# Report to the Management of the Automated Manufacturing Research Facility National Bureau of Standards

by

## AMRF Research Advisory Workshop

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Gordon Millar, Co-Chairman

Philip Nanzetta, Co-Chairman

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# AMRF Research Advisory Workshop

## Executive Summary and Recommendations

The Automated Manufacturing Research Facility (AMRF) was authorized in 1981, received its first major funding from the Navy Manufacturing Technology Program at the end of 1982, and demonstrated a two-workstation subsystem in December, 1983. During 1984 and 1985 three public test runs were held of successively more advanced subsystems of the AMRF. The entire physical facility is scheduled for full operation by the end of 1986, initiating a new phase of research emphasis.

During its brief lifetime, the AMRF has become a model for the way technology should be transferred from national laboratories. It has been cited by legislators and administration officials alike as an example to be emulated. This reputation has been earned because of the extensive industry and university interest in the work of the AMRF and because of the support of these groups. Over 60 industrial Research Associates from 34 companies have worked at the AMRF since 1982. More than 100 university affiliations have been formed, including a grants program for cooperative research, sabbatical opportunities for university faculty, PhD thesis research, and cooperative employment for undergraduate and graduate students.

Since the AMRF will be entering a new phase of research emphasis at the end of 1986, the management of the National Bureau of Standards (NBS) decided in early 1985 to institute a rigorous cycle of planning for that research and technology transfer. As part of the planning, representatives from sixty university, manufacturing research, and manufacturing production organizations were invited to join NBS staff in a three-day workshop, the *AMRF Research Advisory Workshop,* to discuss the post-1986 emphases of the AMRF. The detailed results of discussions at the *Workshop* are now being incorporated in the planning being done by NBS management.

This report summarizes the macro-level recommendations from the *AMRF Research Advisory Workshop* and presents the reports of the *Workshop's* six panels.

### Conclusions and Recommendations

The AMRF is playing an important role in the development of American computer integrated manufacturing. NBS has built an outstanding staff, which has begun to understand many of the problems of the industry. Contributions to the Manufacturing Automation Protocol (MAP) standards effort and to the formulation and testing of the hierarchical model for factory control are most noteworthy.

Several of the *Workshop's* panels, on their own initiative, explicitly addressed the question: "Is the work of the AMRF appropriate for the government to do; should NBS continue to conduct research in automated manufacturing at the AMRF?" In each case, the conclusion was unanimous support for continuation and strengthening of the program, with emphasis on critical research needs and transfer of results to industry.

Reflecting the existing policy of the AMRF, the *Workshop* recommended that every effort should be made to avoid replicating capabilities that already exist in industry or re-inventing and building devices that are commercially available.

The specific recommendations of the *Workshop* fall into three categories: research targets, technology transfer modes, and activities in which NBS should seek to catalyze the efforts of others.

## Research Targets

*Workshop* attendees agreed that basic research is a vital NBS activity which should continue on its present course. The panels recommended specific research targets within each field. To address these targets, the AMRF staff must continue to have an active knowledge of the unfolding technology of computer integrated manufacturing and a growing understanding of the needs of industry. One common idea emerged: research in the AMRF should aim to support the measurement and standards needs of industry. To support these needs, five major areas for future research were identified.

1. *System Architecture:* NBS has primary expertise in the areas of system architecture. This expertise cuts across industry boundaries in such a way that the measurement research cannot be conducted by a single manufacturer. Development and testing of factory control and data flow architectures for automated manufacturing fall within this research. Conceptual development is not enough; actual physical implementation and testing are required. The AMRF facility is a suitable test bed for control, scheduling, communication, and data management software.

2. *Robot and Machine Tool Performance:* NBS should continue to build its research programs on robot and machine tool performance. This includes definition of robot performance measures and studies of machine tool static, thermal, and environmental sources of errors. The research should lead to standards for robot and machine tool performance specification, dynamic models of machine behavior, and techniques for performance enhancement.

3. *Standard Interfaces and Integration Techniques:* The AMRF should increase and sharply focus its research on standard interfaces and its testing of interfaces and integration techniques. The results of this research must find their way into the standards environment in order to have transferable use for industry. To link components furnished by unrelated

vendors, standard interfaces are needed for sensors and sensory systems as well as for elements of the control hierarchy and the data system. Study and testing are needed for system implementation languages and emulation/simulation techniques for design and testing.

4. *Preparation of Manufacturing Data:* As the work on shop-floor control moves into the standards phase, increased research is appropriate in the area of manufacturing data preparation, including process planning, off-line programming of robots, and intelligent use of geometry and tolerance data. The next generation of data preparation systems will employ rule-based systems for selection of tools, feeds and speeds, sequences of cuts, deburring approaches, and inspection routines.

5. *Manufacturing Data System:* NBS has made major contributions to development of network standards. The AMRF provides an ideal test bed for further work on the applications-level network protocols and for study of all aspects of a manufacturing data system.

**Technology Transfer**

The panels were even more active in making recommendations for technology transfer efforts than they were for research targets. The Research Associate program was seen as a major way to transfer technology effectively, but an approach that might serve large firms, which can afford to send a researcher to NBS, better than small ones.

1. *Traditional Technical Work:* NBS continues to make significant contributions in areas of its traditional technical work, including participation in standards development, development of benchmarks, preparation of prototype specifications for procurement or acceptance testing, investigation of techniques for performance measurement, and conformance testing. The *Workshop* recommends that the AMRF continue and further evolve its activities in these areas.

2. *Traditional Technical Dissemination:* The AMRF already makes extensive use of the traditional means for dissemination of technical and technological information, and it is encouraged to continue doing so. These means include organization of conferences, presentations at conferences, publications, hosting industry visits, and participation in workshops on automated manufacturing.

3. *Special Educational or Consulting Efforts:* The AMRF is encouraged to build on its high credibility and technical expertise to reach out with special efforts that include public test runs, technical briefings, distribution of newsletters, preparation of educational videotapes (and even course materials), organization of bibliographic information, and production of an online data system for automated manufacturing.

4. *Gathering Users Together:* The AMRF can play a key role in fostering communication among all of the researchers in automated manufacturing. One panel recommended a bi-annual round table discussion at NBS for vendors of relevant equipment. Establishment

of an AMRF facilities user's group was suggested. The strong recommendation was made that the AMRF coordinate with other organizations around the country which are putting together related facilities to support manufacturing research.

5. *Research Associate Program:* The Research Associate program was recognized as an important means for industrial participation in research at the AMRF, and an important means for transfer of technology. Development of corresponding reverse sabbaticals, under which NBS personnel go to work in an industrial setting, was recommended as one antidote for the problems of small companies which can not afford to send a key person to NBS.
6. *Commercialization:* True technology transfer is only accomplished when the technology is incorporated into products that can be bought and used by manufacturers. The panels urged that NBS continue to follow its standing practice of buying off-the-shelf items or contracting, whenever possible, with private industry for development efforts. In addition, the AMRF should work closely with government and large industrial users to provide the ''leverage'' and buying power to bring the technology into the commercial sphere.

## Catalyst Roles

The *Workshop* made recommendations for technology transfer activities that appear to fall outside the NBS mission, but for which NBS can be an organizer or catalyst. These include:

1. *Economic Justification:* Present industrial practices concerning accounting and management decision schemes, developed at an earlier time, do not adequately consider the factors that need to be evaluated in making automation decisions. NBS should stimulate, support, and provide technical input for projects to study accounting and justification principles and revise guidelines to reflect the latest technology of manufacturing.
2. *Education:* Education is the responsiblity of universities, colleges, schools, and professional societies. The physical AMRF facility and the reservoir of AMRF technical expertise are resources which NBS should make available to these educators. In this way, the educational needs of vastly more individuals can be served than NBS could possibly address directly. In this way, also, the primary efforts of NBS are not diverted from technical activity.
3. *Demonstration Facilities:* Manufacturing organizations generally need to see a new technology in action before risking an attempt to adopt it. As the premier research laboratory in automated manufacturing, the AMRF should provide technical information and guidance to support development of demonstration facilities by universities, industry, or other agencies.

---- Gordon Millar

---- Philip Nanzetta

# AMRF Research Advisory Workshop

## Opening Remarks

**Dr. John W. Lyons, Director**
**National Engineering Laboratory**

Characteristics of the AMRF

A test bed for experimental verification of new concepts for fully automated manufacturing, the AMRF has been built with special emphasis on developing measurement methods for the factory of the future and interface standards for connecting a variety of disparate computers and computer-driven machines. The facility has deliberately been assembled with equipment from as many different suppliers as possible in order to challenge the interface concepts. When you examine the facility you see that it is indeed a research installation; it has not been optimized for a particular kind of product mix. Neither has the equipment been packaged in sleek commercial covers. We are constantly rearranging the machines, reworking the software, and extending the scope.

The AMRF is a publicly owned and operated facility. Everything we have done on it has been published or will be. We have had thousands of visitors come to listen to seminars on the technology and visit and study the system. We have received donations and loans of machines and computers from the private sector totaling $3,300,000. We have had at the AMRF many industrial Research Associates (senior staff from industry paid by industry and working full-time at NBS on projects of mutual interest); currently there are 14 of them here. We have collaborations with a total of 22 universities and 14 grants. There are other Federal agencies involved; one, the U.S. Navy, is a major sponsor. So the AMRF is an excellent example of a cooperative endeavor among government, academe, and industry - as good an example as I know anywhere.

### Where are we?

We have or will have by the end of the year five work stations under integrated computer control. We have a smart, quick-footed staff. We have a number of collaborators. We have a set of research problems on our own agenda to last us a while. So why this *Workshop?*

To answer that let me first digress to make a few observations from my own perspective about what we have learned so far and what the barriers are or will be to adoption of this technology. First, as a manager I have learned not to sell the technology and its potential short. I recently testified before the Congress on this subject. Let me quote from that testimony:

"After several years of observing our team of engineers and computer scientists solve seemingly intractable problems it is my belief that technology will not be limiting, that given the staff, funds, and equipment we can devise a technical response to just about any problem in automation that may arise on the factory floor. This is not to say there aren't difficult challenges but rather that there will be a very large store of new technology accumulating over the next decade from research and development programs all over the world. The challenge is to take advantage of all this new knowledge in our production facilities, for only by putting the technology to use will there be an effect on our industrial competitiveness."

"There are two barriers to the rapid adoption of this new technology. One is the slow pace of investment in the technology by top management; the other is the relative scarcity of trained personnel to install and operate fully automated factories. Studies by various groups indicate that management remains reluctant to adopt the new concepts of fully automated production probably for reasons grounded in tradition, inertia, and fear of the unknown. There are not yet enough examples of success to provide the kind of economic performance data that make investment in this technology a sure thing; adopting the new technology entails a fair amount of risk. We need much more microeconomic data on the advantages of automation."

"The second barrier is lack of highly skilled personnel. I am not expert on the effects of automation on the labor force and there is much controversy about this. I do know that the factory of the future will require technically sophisticated staffing."

I went on to discuss the educational challenges.

### Purpose of the Workshop

We are holding this *Workshop* both to seek out a set of research problems we can address in a collaborative mode with industry and at the same time to help our technical colleagues in industry remove barriers to acceptance of this technology back home. This *Workshop* will help define what sorts of things we might address with you at the AMRF. I hope that conducting such an activity will also add to your ability to convince your associates back home that they really ought to invest in new manufacturing technology.

I leave you with one last thought. Recently I attended a workshop of the Manufacturing Studies Board of the National Research Council. At one committee meeting on technology transfer we developed the idea of transfer of technology within the corporation from technical staff to corporate decision makers. Strictly speaking this isn't technology transfer at all - but simple internal selling. The point we were making is that until the CEO becomes an advocate we haven't done the job and we can't complete the transfer of the know-how without first making the sale. I hope that by working with us industry will find the job of technology transfer and the job of persuading the CEO and the finance committee easier.

# AMRF Research Advisory Workshop

## Keynote Address


## Mr. Walter Vogel, Executive Vice President
## Deere and Company


### Industrial Automation and International Competitiveness

Good Morning Ladies and Gentlemen.

It is a pleasure to have an active role at the opening of this *AMRF Research Advisory Workshop*.

I want to congratulate the National Bureau of Standards for organizing and assembling it--further proof, to my mind, of NBS's willingness to assume a leadership role in advanced manufacturing research. May it keep up the good work--keep the superb scientific minds and other resources of NBS focused on quality research, including research into advanced manufacturing technologies.

I also want to say that this *Workshop* represents, to me, a step in a direction urged upon us by the recent report of the President's Commission on Industrial Competitiveness. That step calls for greater cooperation among industry, academia, and government for the mutual benefit of us all in an era of global competition. It's something I think we need to do more of.

I'd like to begin this morning by sketching some sober realities of the current business environment. I want to do this by referring to the off-highway industry--the one I really know well--while suggesting that what I say about the off-highway industry has its parallel in many other areas of the American manufacturing scene.

The grim fact is that the principal off-highway industries--farm equipment, and industrial and construction equipment--are becalmed. The doldrums are upon us--have been for several years--and we yet search for the hint of a favorable breeze.

Numbers tell the discouraging tale. Agricultural equipment makers shipped 12.9 billion dollars worth of goods in 1981, according to the Department of Commerce. It's been downhill ever since. This year they'll ship an estimated 5.7 billion dollars worth, a shocking 56 per cent decline from '81. Industrial equipment shipments by American manufacturers hit 10.1 billion

dollars in 1981. This year they may reach 7.4 billion, 26 per cent less. There is a wealth of reasons to explain the listlessness our industries endure. In broad terms, they include world-wide recession in the early 1980s and slow recovery therefrom in many areas. A highly valued--some would say over-valued--dollar that benefits imports and handicaps American exports. Belt tightening by over-extended debtor nations. Alarming federal budget deficits, and consequent high domestic interest rates. And so on, ad nauseam.

These are some of the fundamental factors underlying the unhappy condition of the principal off-highway industries. Fix them, one might think, and business will perk up. The good times will roll again. That, at any rate, seems a reasonable inference to draw.

But will it really be so simple? Come the upturn, will it really be back to business as usual? Is the high degree of cost awareness so apparent today in prospective customers a passing fancy, to be blown away with the first favorable economic wind that stirs the sails of the farm and industrial equipment industries?

I think not. Business as it may have been conducted before the now lengthy economic down-turn affecting the major off-highway industries--business as usual--is dead, crushed by the new reality of global competition.

And in this new era of intensified global competition, many American manufacturers have been sorely vexed. For the melancholy nub of the matter is that too often, in too many products where we compete with overseas manufacturers, at home and abroad, we are no longer the low cost producer.

Often, of course, we're able to compete on the basis of quality or style or service or traditional brand loyalty. But in general, overseas competitors seem able--increasingly and consistently--to offer products equal or better in quality than ours. And do so--this is the rub--and do so at a cheaper price.

We in the off-highway industries are not alone. The same problem exists, to a greater or lesser extent, in the steel, automobile, electronics, and machine tool industries, among others.

What, then, can be done about this situation? When your customers aren't as numerous as they once were anyway--when those prospects who may be inclined to buy are increasingly picky about cost--when your business is gradually being undermined by overseas competitors usually able to beat your rock-bottom price--what in the world can you do?

Well, for one thing you can complain. You can rail and rant and rave about alleged Japanese manipulation of the yen to keep it weak and thus enhance Japanese exports. You can point a finger at the European Common Market with its duties and quotas. You can cry foul to the newly industrialized countries like South Korea and Brazil for erecting high tariff walls and slapping restrictions on incoming investment while invading this country with low-cost imports. You can righteously demand from trading partners their strict adherence to the rules of the game as you, at least in theory, wish it played--if not totally free trade, at least fair trade--in the sports idiom, a level playing field.

You can do all this, and at the same time you can fill your lungs with air, point yourself in the general direction of Washington, and, as loudly as possible, yell for help--for the imposition of tariffs or quotas or licenses or voluntary restraints or some other tried and true tactic intended to keep the rascals out, or at least make it tough for them to compete here. Indeed, anti-import fever rises in Congress as trade deficits mount and specific industries and specific geographic regions are directly threatened by import competition. No American politician can stand idly by while jobs disappear and growth in the Gross National Product shrinks. The Federal Reserve figures the trade deficit, which hit about 150 billion dollars in the fiscal year ended September 30th, already has cost some two million jobs and two-to-three per cent lost growth in GNP.

In addition, structural changes have occurred in the country's industrial base. While the estimated trade deficit may have cost some 2 million jobs, often in heavy manufacturing, it must be noted that since 1980, 7.5 million new jobs have been created. Many are in the service industries.

I suppose one can not really fault industries, companies, labor unions and others hard-hit by imports for struggling mightily in every legal way to protect their basic interests. Not when the very existence of entire enterprises, even entire communities, may be at stake. Still, protectionism remains a very flawed solution to a very serious problem. The effect of anti-import measures is to inequitably tax consumers of the protected good, who must pay higher prices because of reduced foreign competition, while artificially enhancing the financial results of protected companies. Moreover, anti-import measures may invite retaliation from affected exporting countries and, in a worst-case scenario, even escalate to an all-out trade war. This certainly would not be in the interests of this country.

Another way for a manufacturer to battle the import threat is to adopt a philosophy of, if-you-can't-beat-'em, join-'em. Domestic production can be shifted to American-owned, already-established or brand new factories abroad. Joint ventures can be established with foreign firms. And there are other variations on the make-it-there, sell-it-here theme.

Many industries, including off-highway capital goods manufacturing, engage in these practices. For instance, farm tractors in the under 100-PTO-horsepower size range--what are generally called utility tractors--accounted for 75 per cent of all farm tractors sold in this country last year. Most carried the brand names and product colors of the best-known companies in these industries. Yet virtually every one of these tractors--some 87,000 in all--was manufactured abroad. In addition, there is an increasing trend toward buying foreign-manufactured parts and components for goods assembled here.

Companies here are sometimes criticized for following overseas-based business strategies like those I have just described. Some people feel that when the competitive going gets tough, the tough are too inclined to get going--out of the country. Yet this route may be the only viable strategy for a company to follow, given its own individual circumstances.

I don't believe, however, that taking the protectionist path or going abroad to manufacture are the only ways for American manufactures to combat the import threat. There is another way.

At least in theory, this way is simplicity itself: Beat out the overseas competition--that is, obtain a comparative advantage--by exploiting your inherent strengths.

This is what our overseas competitors are doing--exploiting their particular strengths.

Commonly it is assumed that their chief advantage lies in dramatically lower labor costs. True enough, usually. Yet, this is not the whole story. They think big. They regard their market as the entire world, of which the U.S. comprises but one very interesting and important segment. They study the U.S. and other segments carefully. Product line fit, quality, appearance and styling are often tailored to specific world market segments.

Sometimes they've also got other aces in their hand--extremely modern factories, for example--a disciplined workforce and lower overheads.

Labor cost, however, is perhaps the area where they enjoy their greatest advantage. We should note its magnitude in order to set our own objectives sufficiently high to minimize their advantage.

According to the Labor Department, U.S. hourly labor costs for production workers are twice as high as those in Japan and nine times higher than those in South Korea. Futhermore, this wage differential has not narrowed dramatically in the last seven or eight years although U.S. productivity growth in the period has not kept pace with other nations. Additionally, the differential in compensation costs is not limited to production workers only but applies to managerial labor as well.

Clearly, it is not hard to see why most of the time, in most of the products where American companies compete with overseas manufacturers, at home or abroad, they are under severe cost pressures.

But what of the strengths of American manufacturers? Where do they have comparative advantages that might be exploited?

There are several such areas--access to capital, for instance--but for today's purposes, let me allude mainly to technology, the general area this *Workshop* will concentrate on.

When I refer to technology as a comparative American manufacturing advantage, I do not mean only the hardware and software but, more so, the brainpower behind the hardware and software.

Let's recall, for a moment, that the word "engineer" has its root not in "engine" but in "ingenuity."

Ingenuity--a marvelous word, meaning inventive skill, and imagination, and cleverness.

Americans have no monopoly on ingenuity, of course. But they are resourceful, they are spunky, they are more willing than most to take risks, they possess a strong drive not to take a back seat to anyone. After the Soviets took the lead in space with Sputnik back in the 1950s, this country did a tremendous job of overcoming the Russian advantage and getting a man on the moon.

I am suggesting that this same drive, this same initiative and creativity--all the strengths I have mentioned--might be put together more assiduously, and probably should be put together more aggressively, by American manufacturers--assisted, as appropriate, by universities, national laboratories, and the like. I think this can be done in areas ranging from design of the end product to its distribution, and with special emphasis on the actual manufacturing process. Some companies already exploit--inside the factory--natural American strengths such as access to funding and technology know-how. But it might not be so common a trait as you might think. Ingersoll Engineers, a consulting group, estimates that fully a third of a thousand or so companies it has investigated have done nothing for years in the area of updating manufacturing technology. Another third, Ingersoll states, are pussy-footing around, doing next to nothing.

In any case, what I have been talking about here is meeting the competition head-on by mainly developing or regaining a comparative advantage in manufacturing processes. In other words, I have been talking about substituting capital for labor, and ingenuity and advanced technologies for outmoded methods and processes.

Let me explore this thought a little further with you, using an example from an industry with which my company is very familiar. In farming, the substitution of capital for labor is called mechanization, and for decades progressive American farmers have increasingly, and usually enthusiastically, adopted it. It's a key reason why today only about 650,000 farmers--less than a third of one per cent of the population--produce the bulk--80 to 90 per cent--of the food and fiber this country grows for both domestic and export purposes. It's not unusual, in the Middle West, for a single farm family with modern equipment to farm a thousand acres or more.

In manufacturing, we call the substitution of capital for labor automation. It is a system whose advanced development--robotics, for example--sometimes seems to be regarded with suspicion that its spreading use will lead eventually to the wholesale elimination of jobs--to an end, even, of human usefulness.

I doubt strongly that will happen in the off-highway or other heavy manufacturing industries of today. The so-called unmanned factory, where a handful of technicians pushes buttons on a computerized keyboard, turning out perfect tractors or combines or dozers with every push, isn't just around the corner. Even General Motors, apparently approaching its Saturn project with no pre-conceived manufacturing notions--with a "clean sheet of paper" encouraging innovation--even GM envisions transferring and hiring thousands of people to produce small cars at its not-yet-built plant in Tennessee.

It is true, though, that the increased use of modern automation techniques will cost some manufacturing jobs. That is, after all, the point of automation or technology or computers--to minimize or eliminate cost, the principal component of which in this country, very often, is total wage and salary cost. Automation will cost some manufacturing jobs. But not all.

In this regard, I believe the work performed so far at NBS's AMRF can aid industry in a significant way in determining which technologies to adopt, and what degree of sophisication to apply to a given task.

I also believe that the increased use of modern technology in design and in the actual manufacturing process within the factory offers the best hope--perhaps the only hope--for regaining or developing a comparative advantage over foreign rivals. Or if not an advantage, at least equality with them.

But I don't want to leave the impression that competing effectively on the global stage requires only the will to do so and the determination to proceed. Of course you need adequate funding and the unwavering support of top management and commitment and faith and brains and technological hardware and software. But much more is required.

Before actually trying to put modern technology to work, we in industry need to sit back and take a very close, objective and hard look at our business and our product lines. Are our products meeting the needs of customers in specific markets? In short, I suggest a critical review of the total business and its strategies is a necessary first step before proceeding with capital outlays. Modern technology should not be regarded as a cure-all for all the competitive problems of a specific business.

Let me mention now some Deere & Company approaches to the manufacturing discipline. Keep in mind as I do so something I alluded to earlier--that a wholistic or overall view of manufacturing is essential to competitive success in the global arena. And that the wholistic view in manufacturing starts with R & D, design and development, runs through production and marketing, and includes after-sales service. Each of these steps is a factor in a product's cost, and thus a determinant of its competitiveness.

To understand how products must be designed to optimize the use of productive resources, and to determine how much a production facility can be altered to accommodate a product without adversely affecting its efficiency or requiring excessive investment, is truly a formidable challenge. In our company we are experimenting with ways to meet this challenge and have established two distinct but clearly related programs.

The first of these is to change the design, development and manufacturing planning process from a series of traditional, well defined, sequential steps to a simultaneous, iterative, increasingly integrated activity. To achieve this, we have enlarged the traditional Product R&D groups by adding representitives of a number of non-traditional disciplines.

So far the results of this initiative have been exciting. It appears we are going to be able to improve the effectiveness with which we use our resources very substantially and produce better products at the same time.

The Product R&D departments in our company, once somewhat isolated and deeply involved with invention and product innovations, and with little or no responsibility for the successful production and marketing of the product, are now a part of the business team. As we struggle to reintegrate the diverse elements and activities which make up the totality of manufacturing, we see an increasing acknowledgment of a collective responsibility for success. This is encouraging.

Reorganization and reorientation by themselves are not going to be enough to insure competitive survival however. Ability to identify and apply rapidly developing computer-based technology will be essential to manufacturing success in the future. It is here we have established our second initiative.

I might add here, parenthetically, that it is in the area of identifying and applying computer-based technology, that we seek input from, and collaboration with, research facilities like the

AMRF. In years gone by, we directed very little R&D effort to the production process itself. When we did, it was usually to solve a specific material processing problem which was affecting quality or restricting production. We did no research which had as its objective the optimization of all manufacturing resources. We are now recognizing the importance of such research and are directing increasing amounts of R&D to this purpose. It is in this area we need and use the kind of hi-tech that represents state-of-the-art in computer-based systems and controls, and in computer graphics, robotics and expert systems.

The most recent advances in manufacturing R&D, which in large measure are Japanese, clearly indicate that there is a tremendous potential for eliminating people and compressing time at each step of the total manufacturing process. Design terminals supported by advanced computer-based systems are shortening design time and increasing design productivity. Material transformation is being accomplished...with drastically reduced human support. We are approaching the point at which expert systems will begin to make design and processing decisions under increasingly complex conditions.

We think it is realistic to believe that within the next 10 to 15 years we will be able to produce the same output in factories one-half to one-third the size we have today with less than one-half as many total people--which is to say, at much less cost.

We also believe that waste from design errors, from communication glitches, from improper processing, from defective material or human error can be reduced drastically, further improving competitiveness.

To do this we need to know and understand much more than we do today about manufacturing and how and why it works. This will require well conceived, well-funded, and high quality research--and a lot of it.

Again, the work being performed here at NBS is of tremendous importance to industry. We need to find ways to leverage this resource efficiently. In addition, the area of standardization needs the leadership role of NBS in all areas of computer-controlled operations.

What I just tried to provide is a brief description of what my company is trying to do by approaching the whole area of technology and engineering in a non-traditional way. Perhaps I may be permitted now to sketch in a few areas where I believe AMRF work should focus in order to benefit industries.

First, we in John Deere believe that on-board diagnostic work is of extreme importance. Sensors which detect the wear of the tool, and initiate adjustment or replacement before failure, is one example. Second, work on systems integration needs to envision a task as difficult as possible. Aggression pursuit of MAP at a demonstration site like the AMRF is essential.

Third, the area of features development should receive more input from people with manufacturing experience in addition to receiving such input from mathematicians and computer scientists. A process planning project would serve this purpose.

Fourth, the excellent work of the NBS and other fine institutions in the field of knowledge or learning needs to be transferred more speedily to industry. We face complex problems in the scheduling of a manufacturing cell, as an example. The assignment of resources to meet the downstream demand and the management of the cell are critical.

I have stated these points in hope they may suffice to stimulate discussion at the actual *Workshop* sessions.

As I said at the beginning of my remarks, I wanted today to highlight some possible strategic choices to bring solutions to the competitive problems facing industries--my own and others. My intent was to point out that the increased use of automation or technology renewal or computer integrated manufacturing, call it what you will, offers the best hope, and maybe the only real hope for American companies in troubled industries.

I do not wish to imply, however, that the increased use of automation is a panacea. It isn't. It has for example, little to do with the tax, trade, regulatory, and educational policies of this country--or with attitudes of workers toward work, managers toward long and short-term goals, the citizenry at large toward savings and consumption. All of these are among the things that bear on a company's competitiveness in the global arena. But there isn't much individual companies can do about them. Cost, however, is an element of the competitiveness equation companies can do something about, It is absolutely vital that we do so. The ingenuity of the engineering profession is being challenged to help bring this about.

It is my hope that an opportunity like this *Workshop* will be used by the various disciplines represented here to develop a strategy to make it possible to take the research results from AMRF to industry in a timely manner. At the same time, it is my hope that industry will focus on the implementation and commercialization of new technological breakthroughs to bring this country into a more competitive position in the global marketplace.

I strongly feel that top management in industry must be made to better understand the significance of the work at NBS. The ongoing research at NBS must be supported with enthusiasm by industry, and top managers must put the proper priority on the subject within their own companies.

Finally, it is my sincere hope that working together, exchanging information, and sharing research results become a priority among industry, government, and academia.

Thank you.

## AMRF Research Advisory Workshop

## Panel on Artificial Intelligence, Automated Generation and Validation of Control Data

### Panel Members

Marvin Denicoff (Co-Chairman), Thinking Machines

Howard Bloom (Co-Chairman), National Bureau of Standards

Ted Hopp (Technical Advisor), National Bureau of Standards

Tien-Chien Chang, Purdue University

Charles Dyer, University of Wisconsin-Madison

Bruce Gras, Symbolics

Robert Kessler, Bendix Kansas City

Steve LeClair, AFWAL/MLTC

Petros Papas, Westinghouse

John Roach, Virginia Polytechnic Institute & State U.

### Synopsis of Discussion

As an introduction to the structure of the panel discussion, the panel was briefed by Co-Chairman Dr. Marvin Denicoff. Dr. Denicoff reviewed the technologies of artificial intelligence (AI) with special emphasis on the application potential in factory automation, and particularly in the AMRF.

The following manufacturing applications were proposed as areas for AI technology: (1) process planning, (2) CAD directed programming, (3) machine intelligence, (4) production planning and scheduling, (5) process control, (6) CAD/CAM, (7) parts on demand, (8) expert systems, (9) autonomous vehicles, and (10) integration of the total process.

Dr. Denicoff identified five AI techniques as possibly appropriate for factory automation. They were: (1) knowledge representation and acquisition, (2) machine reasoning (including language understanding and expert systems), (3) learning, (4) adaption, and (5) smart sensors such as vision, touch, and acoustics.

The panel was charged with developing a research agenda for the future by considering the following seven questions:

1. What criteria are appropriate for choosing research topics?
2. What should be the assignment of roles for NBS, industry, and universities, once the proper problems have been chosen?
3. How should the research be funded?
4. What is the state-of-the-art in AI as applied to manufacturing?
5. How should NBS interact with other groups such as the AI community and related disciplines?
6. Who is performing advanced research and where is it being done?
7. As the most visible AI technology today, what is the significance of expert systems to AI in manufacturing?

In conclusion, Dr. Denicoff discussed the assets of NBS in its role as a national research laboratory with its focus on the development of measurement techniques and standards. In terms of assets, he pointed out that NBS has the AMRF, a facility with an environment where manufacturing problems can be readily addressed. It has an outstanding staff with expertise across many relevant disciplines such as AI, scientific computations, sensors, manufacturing, and materials and is conveniently located in the Washington metropolitan area. Based on its assets and the goals of NBS, the AMRF is ideally suited to conduct research and development in selected AI areas of automated manufacturing.

Using the AMRF as a focal point, NBS has a proper role to play in the development of standards (where standards are appropriate) and can serve as a coordinator of related AI activities among both university and industrial institutions. Training and the transfer of AI technology can be accomplished through the Research Associate program.

## Recommendation Areas

Using Dr. Denicoff's original charge as a guide, the panel concluded that there are five AMRF missions that would be appropriate for the AI category. Panel members stressed that basic research is a vital NBS activity which provides the technology base that will make the five missions possible to perform.

### *A. Missions*

The missions in priority order are: (1) integration/interfacing, (2) standards, (3) technology transfer, (4) benchmarks, and (5) education/training. Details of each mission follow along with projects suggested to carry out the mission.

1. *Integration/Interfacing:* This was considered the most important mission because of the expressed need to interface the variety of AI tools, equipment, knowledge bases, and

applications. The eight AI projects in this category are:

a) Intelligent computer networks,

b) Generic AI engines,

c) Goal-driven descriptions,

d) Cooperative exchange of knowledge,

e) Integration of symbolic and numeric (or algorithmic) knowledge,

f) Integration of standard simulation techniques with AI,

g) Representation issues, and

h) Intersystem integration (tools, computers, etc.).

2. *Standards:* The most pressing need in this mission is a common approach to representing the different kinds of manufacturing data. This mission has five major projects:

a) Database translator for manufacturing,

b) Types of knowledge representations,

c) Descriptions of rule semantics,

d) Rule definition and validation process, and

e) Software quality.

3. *Technology Transfer:* Since NBS is a public institution, it can make information and technology available without any proprietary concerns. Technology transfer has been an important element of NBS for fifty years but the panel felt that there has not been a sufficient effort to promote this activity in the AI arena. This mission has eight major projects:

a) Visibility in the AI community,

b) Publications, user group, communication network for exchanging ideas,

c) Funding,

d) Metrics (i.e., the value of the transfer),

e) Internships and research associates,

f) Demonstrations - preferrably available on tape,

g) Simulation graphics to show systems (perhaps available as electronic mail), and

h) Identification of appropriate clients for the technology.

4. *Benchmarks:* There is some hesitation in industry to use AI in factory control without some means of determining that decisions can be made correctly and in a timely manner. Benchmarking will help to establish a means for determining if a specific AI application

meets the given functional specification. This mission has four major projects:

a) Automatic generation of protocol testing software,

b) Test suites for circulation,

c) Establishment of metrics, and

d) Provision of a facility for testing AI systems.

5. *Education/Training:* As with mission 3, NBS as a public institution can make information available without any proprietary concerns. The panel's comments were directed mostly toward the preparation of training materials. This mission has five major projects:

a) Tutorials,

b) Computer aided training,

c) Audio tapes,

d) Short courses, and

e) Video tapes.

*B. Basic Research*

Since the panel felt that NBS could not carry out its five missions without a sound foundation of basic research, it discussed current basic AI research under the following six project categories: (1) feature representation, (2) knowledge acquisition, (3) reasoning, (4) sensory perception, (5) learning and adaption, and (6) automated program generation. The panel detailed points for consideration in each project area.

The panel was presented with a description of current AMRF projects that are presently using AI techniques or are potential candidates for AI applications. The projects fall into four major categories: (1) process planning, (2) production planning and scheduling, (3) machine intelligence, and (4) CAD directed efforts. Topics within each category were addressed and the panel was told of future plans for each area.

The panel concluded that the present efforts of the NBS staff in the area of AI and on projects that are suitable candidates for AI applications are a good foundation for future research.

## AMRF Research Advisory Workshop

## Panel on Data Management

**Panel Members**

Neal Laurance (Co-Chairman), Ford Motor Company
Mark Skall (Co-Chairman), National Bureau of Standards
Mary Mitchell (Technical Advisor), National Bureau of Standards
Ed Barkmeyer, National Bureau of Standards
Chin Chung, GM Research Labs
Jim Foley, George Washington University
Cita Furlani, National Bureau of Standards
Joan Milloy, Control Data
Rex Nelson, IBM
Gerald Schumaker, USAF, AFWAL/MLTC
Neal Snodgrass, D. Appleton Company (DACOM)
Stanley Su, University of Florida
Joan Tyler, National Bureau of Standards

**Synopsis of Discussion**

Before beginning its discussion, the panel heard presentations by four of its members. Subjects of the presentations were:

1. The activities of the NBS Integrated Systems Group given by Ed Barkmeyer,
2. The need to define good research problems to be addressed by the AMRF given by Dr. Su,
3. The need for development of standard methods of process validation given by Dr. Foley, and
4. The needs for distributed data bases given by Dr. Chung.

A general discussion of the content and structure of the panel report followed the presentations. Panel members agreed on two guidelines for their considerations and recommendations. They were (1) identify unique AMRF requirements, and (2) focus on high pay-off areas for industry, especially small industry.

To limit the scope of the considerations, panel members agreed to:

1. Keep the time scale of recommendation to 5 years,
2. Remember that the fundamental missions of the AMRF are metrology and the development of standard interfaces,
3. Keep in mind those things which can be expected to appear from commercial developers, and
4. Focus on developments which will not be undertaken by private industry.

The panel used a brainstorming approach to collect ideas. The merits of the various suggestions were discussed and measured against the constraints developed by the group. Through this process, the panel arrived at its set of recommendations.

### Recommendation Areas

The panel recommended that NBS do the following in the area of data management:

1. Develop a model which contains structural properties, constraints, operational characteristics of manufacturing data and interfaces to manufacturing functions in order to capture industrial sector requirements.

   This recommendation recognizes the fact that ordinary data base models, whether network, hierarchical or relational, are not sufficient to handle the complex interrelationships present in manufacturing data. A data model which can formally represent and maintain these properties is needed to address this area, and the AMRF is well positioned to lead in this research area.

2. Continue current efforts to integrate shop and facility levels.

   The current prototype implementation encompasses only the machining cell; this recommendation concerns extending the data base integration to the higher levels of the factory hierarchy.

3. Investigate extending the model to other industries, e.g., the electronics industry and continuous process industries.

   While it may be appropriate for the major parts of the AMRF to focus on machining operations, to be successful the data model must be more general, i.e., it must be capable of supporting a variety of application processes.

4. Expand into assembly in the domains of mechanical and electronic technology.

   This recommendation concerns the AMRF as a whole, not just the data management activity. Assembly is seen as an integral part of any manufacturing activity.

5. Participate in voluntary standards committee activities aimed at data base interchange and manufacturing communications to insure that unique manufacturing characteristics and requirements are supported.

   This recommendation recognizes the fact that the data and experience gained from the AMRF represent a unique resource which is essential for the voluntary standard activities now underway in this area.

6. Take the lead in providing systems for conformance testing of data base interchange standards for manufacturing (online, if technically feasible).

   A key element to the data management problem faced by computer integrated manufacturing environments is that of data base interchange between the heterogeneous mix of data bases involved in the typical shop. The AMRF is in a unique position to lead the development of interchange techniques and standards, and the logical extension is to include the conformance testing for proposed solutions to this problem.

7. Examine appropriate roles in alternative forms of technology transfer such as:

   a) Financial justification models,

   b) Short courses for executives,

   c) Developing interactions with business schools, and

   d) Demonstrations off-site.

   This recommendation includes two separate but related ideas; the role of the AMRF in technology transfer and the need for improved methods of financial justification of advanced technology. The first idea recognizes the fact that the AMRF is a unique facility in our country and to achieve its long range goal of improving the productivity of American industry, it must address the problem of technology transfer. While the panel found the program of industry affiliates a good approach to the problem, it thought that the AMRF should explore other avenues to move its technology to practical applications. The second idea is in response to the fact that often advanced technology is limited in application by the requirement to meet return on investment objectives. This recommendation encourages the AMRF to establish working arrangements with business schools to develop more advanced financial justification models which take into account the improved quality and productivity inherent in fully computer integrated manufacturing.

8. Play an active role in developing, integrating, testing, and demonstrating the technology (both tools and techniques) required to effectively manage shared data in a heterogeneous hardware and software environment.

   It was the opinion of the panel that, while significant developments in this technology exist in various public and private laboratories, it is still in an embryonic state. While the preceeding recommendations have focused on the representations, requirements, and services from the data management activity, this recommendation concerns the tools of this activity. It acknowledges that the development of heterogeneous distributed data base technology is a key element in future CIM environments, and the AMRF represents a unique facility for testing implementations of such technology. Because of this unique opportunity, the AMRF bears a responsibility to test the suitability of proposed heterogeneous distributed data base management facilities, and by extension, to develop them.

# AMRF Research Advisory Workshop

## Panel on Machine Tools, CMM's, and Manufacturing Processes

### Panel Members

Richard Kegg (Co-Chairman), Cincinnati Milacron

Robert Hocken (Co-Chairman), National Bureau of Standards

Tyler Estler (Technical Advisor), National Bureau of Standards

Anderson Ashburn, American Machinist

Anthony Bratkovich, NMTBA

James Bryan, Lawrence Livermore Labs

Daniel DeBra, Stanford University

George Dieter, University of Maryland

Jack Hicks, DEA

Richard Johnstone, Kearney and Trecker

David McMurtry, Renishaw

Donald Plymale, BDM

Roger Utz, Texas Instruments

### Synopsis of Discussion

The panel unanimously endorsed the continuation of the AMRF project. Its discussion was centered on four main areas which particularly impact its field of expertise. They were (1) technology transfer, (2) standards, (3) frustration with the accounting field, and (4) government attitude toward joint ventures. Details of the discussion of each area were as follows:

1. *Technology transfer:* Panel members were concerned about the effectiveness of technology transfer from the AMRF to private industry. When compared to methods used by foreign governments, the U.S. methods seem lacking. However, each method that the committee suggested to improve on what is presently being done met with some objection in terms of government rules or policy. Nevertheless, the panel strongly suggests that NBS find more direct and effective technology transfer mechanisms.
2. *Standards:* Panel members recognize NBS as one of the leading worldwide centers in machine tool accuracy. Panel members urged that this technology be pushed in terms of standards, with research done to increase the capability of machines and improve knowledge on inaccuracy induced by environmental or thermal changes. The group

expressed the worldwide industrial frustration with the proliferation and incompatibility between modules of manufacturing support software. Panel members asked NBS to play a leadership role in the rationalization of this problem.

3. *Frustration with the accounting field:* Panel members expressed considerable frustration with the accounting field and the way it misuses financial numbers to cause incorrect manufacturing decisions. The panel pointed out that if overhead costs are distributed in such a way that an hour of machining time costs as much as an hour of drill press time, then the drill press is clearly overpriced and the machining center, a bargain. These incorrect costs will lead to incorrect distribution of workload on the two machines. The panel saw a clear need for accounting procedures and justification approaches that will drive manufacturing management decisions in the proper direction. In addition, help is clearly needed in the area of financial justification of new manufacturing technology.
4. *Government attitude toward joint ventures:* The panel felt that the government needs to remove barriers or perceptions of risk to encourage U.S. companies to join together, even if competitors, in projects which will improve this country's position against overseas competition. It felt that although much has been written about the change in government attitude toward these ventures, industry is still not convinced that they will be allowed.

The panel did not make any recommendations for action in the last two areas but felt that the problems in these areas were too important to omit.

One more area addressed by the panel was the problem of keeping up to date on new developments in manufacturing technology without being swamped by information.

## Recommendation Areas

The panel made the following recommendations for the post-1986 effort:

1. We urge NBS to contract with U.S. companies when new designs and innovations are needed rather than do the work itself. We realize that this must be done within NBS policy, project objectives, and schedules.
2. We recommend increased effort toward technology transfer and suggest meetings at least every six months with more interactive round-table-like sessions.
3. We endorse the Research Associates Program and encourage its expansion. We ask NBS to recognize that this is not convenient for many companies, especially small ones, and urge that NBS explore solutions to this problem.
4. We encourage the development of machine tool accuracy standards and suggest starting with machining centers. We support research work toward upgrading machine tool accuracy.

5. We believe that thermal sources of inaccuracy are so important that they need to receive specific research attention.
6. We request a strong push for data communication standards between software packages including the definition of boundaries of functional modules.
7. We recommend that NBS keep current the process of top-down planning and bottom-up implementation so that research staff inexperienced in manufacturing cannot overlook the practical problems at ''the bottom''.

## AMRF Research Advisory Workshop

## Panel on Robotics & Intelligent Machines

**Panel Members**


Roger Nagel (Co-Chairman), Lehigh University

James S. Albus (Co-Chairman), National Bureau of Standards

Harry G. McCain (Technical Advisor), National Bureau of Standards

Frank P. Caiati, General Motors

Richard B. Curtin, Southwest Research Institute

John Evans, Transitions Research

Alfred I. Hollander, Sacramento Army Depot

Frode Maaseidvaag, Ford Motor Company

Walter Vogel, Deere & Company

Richard A. Volz, University of Michigan

William Wells, Bradley University


**Synopsis of Discussion**

The panel agreed that the primary goals of the AMRF are the development of manufacturing automation technology and the discipline and structure to integrate it and make it work. Within this framework, panel members singled out three major areas where they would like to see the AMRF assume leadership roles. These areas are (1) interface standards development, (2) metrology, and (3) technology transfer.

Further decomposition of the areas produced five major topics which the panel discussed in detail within the context of robotics and robotics related issues in the AMRF. These topics were: (1) road map and objectives, (2) project selection criteria, (3) accomplishments and areas of expertise, (4) leadership opportunities, and (5) technology transfer mechanisms. The panel produced recommendations in each topic area.

**Recommendation Areas**

*A. Road Map and Objectives*

The panel concluded that, just as the first phase of the AMRF has followed a project plan developed by its founders, a plan is needed for the future. It recommended that this plan include specific milestones which drive toward well defined objectives. The plan should be made available to the manufacturing and research communities; however, no specific mechanism for doing this was suggested. Plans and objectives developed should include the following specific areas of research and development:

1. *Logical System Architectures:* The word "logical" is used to differentiate these architecture investigations from those dealing with hardware architectures. These logical architectures are intended to provide a functional, structured partitioning of intelligent robot and sensor systems. The development of these "logical" architectures will lead to robot and sensor system interfaces which can be standardized.
2. *Robot Performance Evaluation:* Standard robot performance evaluation parameters and measurement techniques should be developed to facilitate comparison and specification of commercial or experimental robots systems.

*B. Project Selection Criteria*

A set of general criteria for project selection was formulated which would support the recommended plans and objectives listed earlier. These criteria are:

1. Impact on interface standards,
2. Impact on metrology (robot performance evaluation),
3. Generic methodology,
4. Transferability,
5. Appropriateness for NBS vs. industry, other government agencies, universities,
6. Level of commercial development,
7. Whether the project is presently in place,
8. Time scale (proper mix of long- and short-term projects),
9. Subjective evaluation of importance,
10. Benefits to NBS, other government agencies, industry, academia.

*C. Accomplishments and Areas of Expertise*

The panel recommended that NBS provide a focused set of achievements for review and possible transfer to industry, academia, and other government agencies. The panel gave a very positive assessment of the current capabilities of the Robot Systems Division and recommended that its personnel maintain or develop expertise in the following areas:

1. Methodologies for robot performance evaluation,
2. Robot programming methodology,
3. Sensor systems,
4. Robot system architecture,
5. Robot manipulators,
6. Robot applications.

*D. Leadership Opportunities*

The panel identified several very specific areas where it felt that the AMRF had a unique opportunity to take a leadership role. It recommended that:

1. NBS should try to play a leadership role on the MAP committee in the work on the interface between MAP and robotics. MAP does not truly address tightly coupled communication below the cell level. This is an important part of what is being developed in the AMRF, and the direction that robotics and intelligent machines are going. The AMRF should try to fill this void in MAP as well as develop alternate solutions for low level communications that are faster than MAP.
2. NBS should take a leadership role in robot languages, especially as they interface to sensors and world models. To develop complex real-time control systems, a "systems implementation language" is required and an environment must be established.
3. NBS should lead an effort to provide standard methodologies for calibration and performance measurement of robot systems. Very little formal work has been done in this area to date, and NBS is uniquely qualified to undertake it.
4. The AMRF should take a leadership role in the standardization of both data and mechanical interfaces between major system elements. This would make multi- vendor configurations of complex robotic systems possible. In addition, the AMRF should focus on a standards effort for interchangeable end-effectors.
5. NBS should use its expertise to define and develop comprehensive robot system simulation capabilities. These could include sensors and dynamic and kinematic models as well as other physical phenomena as required. This effort should be done in cooperation with the commercial world rather than in competition with it.
6. The AMRF should provide a forum for industry interchange in the area of robotic system development and applications.

**Technology Transfer Mechanisms**

To be totally useful, the technology developed at the AMRF must be transferred to the manufacturing industry. The following mechanisms were recommended by the panel to implement this transfer:

1. Research Associates,
2. AMRF Research Associate User Group,
3. Standards,
4. Procurement specifications,
5. Performance measurement techniques,
6. Publications including papers, bibliography, and newsletters,
7. Video tape lectures,
8. On line network for communications among users of the technology and for access to a database of information on automated manufacturing,
9. Industry visits and test runs,
10. Technical briefings, workshops, symposiums,
11. Commercialization.

## AMRF Research Advisory Workshop

## Panel on Sensors and Unit Process Operations

### Panel Members

David Godfrey (Co-Chairman), ACME Cleveland
Donald Blomquist (Co-Chairman), National Bureau of Standards
Daniel Flynn (Technical Advisor), National Bureau of Standards
Duane Bruley, California Polytechnic State University
David Dornfeld, University of California at Berkeley
Gerald Freeman, Caterpillar Tractor
Ronald Gasser, Litton
James Kent, University of Detroit
Edwin Kolb, Hardinge Brothers
Herbert Sullivan, J. I. Case

### Synopsis of Discussion

Panel discussion was based on the understanding that when the first phase of the AMRF is completed in 1986, there will be relatively few sensors on-line. Those that are anticipated include tool dimension, chip formation (acoustic emission), limit switches, over-travel switches, and position encoders. Sensors will be used off-line, particularly at the Inspection Workstation, to measure surface finish and dimensions.

The panel concluded that there are numerous areas of opportunity for NBS to carry out needed research on the use of sensors in automated manufacturing. Panel members concurred that two major areas for sensor use within an automated manufacturing facility are (1) to inspect the product being manufactured, and (2) to predict the failure of a machine, component, or process. Within these two areas, three categories of research needs were identified. They are:

1. Sensor development and application,
2. Signal conditioning and processing, and
3. Interfaces of sensors, controllers, and actuators.

The need for interfaces (3) was identified as a generic problem that is important for a wide variety of applications of sensors. The panel discussed the other two categories and developed weighted recommendations in each area.

Transferring the results of NBS research to practical use in industry was another major subject which the panel covered. It concluded that a combination of transfer mechanisms was best and made recommendations for those.

A discussion of unit process operations, both those presently in place and those planned for the future, concluded the panel's agenda.

## Recommendation Areas

### *A. Research Areas*

Using the first two of the three categories of research needs and a rating of high, medium, or low, the panel classified the opportunities for future sensor research in the two major areas as shown in the accompanying table.

Motivations for further research in the use of sensors for inspection of a product are the elimination of non-value added operations such as off-line, after-the-fact inspection and the elimination of scrap and rework. Motivations for further research in the failure prediction area include facilitation of untended operation and increased use of machines.

The panel noted that in defining the research need, it is important to identify the real issue. For example, is the issue that of not having the proper sensor or is it one of analyzing a sensor signal to sort out what the problem is that causes that signal? The panel felt that there is a general need to develop sensors that (1) are more robust and can survive coolant, collisions, and a generally hostile environment and (2) have the capability of self-diagnosis.

As well as identifying specific research areas for recommendation, the panel discussed the criteria it felt NBS should use to narrow down the possible topics and select those where AMRF researchers can make the best contributions. The panel's selection criteria represent not only a screen to test future subjects in the sensors area but also other AMRF technologies as well. Criteria were defined recognizing that the identification of ideas for new programs will be an on-going process. The panel noted that any winnowing process should be done in the context of the post-1986 objectives which it also outlined for purposes of discussion.

Table 1. Opportunities for Sensor Research

| Areas of Use | Priority | Application | Sensor Development and Application | Signal Conditioning and Processing |
|---|---|---|---|---|
| Inspection | High | Dimensions & Geometry | X | X |
| | | Surface Finish | X | X |
| | Medium | Flaw Detection | X | X |
| | Low | Hardness | X | X |
| Failure Prediction | High | Tool Wear | X | X |
| | | Chip Condition | X | X |
| | | Broken Tools | X | X |
| | | Sensor Problems | -- | X |
| | | Bearings | -- | X |
| | Medium | Gears | -- | X |
| | | Lubrication | X | X |
| | | Electrical Problems | -- | X |
| | | Actuator Problems | X | X |
| | Low | Mechanical Interference | X | X |
| | | Coolant Status | -- | X |

*B. Project Selection Criteria*

Projects selected should meet at least one of the following criteria. They should be:

1. Complementary to the goals of U.S. industry - the results of NBS research should be transferable to production and should help U.S. industry compete in world markets.
2. Measurement related - since measurement is the main charter and the main strength of NBS.
3. Too high risk or high cost for any one company to address.
4. Standards or standards related - another natural area for NBS to address.
5. Supported by the unique expertise at NBS - for specific projects, NBS may have a unique combination of mission, facilities, and expertise to carry out the work.

*C. Post-1986 Objectives*

1. Minimize non-value added components and operations such as the use of coordinate measuring machines for after-the-fact inspection.
2. (a) Model the dynamics of what is actually happening (both in the process and the system) and (b) analyze that model to develop optimal control strategies that make the most effective use of available sensor information.
3. (a) Develop practical, effective sensor interfaces and (b) promote interface standards so that sensor outputs can be used effectively for process control and failure prediction.
4. Extend the 1986 AMRF system to (a) increase untended run time, (b) enhance performance, and (c) gain generic knowledge from analysis of problem areas.

*D. Technology Transfer Mechanisms*

The panel identified mechanisms for technology transfer and listed them under the following categories:

1. Financial incentive - Either pay industry to take the technology from the AMRF or let industry buy the technology, and hence, be committed to using it. Either of these programs could involve academia as well. Another approach is to try to leverage other programs that already support technology development (for instance, DoD or DoE programs) by having those programs pay for transfer of NBS-developed technology to industries that can put it into practice.
2. People commitments - Build on the already successful Research Associate program by encouraging ''reverse sabbaticals'' where NBS sends personnel to work in industry to put their research findings into production operations. Once again, academia could consider this kind of commitment with assistant and associate professors.
3. General communications - Expand communications by putting out a short newsletter. NBS should continue producing publications, hosting seminars and workshops, and taking an active part in professional meetings.

*E. Unit Process Operations*

Since the panel concluded that there are no obvious processes missing from the AMRF that prevent NBS from addressing the major issues of flexible manufacturing, it recommended that:

1. NBS assess the current product capabilities of the AMRF together with the emerging product mix for the discrete parts industry. For instance, NBS is currently addressing metal

removal - perhaps it should address material removal since many products are no longer made from metal using drill presses and milling machines. These new processes may generate new applications for existing sensors or create needs for new types of sensors.

2. The panel recommended that the addition of any new unit processes to the AMRF should be considered against any unique system capabilities or sensor requirements that would enable research efforts not possible with current processes. It further recommended that NBS consider the core technologies available at the AMRF, the capabilities being developed, and the transportability of those technologies to other emerging processes.

## AMRF Research Advisory Workshop

## Panel on Systems Integration

### Panel Members

Gordon VanderBrug (Co-Chairman), Automatix
John Heafner (Co-Chairman), National Bureau of Standards
Albert Jones (Technical Advisor), National Bureau of Standards
Pat Amaranth, GM Tech Center
Richard Brown, BDM
Mark Cooper, California Polytechnic State University
Ronald Garrett, Litton
Raymond George, U.S. Department of Energy
Fred Michel, U.S. Army Material Command
Nicholas Odrey, Lehigh University
Richard Perry, NASA
Paul Reynolds, University of Virginia
Craig Skevington, Rensselaer Polytechnic Institute
Jerome Smith, Industrial Technology Institute
Donald Weinert, National Society of Professional Engineers
Tom Willis, Intel
Richard Wysk, Pennsylvania State University

### Synopsis of Discussion

The panel adopted the approach that systems integration provides the link among computer aided engineering, computer aided design, computer aided manufacturing, and computer aided quality. It is the "glue" that makes a collection of disparate entities function as a system. Panel members agreed that the principles of systems integration must be incorporated into the design philosophy of every component from the very beginning (if not, there will be no system).

While the AMRF provides a solid technology base, more research is required in many areas related to system integration.

Discussion was divided into six topic areas. They were (1) technology transfer issues, (2) factory model architecture, (3) network communications, (4) real-time control, (5) integration of CAD and CAM, and (6) software engineering.

The panel recognized that there are ongoing AMRF efforts in some of the topic areas which will extend beyond 1986. Attempts were made to determine what the status of those efforts would be at the end of 1986, but this was not always possible. Therefore, although it was the intention of the panel to recommend relevant research for the post-1986 time frame, this may not always have happened. However, the panel did produce recommendations in each of the topic areas.

**Recommendation Areas**

*A. Technology Transfer Issues*

The discussion on technology transfer centered on the problems which contribute to the current lack of competitiveness in the U.S. and research topics which might lead to solutions to those problems. The problems were divided into three categories: (1) management, (2) engineering, and (3) manufacturing.

The panel felt that the basis for the problems in each area was:

1. *Management:* Management has a tendency to demand short-term paybacks on investments, is reluctant to incorporate new automation technologies, and has a poor understanding of the changing manufacturing process.
2. *Engineering:* Design engineers are not held accountable for producing practical manufacturing designs. Process engineers do not give enough thought prior to producing test and inspection plans.
3. *Manufacturing:* Systems engineering principles which could improve the entire process are not used.

Research projects suggested to help solve these problems were:

1. Perform a thorough cost/benefit analysis of automation for both vendors and users.
2. Develop methods for predicting the best candidates for automation, its effects on job design and organizational structure, and the best strategies for phased implementation.
3. Measure the value of flexibility, along with potential improvements in quality using automated manufacturing systems.
4. Facilitate the transfer of technology through user groups, workshops, publications, more university interaction, and the Research Associates program. In addition, panel members suggested that AMRF researchers actively pursue new avenues of technology transfer.

*B. Factory Model Architecture*

The panel was in general agreement that (1) factories tend to operate in a hierarchical manner, (2) the NBS five-layer model is a valid approach, and (3) NBS should continue the development of that model.

In this topic area, the panel recommended the following areas for further research:

1. Do a definitive analysis of the individual controller development efforts within the AMRF and put forth a statement regarding these experiences in the context of a generic controller. (The panel was informed that NBS is developing a single, data-driven modular architecture which can be used at every level.)
2. Concentrate on the relationship between the logical model (which is static) and the physical model, its implementation (which is dynamic), and the research areas associated with it. The panel noted that the physical translation of the logical model into a real factory will have an important impact on the solution to many problems - initialization, restart/recovery, and dynamic reconfiguration among others. Recent developments in networks make this research on the physical model possible now. It was noted that the emulator will still be necessary to address some of the problems.
3. Obtain and provide the information needed for each level of the hierarchy. For successful implementation of the model, detailed information on the quantity, contents, formats, and timing requirements for all data is essential.

*C. Network Communications*

The panel discussed MAP, Open Systems Interconnection (OSI), and the role of NBS in the development of protocol definitions, implementation specifications and test methods for communication networks. An area for further investigation is to determine the applicability of communications, computer standards, and technologies at all levels of models.

Recommendations for further research in this area included:

1. Develop methods to assess the impact of timing requirements and "virtual cells" on the network design.
2. Investigate the applicability of communications standards and technologies at all levels in the hierarchy.
3. Use the AMRF as a test facility for MAP. (Both 2 and 3 were specifics of ways that NBS could carry out the panel's general recommendation to become more involved in standards activities.)
4. Develop and experiment with an engineering economic model for translating from the logical model to the physical model of a factory. Further research in this area should be

especially useful because the cost/performance ratios for the communications technologies that will be used to implement factory control will evolve over time.

*D. Real-Time Control*

The panel discussed the following four topics under this heading: (1) error recovery, (2) planning, (3) software implementation techniques, and (4) safety.

Suggestions for further research in each area were:

1. *Error recovery:* Define and investigate data, control, and physical errors. Initiate work to classify errors, determine where in the hierarchy they will be addressed, and develop general methodologies for strategies for prevention and recovery.
2. *Planning:* With respect to the factory model, define the appropriate time horizon and exact nature of the planning and scheduling that should be performed at each level. Determine the impact that decisions at one level have on other resolutions. Develop contingency plans for conflict resolution. Investigate the impact of task decomposition, fixture planning, and on line Manufacturing Resource Planning (MRP) on these functions. Make sure that generic controllers have the flexibility to perform the necessary optimization chores.
3. *Software implementation techniques:* Continue the effort to separate "data from control" in the development of data-driven controllers. Conduct an evaluation of the state-table approach to (a) compare it with other approaches such as interrupts and procedures, (b) determine which functions are best handled using this technique, and (c) determine which levels are best suited for this approach.
4. *Safety:* Address research areas related to safety.

*E. Integrating CAD and CAM*

The panel felt that a great void exists between computer aided design (CAD) and computer aided manufacturing (CAM). They asked NBS to play a role in filling that void in two research areas:

1. *Tolerances:* NBS should investigate consistency checking, process association, stack-up, and communication.
2. *CAD Output:* NBS should conduct research to define the next generation output for CAD systems since current output (the engineering drawing) is partly responsible for difficulties experienced in developing process plans.

*F. Software Engineering*

The panel noted that the special capabilities required of AMRF software control systems (modularity, portability and dynamic reconfiguration) have a significant impact on the design of these systems. The issues of initialization, synchronization, shutdown, restart, and error recovery are compounded by these requirements.

The panel's recommendations for further research in this area are:

1. Develop and experiment with additional techniques for at least a validation (possibly using the emulator) and preferrably, a verification (using a formal mathematical proof) of all AMRF software. These would demonstrate that the software is correct and performs its intended function, free from synchronization errors and potential deadlocks.
2. Consider the use of other languages in implementing these systems.

## AMRF Research Advisory Workshop

## Attendees

## October 22-24, 1985

Pat Amaranth, GM Tech Center

Anderson Ashburn, American Machinist

Anthony Bratkovich, NMTBA

Richard Brown, BDM Corporation

Duane Bruley, California Polytechnic State University

James Bryan, Lawrence Livermore Laboratory

F. Caiati, General Motors

Tien-Chien Chang, Purdue University

Chin-Wan Chung, GM Research Labs

Mark Cooper, California Polytechnic State University

Richard Curtin, Southwest Research Institute

Daniel DeBra, Stanford University

Marvin Denicoff, Thinking Machines

George Dieter, University of Maryland

David Dornfeld, University of California

Charles Dyer, University of Wisconsin - Madison

John Evans, Transitions Research Corporation

James Foley, George Washington University

Gerald Freeman, Caterpillar Tractor Company

Ronald Garrett, Litton

Ronald Gasser, Litton

Raymond George, U.S. Dept. of Energy

David Godfrey, ACME Cleveland

Bruce Gras, Symbolics, Inc.

J. Hicks, Digital Electronic Automation, Inc.

Al Hollander, Sacramento Army Depo

Richard Johnstone, Kearney & Trecker Corporation

Richard Kegg, Cincinnati Milacron

James Kent, University of Detroit
Robert Kessler, Bendix Kansas City
Edwin Kolb, Hardinge Brothers, Inc.
Neal Laurance, Ford Motor Company
Steve LeClair, AFWAL/MLTC
Frode Maaseidvaag, Ford Motor Company
David McMurtry, Renishaw Plc.
Fred Michel, U.S. Army Material Command
Gordon Millar, Deere and Company (retired)
Joan Milloy, Control Data Corporation
Roger Nagel, Lehigh University
Rex Nelson, IBM
Nicholas Odrey, Lehigh University
Petros Papas, Westinghouse Electric Corporation
Richard Perry, NASA
Donald Plymale, BDM Corporation
Paul Reynolds, University of Virginia
John Roach, Virginia Polytechnic Inst.
Gerald Shumaker, AFWAL/MLTC
Craig Skevington, Rensselaer Polytechnic Institute
Jerome Smith, Industrial Technology Institute
Neil Snodgrass, D. Appleton
Stanley Su, University of Florida
Herbert Sullivan, JI Case
Roger Utz, Texas Instruments
Gordon VanderBrug, Automatix
Herbert Voelcker, National Science Foundation
Walter Vogel, Deere and Company
Richard Volz, University of Michigan
Donald Weinert, National Society of Professional Engineers
William Wells, Bradley University
Tom Willis, Intel Corporation
Richard Wysk, Pennsylvania State University

# APPENDIX

AGENDA
AMRF RESEARCH ADVISORY WORKSHOP
OCTOBER 22-24, 1985

Tuesday, October 22

8:30 - 9:00 Registration - Lecture Rm. A., Admin. Bldg.

9:00 - 10:45 Plenary Session - Lecture Rm. A., Admin. Bldg.
Call to Order, Introduction of Platform Participants
Introduction of Dr. Lyons -- Phil Nanzetta
AMRF Project Manager
Opening Remarks -- John Lyons, Director
National Engineering Laboratory, NBS
Introduction of Workshop Chairman Dr. Gordon Millar
Opening Remarks -- Gordon Millar, Vice President,
Deere & Company (retired)
Introduction of Dr. Simpson
History of the AMRF -- John Simpson, Director
Center for Manufacturing Engineering, NBS
Showing of New AMRF Film

10:45 - 11:00 Coffee Break

11:00 - 12:30 Plenary Session (cont.)
Introduction of Keynote Speaker Walter Vogel
Keynote Speech: Industrial Automation and International Competitiveness
-- Walter Vogel, Vice President,
Deere & Company
Charge to the Workshop -- Dr. Millar
Conclusion of Plenary Session -- Dr. Simpson

12:30 - 1:30 Lunch - NBS West Square Cafeteria

1:30 - 2:00 General Session - Lecture Rm. A., Admin. Bldg.
Introduction of Panel Chairman

2:00 - 5:30 Panel Sessions
Data Management - Shops Conf. Rm. (Rm. 126), Bldg. 304
Robotics & Intelligent Machines - NEL Conf. Rm., (B-111), Bldg. 225

Sensors/Unit Process Operations - Dining Rm. A, Admin. Bldg.
Artificial Intelligence - CME Conf. Rm. (A-346), Bldg. 220
Machine Tools, CMM, & Processes - Rm. A-340, Bldg. 220
Systems Integration - CEEE Conf. Rm., (B-365), Bldg. 220

6:30 - 9:00 Banquet -- Quality Inn
6:30 - 7:30 Reception
7:30 - 9:00 Dinner

Wednesday, October 23

8:30 - 8:45 Coffee & Danish Available - Lecture Rm. A, Admin. Bldg.

8:45 - 12:30 Panel Sessions - Same Location as yesterday

12:30 - 1:30 Lunch - NBS West Square Cafeteria

1:30 - 5:30 Panel Sessions

Evening

Workshop attendees on their own equipped with dining suggestions, reservations, maps, etc.

Thursday, October 24

8:00 - 9:00 Buffet Breakfast - Quality Inn

9:00 - 9:30 Break for Room Set Up

9:30 - 11:30 General Session - Quality Inn
Final Presentation of Panel Discussions

11:30 - 12:00 Closing Thoughts: Where From Here -- Gordon Millar

12:00 Adjourn

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October 22-24, 1985

5. AUTHOR(S)

Philip Nanzetta, Joan Wellington

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National Bureau of Standards
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Gaithersburg, MD 20899

10. SUPPLEMENTARY NOTES

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Representatives of 60 organizations active in manufacturing research and production met, at NBS's invitation, for a three-day workshop to advise the managers of the NBS Automated Manufacturing Research Facility on the future research and technology transfer targets of highest value to industry. The workshop, held October 22-24, 1985 produced a series of recommendations with reports from six panels,

-- Panel on Artificial Intelligence, Automated Generation and Validation of Control Data
-- Panel on Data Management
-- Panel on Machine Tools, CMMs, and Manufacturing Processes
-- Panel on Robotics and Intelligent Machines
-- Panel on Sensors and Unit Process Operations
-- Panel on Systems Integration

This is the complete report of the workshop.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

automated manufacturing; technology transfer; robotics; sensors; machine tools; control data; validation;

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