate the research. The end result of NSF in the long term is to meld education and research. So I can't talk separately about the Coalitions and the Research Centers.

So I think—yes, I think generically design has not been considered an intellectual goal in academe, and we have to change that. But we're not going to change it, I think, just by going on design. We're more clever than that. And so the idea of integration and collectivity and design and manufacturing.

So, yes, I don't think it's enough on design. But, on the other hand, it's very difficult for us at NSF, on the basis of what I've said so far, to separate the pieces. You see, we're very worried about if we pick out a piece and just dwell on that and talk about that in the context of this must be done. It may be true. But we worry about having it done in a disconnect from the rest of the thing that has to be done. So, to us design and manufacturing are critical to be linked, and that's why the division of design and manufacturing was set up and not two separate ones.

And I've mentioned about concurrency—one reason it was set up as it was at NSF is design and manufacturing must be concurrent, and there is no argument among any of us on that. I think there's not enough being spent on manufacturing, not enough being spent on design as entities in themselves. But it's more important to make these additions of money in the context of the overall effort.

Mr. BOUCHER. Well, you're giving me a sense of how difficult it is to heighten the focus on design. But what are the answers to those problems? I mean, how do you do it? You're saying you don't want to disengage it from manufacturing, per se. You're probably right about that. On the other hand, if it needs more emphasis, how do we give it more emphasis?

Dr. BORDOGNA. Well, I—it needs more resources to get to a stage in research that it should be. So I agree with that fully.

Mr. BOUCHER. Do you intend to allocate more resources to it?

Dr. BORDOGNA. Sure. In fact, in the $25 million there is at least twice as much. And that's, of course, the $3 million and one-half million kind of argument here. And yes, there's more money allocated, but it's done in the context of the overall idea.

Mr. BOUCHER. There was a suggestion also that in the broad category of soft science you are undervaluing the need and are, I guess, providing something like one million out of your budget of 104 million for that. The suggestion was that maybe a 500-percent increase in that might be appropriate?

Dr. BORDOGNA. Yes.

Mr. BOUCHER. Do you have any comment with regard to the soft science——

Dr. BORDOGNA. I don't know where the one million came from. I think, again, you have to define what soft science is, and it could mean social sciences.

Mr. BOUCHER. Well, it is—social sciences.

Dr. BORDOGNA. Yes. Okay. All right. If that's what you mean, I can answer that clearly.

This is an important issue, and I mention in my prepared testimony that the appointment of the new head of that directorate is someone who has done research on the human dimension in manufacturing. Now that wasn't trivial. That was a part of that appointment.

We're very interested in making—engineering at NSF has a very up front connect with the Social, Behavioral and Economic Sciences Directorate for this purpose. So we put $1 million in management of technology in the fiscal 1993 budget. That's a controversial thing to do because NSF is not supposed to do management of technology. They're supposed to do hardware kinds of things and research.

So the best way to answer that is no, it's minimal, but it's a foot in the door. But it's a very, very important issue because enabling work force, enabling technologies, enabling management—these are all the things that have to be put together to do manufacturing.

I would like to put more in.

Mr. BOUCHER. Okay.

Dr. BORDOGNA. I think it's a big, overarching thing we have to worry about.

Mr. BOUCHER. Well, we've identified the problem, and we'll continue to focus on that.

Let me inquire of our other two panel members about another subject that has been raised repeatedly this morning, and that is the need to have more integration between industry and the universities in terms of manufacturing technology and engineering design. How effective are the programs at your universities in attracting industry support? To what extent do you have programs that exist in conjunction with industry today? And how interested is industry generally in hiring people who have graduated from your program?

Dr. Solberg, would you care to begin?

Dr. SOLBERG. Yes. Well, of course connection to industry was one of the explicit objectives of the ERC program. So we've pursued that very actively from the very beginning, with surprising success, I think. I was a little surprised at how eager the companies were to work with a university.

It's not uniform, though. One of the lessons I have learned is that you have to be cautious about generalizations here. We are working very successfully with our member companies. Of course, those are the companies who have come to us. They're, perhaps, not representative of American industry generally. They tend to be big companies because the big companies can afford to work with us, not just financially, but in terms of allocating people to the effort.

And it's been troubling throughout that we were not really getting to very many small companies, some, but not very many.

As for hiring the graduates, we found that they've been very eager to get our graduates. I alluded to the study earlier that this has been a general experience of ERCs. The graduates that have come out and been employed seem to surprise the companies at their capabilities. It's very gratifying to get those stories back. It shows we're on the right track.

Again, though, that's not a uniform experience. There are many companies that haven't yet awakened up to this need for the team-player-kind of engineer and are still looking for the specialist. So it's a mixed message.

Mr. BOUCHER. All right. Dr. Agogino?

Dr. AGOGINO. I've been totally overwhelmed by the support that we receive from industry. For every one dollar from NSF, we get three or four times, in terms of just a monetary contribution, from industry.

In addition, they're enthusiastic. They're so excited that they can be involved intellectually in changing the direction in undergraduate engineering education. I've been asked to speak in front of the board of directors of at least three companies so far. We've made presentations not only at the very high level, but working at all levels through the companies. They're getting—they were involved in our proposal-making process to start out with. When we decided what problems we want to tackle, we worked with industry to identify those very difficult problems.

I view, and this is also the view that I received from industry, that the education of an engineer is really a 10-year period and that we have to look at the 10-year education. And the university provides one part of that education. That like the medical school analogy, the experience in working with industry provides another part of that, and we need to work together to have an integrated engineering education policy.

They've not only been involved at the intellectual level in terms of telling us advice on our programs, but also I think through working through the Coalition we've seen a kind of collaboration between industry as well in working with us. At UC Berkeley in our industrial liaison program for the first time ever, we had a program on the Coalition and on undergraduate engineering education. And during this tough period in California and the Nation, travel to go to industrial-type programs at universities are one of the first things that are cut. We had standing room only at our presentation. The involvement and the response from industry has just been overwhelming.

Mr. BOUCHER. Well, that's encouraging to hear.

Do you have the sense that at other engineering schools throughout the country a similar success story could be told?

Dr. AGOGINO. Well, certainly that's true through the members of our Coalition. That's where I have the most experience.

Mr. BOUCHER. How many universities are involved in that?

Dr. AGOGINO. There are eight universities.

Mr. BOUCHER. Okay. This is a pilot program and it's fairly new, I gather.

Dr. AGOGINO. Yes. There have been major changes. To add to that point, there are three Historical, Black Colleges and Universities in the Coalition, and I think that they are getting a level of attention and response from industry that they would not have received if they had not been part of the larger Coalition. So major corporations are now going and looking at their networking infrastructure or reviewing the curriculum or looking at their graduates, and I think that that has been a tremendous impact that would not have happened if it had not been a collaborative activity.

Mr. BOUCHER. Would you argue, based on that success, for the application of this program to engineering schools nationwide at this point?

Dr. AGOGINO. Absolutely.

Mr. BOUCHER. Do you think——

Dr. AGOGINO. I think it's important that we should continue funding more coalitions.

Mr. BOUCHER. Okay. Where do you get your funding from for the Coalition?

Dr. AGOGINO. Well, the NSF provides the seed money for the funding. As I said, it's a significant part, I'm sure, of NSF's budget. But industry has multiplied that three or fourfold, and our universities have matched as well. And another part that was unexpected was the tremendous response from our universities. The—in, again, tight budget times, I am sure, on all campuses, it is the match to the Coalition funds that have been preserved, and, in fact, in many cases increased.

Mr. BOUCHER. Dr. Bordogna, do you share her enthusiasm for the success of the program?

Dr. BORDOGNA. Well, Dr. Agogino and I are teammates on this, so we're biased.

Let me just add that there are four coalitions and there are upwards—over 30 schools involved, and two more are coming on line next year. So it will be about 50 schools involved. And there are 300 engineering schools, more or less, in the country. So that's 50. And the schools involved are schools, many of which operate under the old paradigm: You just do your research. And they're given a signal. They're given an image. So I think this is barreling along very, very nicely, and I think we're going to have change.

Mr. BOUCHER. Well, should we be trying to apply this to all 300 schools instead of simply 50?

Dr. BORDOGNA. The objective is to apply the philosophy and context of integration to all schools, and that will be a paradigm shift, but to also allow schools to do it in their way. That's another piece of this. That different schools in different regions of the country, different cultures, different makeups, and they should apply this process of up-front engineering in the freshman year and integration in their own way.

But yes, the intent is to change the paradigm for engineering education. It's not a science education. It's an engineering education.

Mr. BOUCHER. Do you only have funding to provide the seed money at these 50 schools? Is it a question of money or is it a question of structure of the program, where you think that this should be something that's sort of short term and just proved out in selected universities and then just offered as a model to others without funding?

Dr. BORDOGNA. This relates very much to the question that you asked previously about the culture, the faculty culture, and how you get promoted and the reward system. We have to carry this on for at least a half a generation, maybe 10 years, so that we get in place who've been rewarded. The young PYIs are involved, so they're coming along with this new melding of teaching and research. That's the overall grand plan. So at least 10 years minimum is the effort. And it's very difficult to bring the money to bear on this.

Mr. BOUCHER. Well, if it's working so well at Dr. Agogino's university and apparently at others—she said that her Coalition partners also are enjoying success, and I would assume you are forecasting for the balance that would bring the number up to 50—then why stop the funding with 50? If it is successful, why not take it on to the other 250?

Dr. BORDOGNA. There's no intent to stop the funding. You have to, first of all—Alice, you've been in line about a year.

Dr. AGOGINO. Year and a half.

Dr. BORDOGNA. And the new ones are just starting, the next two. So that there are two underway for a year, and the next two for the next year.

Mr. BOUCHER. But why is the pace so slow? I mean why not accelerate the number of universities?

Dr. BORDOGNA. Well, I think we can, maybe in a bit. But this is an experiment too, and we're learning a lot from the feedback of this. We're not quite sure how to conduct this program specifically. We know how to conduct it generally. And so part of the up front is like a research project.

Mr. BOUCHER. Are you getting any clamor from other universities saying, "Me, too; I want to be included"?

Dr. BORDOGNA. Well, sure. Sure. We have another announcement out right now. In fact, I just delayed the receipt of letters of intent because so many universities are getting together, and they need more time to collect themselves.

In this new round we're trying something a little different. It is another experiment. They've been generic before and sort of get together in big groups. Now we're saying maybe a smaller group of universities and the focused kind of piece of this might be good.

Mr. BOUCHER. All right. Dr. Solberg, are you participating in this?

Dr. SOLBERG. I've had some involvement. I'm not sure whether we're going to be involved in this next round.

My—just to echo something that he said in slightly different words. I sense very little disagreement about what needs to be done either in the research or education area. The challenge is to get it all together and integrate it. So there are probably many models to be explored here, and the typical American pluralistic approach here is probably wise.

Mr. BOUCHER. Well, ladies and gentlemen, I thank you for the enlightenment that you've provided today. We could carry on this subject for a lot longer. I, unfortunately, have another meeting I have to attend.

We appreciate this panel of witness' contribution to our work. This is a subject that we will continue to examine. And we wish you well in your efforts.

Dr. BORDOGNA. Thank you.

Mr. BOUCHER. Subcommittee stands adjourned.

[Whereupon, at 11:30 a.m., the subcommittee was adjourned, to reconvene subject to the call of the Chair.]

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