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A Report to the National Bureau of Standards

Manufacturing Studies Board
Commission on Engineering and Technical Systems
National Research Council

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PREFACE

The Automated Manufacturing Research Facility (AMRF) of the National Bureau of Standards is used to conduct research on the technology standards required for a fully automated metalworking machine shop. While the research developments at the AMRF have received a great deal of attention from large corporations, relatively few small machine shops have shown interest. In an effort to understand better how AMRF technology could be transferred to small machine shops, the Bureau requested that the National Research Council, through its Manufacturing Studies Board, assemble a group of small machine shop owners to visit the AMRF, hear briefings on the technology being developed there, and offer their reactions regarding the relevance of AMRF technology to their commercial operations.

In response to this request, a panel of the Manufacturing Studies Board, composed of Robert B. Kurtz, Barbara A. Burns, and Anderson Ashburn, identified a small group of machine shop owners who agreed to visit the AMRF. The meeting was held in Gaithersburg, Maryland, on October 10-11, 1984. In addition to the technical briefings presented by the Bureau, the meeting included several question and answer sessions with AMRF personnel and a roundtable session to discuss the varying views of the machine shop owners. This report documents the results of that meeting.

Staff Officer Thomas Mahoney was primarily responsible for the management of the project and the writing of the report. George Kuper, Executive Director of the Manufacturing Studies Board, contributed much to the substance of process of the project.

INTRODUCTION

The Automated Manufacturing Research Facility (AMRF) of the National Bureau of Standards (NBS) is used by engineers and scientists to conduct research on the technology, control, accuracy, and communication standards required for a fully automated metalworking machine shop. The AMRF combines a hierarchical control system and a variety of machining centers, robots, and sensors from several different vendors. Equipment used on the AMRF shop floor includes a White Sundstrand Series 20 Omnimill, a computer numerical control (CNC) horizontal spindle machining center; a Hardinge Superslant CNC Turning Center; a Monarch VCM 75 CNC Vertical Spindle Machining Center; a Bendix Horizontal Arm CNC Coordinate Measuring Machine; and several robots from Cincinnati Milacron, Bendix, Unimation, and American Robot. It should be noted that all this equipment is made in America. These machine tools and robots, along with other apparatus developed by the NBS, are combined into five work stations to simulate the operations of a small job shop or a manufacturing cell in a large factory.

Because the AMRF is strictly a research facility, it is not operated under production constraints and much of the technology developed at the AMRF has not been used in a production context. Some of the sensors and accuracy enhancement software for machine tool controllers developed at the AMRF have been commercialized and are available to private machine shops.[1] However, the majority of the technology under development at the AMRF, such as vision systems, end affectors, the emulator, and the hierarchical control software, is unique, is not yet available from commercial vendors, and consequently, has not yet had an impact on the operations or productivity of commercial machine shops.

In an effort to understand better how AMRF technology could be transferred to small commercial machine shops, the NBS asked the Manufacturing Studies Board of the National Research Council to organize a meeting of small shop owners--specifically, owners of machine shops with fewer than 100 employees. The shop owners would visit the AMRF, hear briefings about the technology, and provide their reactions to the facility based on their experience in their own shops. In response to the Bureau's request, the Board identified a list of approximately 65 candidates, compiled from Board members' knowledge of specific shops and contacts with relevant trade

associations. From that list, only a group of ten small machine shop owners* (Appendix I) were both interested and able to attend the quarterly technical briefings on the AMRF on October 10-11, 1984. The typical responses of those people who declined the invitation were that they could not afford the time for the meeting, or they were skeptical of the value of government research in this area, or they did not expect to use or need automation technology in the foreseeable future. Those who accepted the invitation were also pressed for time, but were interested in the work being done at the AMRF and felt that it could have an impact on metalworking shops in general and their own businesses in particular. Most of these participating shop owners are members of the National Tooling and Machining Association (NTMA), the major trade association for the metalworking industry, representing some 3,600 shops.

The group of small shop owners, along with representatives of the Manufacturing Studies Board, attended the presentations arranged by the Bureau for their quarterly technical briefings. (A schedule of the presentations is attached as Appendix II.) These briefings are being held by the Bureau in response to growing demand from industry for information on the state of technology in automation. Of necessity, the briefings are structured to appeal to a broad audience with various levels of technical expertise. As the schedule illustrates, many of the presentations focused on control system architecture and software, but enough information was presented on the practical capabilities or potential of AMRF technology to satisfy the primary interest of the small shop owners.

Although the presentations were not ideal for the purposes of this project, the briefings provided the small shop owners with a good overview of the major research thrusts at the AMRF and gave them a basis for discussions on the relevance of this research to their operations. These discussions were held in the evenings of October 10 and 11, and on October 12. At these sessions, the group was given an opportunity to express their ideas on the relevance of specific aspects of AMRF technology to their operations and on techniques for transferring relevant information and technology to small commercial machine shops.

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* Of the 65 shop owners contacted, 16 invitees agreed to participate but 6 cancelled at the last minute. The term "owner" is used throughout the report, but the group included three chief operating engineers.

USE OF TECHNOLOGY IN SMALL MACHINE SHOPS

The shop owners who participated in this project operate businesses with a variety of specialties and sizes. The smallest shop has eight employees on the shop floor and only one CNC machine tool. Another shop has 50 workers and 16 CNC machine tools; tolerance for its punching and milling operations are in the range of plus-or-minus 2/1000 of an inch. Another shop has 37 employees on the shop floor, 26 CNC machining centers, 4 DNC machining centers, and uses computer-assisted programming. This shop produces parts to a tolerance of plus-or-minus 3-4/10,000. The largest participating shop, in terms of employees, has 62 floor workers, 8 CNC machining centers, and does precision work to plus-or-minus 1/1000 of an inch. These examples illustrate the diversity and the varying levels of sophistication that were represented in this small group of shop owners. Although such a small group can be only marginally representative of the approximately 7,300[2] independent machine shops in the country, the group was diverse enough to have a broad range of concerns and opinions.

In many ways, these participants represent the most progressive, informed element among small machine shops, and therefore may be more receptive to the advanced technology being developed at the AMRF than the small shop community as a whole. They have experience with CNC; some have begun to experiment with computer-aided design (CAD); and others are using advanced computer systems such as the IBM System 3. However, it is important to note that this experience with computers and interest in new technology is not representative of the industry.

The NTMA has done a survey of its members concerning the use of computers in commercial machine shops.[3] Probably the most pertinent finding was that for machine shops with less than 30 employees, almost 75 percent had no computer in 1980 and no interest in acquiring one. For all companies in the survey, 58.6 percent had no computer and no acquisition interest. Conversely, these percentages do indicate that many shops are using computers, at least for accounting and scheduling purposes, but the smaller the shop, the less likely it is to use computers or to have plans to acquire one. Consequently, progress toward disseminating automation technology to small machine shops is likely to be long and difficult, and the process of disseminating information on the AMRF to small commercial machine shops must reflect this relatively low level of familiarity with computers.

Although some shop owners are more progressive than others in accepting new technology, market pressures can have a tremendous effect on a shop owner's interest in new technology. Machine shops tend to compete for orders based on price, accuracy, and delivery times. If new technology can increase accuracy, or increase reliability and repeatability, or reduce inspection times, a shop may be able both to bid for jobs that were previously beyond its capability and to cut delivery times; for several of the participating shop owners, a reduction in delivery times as small as 5 percent can make the difference between winning and losing a new order. These shop owners are willing to invest in technology that can provide these types of advantages if the investment is within their financial reach and the payback period is relatively short. Such new technology can make a shop more competitive, either to gain market share or to respond to challenges from other shops.

Even though competitive pressures can make new technology purchases a virtual necessity, small shop owners are very aware of costs. They will be willing to invest in new technology only if competitive pressures or specific new orders require it, and only if the improvements in parts scrappage, productivity, running times, and overall costs make the investment clearly worthwhile. Usually these calculations are roughly made by the owner himself. For example, the shop owners participating in this project were asked how much they would be willing to pay for Drill-Up, the NBS-developed drill breakage sensor which is now produced and marketed by Valaron Corporation. The owners calculated that, when a drill breaks, the shop loses about three hours of running time and the part being machined will probably be damaged. With time costs approximated at $40/hour, the shop loses $120 each time a drill breaks, plus the cost of the tool and the cost of the damaged part. Consequently, the value of Drill-Up to the shop and the price the owner is willing to pay for it depend on how much drill breakage the shop normally has and the value of the parts that are being scrapped, which, in turn, depend on the materials, equipment, and operating procedures of individual shops.

If it is clear that an investment will have a fairly rapid payback and improve the shop's productivity, the shop owners participating in this project did not appear hesitant to make new investments. These shop owners reported that, in the past two years, their investments in new equipment ranged from zero to $1.5 million, including tooling. Over half of this investment money purchased Japanese machines. These shop owners claim that, in general, Japanese machine tools are cheaper, more reliable, more accurate, and the service provided for set-up and maintenance is superior to that of American manufacturers. According to these shop owners, there are some excellent American-made machines, with higher accuracy and durability than their Japanese counterparts, but these advantages are not always sufficient to outweigh the much higher prices of the American machines.

Although some of the participating shop owners were initially skeptical about the relevance of the AMRF and the value of government research in general, they recognized the inability of small machine shops to conduct research on their own. Once having seen the

facility, these shop owners thought that much of the research was potentially important to small commercial machine shops, though they were more interested in specific devices developed at the AMRF than with the hierarchical control and other research aimed at a fully automated machine shop. The work being done in accuracy enhancement, sensors and feedback mechanisms, calibration, and automated inspection is of particular interest because it responds to specific problems confronting small shops, and because it promises rapid results in the short term.

However, the overwhelming majority of machine shops have fewer than 20 employees;[4] work in the areas of robotics, hierarchical control, and other sophisticated aspects of an untended, automated shop is less responsive to the immediate or foreseeable needs of these shops. The shop owners recognize the tangible benefits that automation technology can have on their operations, in terms of increased accuracy and reliability, faster deliveries, and lower costs, but they cannot afford it. Sophisticated computer systems are beyond their financial reach and, at least currently, unnecessary for their daily operations. This research could be helpful to companies in the business of selling work station packages that combine machine tools and robots, since they need hardware and software compatible capabilities to reduce programming costs and increase sales; however, robotics and hierarchical control technology does not seem to have broad appeal for typical small machine shops. They cannot afford it and do not have the expertise to use it, regardless of its potential benefits.

CURRENT PROBLEMS OF SMALL SHOPS

The aspects of the AMRF that were of particular interest to the small shop owners were those technologies, such as accuracy enhancement and automated inspection, that directly address the production problems of their shops. In general, these problems focus on three areas: performance, calibration, and inspection.

PERFORMANCE

The shop owners were very impressed with the Bureau's detailed knowledge of the performance of the machine tools used in the AMRF, which contrasts sharply with their own experience. The small shop faces problems with unknown performance that directly affect the shop's investment decisions and productivity. Decisions on machine tool purchases are based on comparisons of manufacturer-supplied performance data and specifications. Unfortunately, the conditions used by the manufacturer to determine these specifications are usually unknown to the shop owner. A machine tool will perform quite differently under load after several hours of operation than when it is first operated. Although the shop owner can assume that the manufacturer tests the machine under the most favorable conditions for that machine, those conditions are not usually specified. Because the conditions are not specified and not standardized among most manufacturers, comparisons of performance data are misleading and provide a poor basis for investment decisions. The problem is compounded when the new machine is installed because the equipment often does not perform according to the manufacturer's specifications. The shop owner is then faced with a machine that may not be as productive as expected, and the owner is forced to do error correction on virtually every new job.

In partial response to this problem, the NTMA is beginning a survey of its members to document the actual performance characteristics of machine tools used in their shops. The survey is designed to provide valuable information about reliability, accuracy, serviceability, and divergence from manufacturers' specifications. Although the data can only be approximate and it will take some time to accumulate a representative number of responses, the survey should

offer shop owners a more reliable basis for comparison for future machine tool purchases.

The results of this NTMA survey could have a substantial impact on the problem of unreliable performance data, but the shop owners participating in this project suggested ways that the Bureau could contribute to providing reliable performance data. The first suggestion was that the Bureau contribute to the NTMA survey by providing data on machine tools used in the AMRF, both before and after any accuracy enhancements have been added. The second suggestion was that the Bureau publish specifications for a wide variety of machine tools under standard operating conditions. These specifications would provide an authoritative, reliable guide for shop owners, both in making purchasing decisions and in evaluating a machine's performance on the shop floor.

Although these suggestions illustrate areas in which the small shop owners perceive a beneficial role for the Bureau, neither is practicable. As a federal government agency, the National Bureau of Standards cannot issue data on specific brands or manufacturers[5] and does not rate equipment. Even if such a program were legally possible, the process of testing hundreds of machine tools would be expensive, time consuming, and divert important resources from the research work being done at the AMRF.

The Bureau could, however, extend the work being done by the B-89 committee of the American Society for Testing Materials (ASTM). The B-89 committee has developed performance standards and test procedures for coordinate measuring machines, with much of the technical work conducted by the Bureau. Similarly, the Bureau could provide additional standard performance test procedures for a variety of machine tools. An intermediary organization would use the procedures and publish the performance data based on these tests. For example, the Bureau could make these standards available to the NTMA or some other intermediary organization, such as interested universities, which would use the testing procedures and publish the performance data for use by the small shops. (The Bureau already has a similar program with the International Association of Chiefs of Police (IACP). The Bureau determines minimum performance requirements and methods of testing for the ballistic resistance of police body armor; these standards are published by the National Institute of Law Enforcement and Criminal Justice,[6] and used by the IACP to determine the performance of specific equipment.[7]) However, having published testing procedures, the Bureau could in no way conduct the tests or force anyone else to conduct them, publish the data, or have responsibility for any data that are published.

CALIBRATION

Calibration of equipment is a major problem for small shop owners, particularly those doing high precision, close tolerance work. The shops themselves cannot afford expensive calibration devices--a five-axis laser interferometer can cost $25,000--and they usually do

not have personnel who are qualified to use these sophisticated measuring devices or to adjust the machines. The participating shop owners explained that machine tool manufacturers and distributors often provide calibration services, but they tend to be expensive and may not be sufficiently accurate. One shop owner described his experience with a manufacturer's calibration service. The service cost $100/hour and lasted four days, during which time the machine was unproductive; when finished, the technicians only told the owner how far off the machine was. Other owners told similar stories of costly, lengthy calibration services employing technicians who seemed so unsteady with the measuring equipment that the owners had no confidence in their findings. Other delivery mechanisms exist for calibration services, including commercial services and some state governments. However, either these services are not widely available or they are not viewed as good enough because all the participating shop owners cited calibration as a problem.

It is not clear what role the NBS could or should play in the area of equipment calibration for small shops. The shop owners suggested that the Bureau provide a calibration service, since the accuracy enhancing controllers developed by the Bureau are virtually useless without a properly calibrated machine; such a service is clearly beyond the Bureau's resources or purview. An alternative role for the Bureau would be to make the calibration algorithms used in the AMRF available to small shops and to calibration services. Several shop owners expressed an interest in obtaining these algorithms, but providing them will have only a small impact on the overall problem of expensive, low quality calibration service.

INSPECTION

Because of the practical manifestations of uncertain performance and unreliable calibration, parts inspection consumes more time and resources than it would under optimal conditions. Several shop owners described their backlog of parts needing inspection and one owner cited inspection as a major drag on shop productivity and delivery times. Despite sophisticated inspection equipment used in some of these shops--one owner felt that his inspection equipment is superior to what he saw used in parts of the Bureau's metrology laboratory--the time and personnel devoted to parts inspection are considered to be a significant hindrance to productivity.

Although the automated inspection work station of the AMRF is not yet completed, the shop owners were excited by the prospect of automated inspection. The current inspection problem is so great and the potential advantages of automated inspection are so clear that the shop owners were very interested in the rapid commercial availability of this technology. In this area, the impact of the technology developed by the Bureau could be enormous, assuming the technology is affordable and commercially available to small shops.

GENERAL REACTIONS TO THE AMRF

The reaction of the shop owners to the prospect of automated inspection is illustrative of their response to the AMRF: if the technology responds to a need and is clearly and quickly cost effective, then the shop owners were interested in making use of the technology. For much of the technology, the response varied according to the type of operation each owner had, while for other aspects of the AMRF, the group's reaction was unenthusiastic. Although specific developments excited the shop owners, the AMRF as a whole was largely considered to be too elaborate, too advanced, and fairly inappropriate for their needs, particularly since these shop owners do not foresee being able to afford the technology or the skills necessary to take advantage of it. Several of these shop owners seemed more impressed with automation developments in commercial shops of which they had heard; for instance, they described a shop that purportedly has been automated using an Apple IIe computer. Although they were unable to provide further details, they found this accomplishment far more impressive, based on their concerns about limited resources, and far easier to understand than the Bureau's fairly complex developments in hierarchical control. These reactions reflect the general lack of knowledge among small shop owners about computers and the skills necessary to adapt computers to control a machine shop.

The specific developments of the AMRF that produced the most interest were the accuracy enhancing controllers, tool sensors, and, in the longer term, plug-compatible machines to form manufacturing cells. In the area of accuracy enhancement, the entire group showed an interest in either built-in or retrofit enhancement controllers, but agreed that the enhancements will not work unless machines can be properly calibrated. Even then, decisions to purchase accuracy enhancing controllers would depend on the business outlook, immediate needs, and competitors' performance, as well as the cost and reliability of the controllers.

In the area of tool sensors, interest depended on the shop's operation. Several shop owners expressed an interest in purchasing tool chatter sensors; these sensors could prevent much part scrappage and would help the shop optimize feeds and speeds. However, in the case of the drill breakage sensor, Drill-Up, one shop owner expressed his reservations about its use in practice. He was able to obtain the

plans for the device several months ago and could have built it, but decided to change his drill bits after every 200 holes instead of using the breakage sensor. The key reason for his decision was that Drill-Up relieved the machine operator from the need to pay close attention to the drilling operation; he felt that if the operator remains alert and the bits are changed regularly, Drill-Up is not that valuable. However, he drills 2000 holes at a time. A shop with less extensive drilling requirements might find the breakage sensor to be very beneficial.

Plug-compatible machines for manufacturing cells stimulated interest among those shop owners who are interested in buying and using such technology, and others who are trying to sell advanced manufacturing technology. Manufacturing cells are available commercially, but they are expensive because they are not plug compatible. If a shop wants to change a piece of equipment in a cell, the entire software package must be rewritten. One participating shop owner, who is trying to enter the business of selling manufacturing cells, has identified a market for a turnkey generic manufacturing cell with three machine tools and a robot. Other shop owners agreed that such a generic cell would be valuable in many small shops, but withheld full endorsement of such a cell until they could see it in a production context.

In fact, this aspect of their visit to the AMRF prompted many reservations and hesitations about the technology. The shop owners would like to see the technology at the AMRF actually producing parts at a profit and to a schedule. Their own decisions to invest in new technology and to purchase particular machine tools are based on how much the equipment will improve their productive capabilities. This bias was so prevalent that, at times, the shop owners lost sight of the fact that the AMRF is a research facility.

Clearly, the group of small shop owners would have been better able to judge the capabilities of the AMRF if they could have seen the technology in a productive mode. Much of the information presented to them during their visit was too technical and beyond their knowledge and experience. They were fairly unfamiliar with the AMRF before their visit, other than knowing about its existence, and remain largely unaware of what aspects of the AMRF are already commercially available and what standards have already been produced by the Bureau. For example, only one participant knew that Drill-Up was available; no one knew about the standards for coordinate measuring machines; and they were not aware that the Initial Graphics Exchange Specification (IGES) was available on demand from commercial CAD equipment vendors. Given this lack of awareness about the availability of technology, and the focused interest displayed by the participants on accuracy enhancement, tool sensors, calibration algorithms, and automated inspection technology, the Bureau's first consideration in a technology transfer program should be an information campaign targeted at these small shop interests.

INFORMATION DISSEMINATION

As part of the workshop, the participating small shop owners were asked to recommend mechanisms that the Bureau could use to improve the transfer of AMRF technology to small shops. The shop owners suggested that the Bureau consider producing material specifically targeted at small shops, presenting technological information in layman's terms and stressing the potential impact of AMRF technology on the production needs of small shops. They recommended that the Bureau work with the National Tooling and Machining Association to disseminate this material; the Society of Manufacturing Engineers (SME) might also be an appropriate intermediary organization. Several members of the NTMA, including the president-elect and staff representatives, have reiterated their interest in cooperating with the Bureau; the NTMA has worked with the Bureau in the past and is willing to assist the Bureau in disseminating information about the AMRF at both the national and local chapter levels.

The small shop owners thought that material designed for use at NTMA local chapter meetings may be the most effective mechanism for addressing this audience. The chapter meetings would offer the Bureau a chance to create positive impressions about the Bureau, the AMRF, and the potential productive benefits of the technology. The shop owners suggested that the Bureau expand the number of videotapes on the AMRF, producing a series of short videotapes, approximately 20 minutes in length, designed to be played at NTMA chapter meetings. These tapes should deal with the practical aspects of AMRF technology instead of the technical details. For example, a videotape that demonstrates the effectiveness of a tool breakage sensor or that illustrates the capabilities of the accuracy enhancements developed at the AMRF would effectively portray the usefulness of the technology. These videotapes could encourage shop owners to purchase these devices, creating demand for equipment vendors to commercialize the technology and advertise its availability.

The impact of such a videotape series might be magnified by scheduling visits to NTMA meetings by Bureau personnel. To some extent, the visits could be coordinated with the videotape presentations to ensure that the audience was somewhat informed about the Bureau's activities. Scheduling of these oral presentations should probably be done in cooperation with NTMA representatives and staff.

The shop owners thought that such a program of videotapes and visiting speakers at NTMA chapter meetings would probably be the most effective mechanism for disseminating information to the target audience, but they agreed that other mechanisms should also be pursued. The Bureau should continue to publish articles in appropriate technical journals, trade magazines, and newsletters. Articles about the AMRF have appeared in such publications as Industrial Engineering and Design News.[8] The practice should be continued, with at least some of the articles specifically targeted at small shop owners. These should be in layman's terms and address such aspects of the technology as performance, costs, estimated payback, and commercial availability.

Another mechanism for transferring AMRF technology to commercial shops, suggested by the participating shop owners, is to provide devices and equipment to demonstrator shops. For example, a project under development in Rockford, Illinois is designed to be a permanent trade show and exhibition for a variety of capital goods, including machine tools. It will give small shop owners and engineers an opportunity to actually work with new machine tools and advanced equipment before they buy it. This project, along with other planned demonstrator shops, would offer hands-on exposure to computers and numerical control equipment to shop owners with no previous experience with such equipment, as well as exposure to more advanced computer-aided design and computer-aided manufacturing equipment, work station control, and automation technology to owners with CNC experience.

The Bureau need not participate directly in such ventures, but could make various devices available for incorporation into demonstrator shops by machine tool manufacturers. AMRF technology might also be made available to interested universities, through mechanisms such as the Thomas Alva Edison Partnership program in Ohio and the Ben Franklin Partnership program in Pennsylvania. Doing so would provide shop owners with familiarity with the technology, generate excitement about its capabilities, physically demonstrate the impact such technology can have on the shop floor, and help create market demand for the Bureau's technology. If a sufficient number of small shop owners had an opportunity to operate the equipment and to determine first hand the tangible time, accuracy, and cost benefits, word of mouth within the industry would multiply the demand. This exposure to AMRF technology would be more interactive than a booth at a trade show, and would provide the type of exposure that would appeal to the practical, production-oriented interests of small shop owners.

Despite these suggestions for disseminating information and making devices available in demonstrator shops, it should be recognized that these ideas are not new to the Bureau. The Bureau already has a fairly comprehensive program to disseminate information about the AMRF, using videotapes, journal articles, and speakers, and the Bureau has participated in past trade shows with little success. The Bureau has worked with the NTMA in the past; the Bureau's current videotapes have been made available to the NTMA, and articles about the Bureau's work have appeared in the NTMA newsletter, The NTMA Record.[9] However, these cooperative efforts do not seem to have been sufficient, judging from the participating shop owners' knowledge of the AMRF.

Although the Bureau has made efforts to disseminate information to the small shop community along the lines recommended by the shop owners, these efforts appear to have had little impact, for reasons that can only be speculated. Perhaps the articles and videotapes produced by the Bureau to date have been too broad or too technical to stimulate small shop interest, in which case a targeted effort may have more success. Perhaps the available information has not been pushed hard enough by the Bureau or by the NTMA, in which case redoubled efforts may prove beneficial. Or perhaps the interest of small shop owners in AMRF technology is limited to what is available commercially, so that the responsibility of promoting the technology should be on the vendors that have commercialized AMRF devices. Although all of these explanations are probably contributing factors, the primary explanation seems to be that small shop owners simply do not have time to read their trade publications so articles in these journals and magazines will never receive more than sporadic attention.

Because past attempts to inform small shops about the AMRF have been relatively unsuccessful, the appropriate information initiative by the Bureau at this point is not clear. The approach likely to achieve the greatest impact appears to be a focused campaign emphasizing specific devices and their commercial availability. Small shop owners are more likely to respond to presentations on technologies that can help their production in the near term than to general descriptions of the AMRF that may satisfy curiosity but not stimulate real interest. Focused information that addresses the pragmatic concerns of small shop owners should stimulate sufficient interest to ensure an audience and make such a redirection in the Bureau's information dissemination campaign worth pursuing. Since the Bureau has only limited control of the use of the articles and videotapes after they are provided to appropriate intermediaries, the success of such an information campaign cannot be guaranteed; however, such a focused, pertinent dissemination effort would ensure that appropriate information is at least available to small shop owners and it would complement progress in transferring AMRF technology through development of commercial products. When and if demonstrator shops are created, participation by the Bureau or by vendors marketing AMRF technology would reinforce the information campaign and improve the overall technology transfer effort.

CONCLUSIONS AND RECOMMENDATIONS

The reaction of the small machine shop representatives to the AMRF was qualified interest. In terms of the devices and sensors that can have a substantive impact on their shops' productivity, they recognize the potential of the technology but are fully aware of the problems that must first be overcome. Accuracy enhancements will be of little use until the performance of existing equipment is known with confidence and the process of calibrating machines is more accessible and reliable. The advantages of tool sensors were recognized, but will vary according to specific shop operations. Work in control theory and cell technology was appreciated, but the benefits were seen as long term and aimed more at large manufacturing operations than small shops. Automated inspection technology could have almost immediate benefits, but the AMRF inspection work station is not completed and commercial availability is undetermined. In all of these areas, these shop owners recognized the value of the research and appreciated the potential benefits that could accrue to them from it, but were skeptical that the many obstacles to full utilization of the technology could be overcome in the near term.

On the basis of these reactions, it is clear that the work being done at the AMRF could be of tremendous value to small machine shops, particularly the research in accuracy enhancement. Many small shops work to extremely close tolerances and the need for accurate machines is increasing. The tool sensors and accuracy enhancing machine tool controllers being developed at the AMRF can respond to this need, but only if the obstacles described by the participating shop owners can be overcome. Shop owners need to be able to evaluate the performance of their machines and to calibrate their machines for peak performance; they could then utilize the technology developed at the Bureau to achieve the maximum accuracy of their existing equipment at an affordable cost.

These conditions define the requirements for effective technology transfer of the AMRF equipment that is most useful to small machine shops. These shops need standard machine tool performance test procedures that they can operate themselves to evaluate the specific machine tools in their shops. Such procedures would allow the shop owners to evaluate the performance of their existing equipment, making it possible to retrofit AMRF-developed accuracy enhancing controllers

to overcome the revealed deficiencies in their machine tools. This combination of performance testing procedures and accuracy enhancements could possibly reduce the need for timely and expensive outside calibration services. As mentioned earlier, testing procedures could also be provided to the NTMA, universities, or other intermediaries for use in a separate testing laboratory that would provide valuable information to shop owners regarding new equipment purchases.

The benefits of such a standard performance test/accuracy enhancement package are clear, since only such a combination would help overcome the obstacles to technology transfer and respond to the needs of the small shop community for improved machine tool accuracy. However, as with the tool sensors and automated inspection technology that are also of interest to small shop owners, the best method for making such a package available to small shops is difficult to determine. The Bureau is unavoidably dependent on the equipment vendors that commercialize the technology. Since the accuracy enhancements and other devices would be of little value without the performance tests, they should probably be marketed together. The Bureau could develop the testing procedures and provide them to the vendors that commercialize AMRF technology, who could then market the devices and testing procedures as a package. An information campaign implemented by the Bureau along the lines described earlier, emphasizing the development and availability of such a package, combined with the marketing efforts of the vendors, should be sufficient to excite interest in the technology and raise awareness of its availability. Assuming this package is affordable to small shops, the AMRF technology should help overcome many of the accuracy, part scrappage, and inspection problems currently faced by these shops.

It is clear that the work being done at the AMRF has the potential to have a major impact on small shops. The shop owners who participated in this project recognized this potential and the benefits AMRF research can have for them, especially since they have no research capability of their own. Presenting the technology in a form that the shop owners can use, and providing the means to overcome the obstacles to using it that were perceived by the shop owners are crucial factors in successful technology transfer. The recommended package combining test procedures and the commercial devices that use AMRF technology would respond to these factors and is the only feasible way to reach the small shop community.

Based on the qualified interest exhibited by the participants in this project, it appears that a well-designed program addressing some of the small shop owners' concerns could have some benefits, but would have no guarantee of extensive success. Although limited activities to reach small shops are worthy of attention, the resources required to develop and implement an extensive technology transfer program for small shops would be extensive, particularly considering the time, personnel, and funds that would be necessary and the likely results. The Manufacturing Studies Board, therefore, recommends that the Bureau continue to focus its limited resources on the successful research being conducted at the AMRF and not divert its efforts to a technology transfer program focused directly on small shops that is unlikely to

be effective. Given the interest in the AMRF that has been demonstrated by a variety of major manufacturers, it is clear that the AMRF is responding well to the needs of a large part of American industry. The Bureau should continue to focus its resources on research that contributes to the advanced manufacturing technology knowledge base of American industry and rely on intermediaries, particularly larger firms, to help disseminate AMRF technology to small commercial machine shops. This mechanism, in which customers of small shops would exert market pressures on the shops to adopt new technology, seems to have the greatest potential for successful technology transfer.

NOTES

[1]For example, the Valaron Corporation has licensed the NBS patent for a drill breakage sensor and markets the device under the name Drill-Up. The GE 2000 machine tool controller, produced by the General Electric Company, incorporates accuracy enhancement software principles developed at the AMRF.

[2]Bureau of the Census. 1982 Census of Manufactures, Preliminary Report, Industry 3544. June 1984. Standard Industrial Classification (SIC) Code 3544, Special Dies, Tools, Jigs, and Fixtures, "includes establishments commonly known as contract tool and die shops, and primarily engaged in manufacturing, on a job or order basis, special tools and fixtures for use with machine tools, hammers, die casting machines, and presses." Despite the 7,270 establishments in SIC 3544, the NTMA estimates that there are an additional 5,000-6,000 job shops in the country, classified under several other SIC codes.

[3]Computer Usage and Acquisition Interest in the Tooling and Machining Industry - A Special NTMA Survey, completed September 1980 with 1,317 member companies participating.

[4]1982 Census of Manufacturers. Of the 7,270 establishments in SIC 3544, only 1,325 have 20 employees or more.

[5]The one exception to this restriction was that the Bureau is authorized to test the flammability of children's sleepwear and report the results by brand name.

[6]National Institute of Law Enforcement and Criminal Justice, Law Enforcement Assistance Administration, U.S. Department of Justice. The Ballistic Resistance of Police Body Armor. NILECJ-STD-0101.01. December 1978.

[7]International Association of Chiefs of Police. Equipment Technology Center Consumer Product Report, Police Body Armor. December 1978.

[8]For example, see Philip Nanzetta. "Update: NBS Research Facility Addresses Problems in Set-Ups for Small Batch Manufacturing," Industrial Engineering. June 1984. pp. 68-73 and "NBS Launches AMRF to Help Improve Productivity," Design News. January 23, 1984. pp. 13-14.

[9]Bill Ruxton. "Automation and the Job Shop." NTMA Record. January 1984. p. 14 and Bill Ruxton, "Another Look at the 'Factory of the Future.'" NTMA Record. May 1984. p. 2.

APPENDIX I

PARTICIPANTS AT THE MANUFACTURING STUDIES BOARD'S MEETING TO REVIEW THE AUTOMATED MANUFACTURING RESEARCH FACILITY OF THE NATIONAL BUREAU OF STANDARDS

Small Shop Representatives

Mr. D. E. Bennett, Jr.
Bennett Tool and Die Company
Nashville, Tennessee

Mr. Deryl Craig
California Jig Grinding
Pico Rivera, California

Mr. Bryce Jewett, Jr.
Bryce Jewett Machine
Manufacturing Company, Inc.
Richmond, Virginia

Mr. Tim Kelleher
Modern Metalsmiths, Inc.
Lorton, Virginia

Mrs. Annette Manning
L & L Machine, Inc.
Ludlow, Massachusetts

Mr. Ralph Palermo
Stamford Tool and Die Company
Stamford, Connecticut

Mr. Bruce Phelps
Fulton Tool Company, Inc.
Fulton, New York

Mr. Merrill Poynter
Molly Products Company, Inc.
Rockford, Illinois

Mr. Alan Reed
Reed Instrument Company
Houston, Texas

Mr. Fausto Pazmino
Wikstrom Machines, Inc.
East Elmhurst, New York

Manufacturing Studies Board Representatives

Dr. Barbara Burns
Manager, Applications and
Project Engineering
Robot Systems, Inc.
Norcross, Georgia

Mr. Robert Kurtz
Retired Senior Vice President
General Electric Company
Fairfield, Connecticut

APPENDIX II

SCHEDULE OF TECHNICAL BRIEFINGS*
WEDNESDAY, OCTOBER 10, 1984

1:30 p.m.	Overview of Center for Manufacturing	Dr. John A. Simpson Director, Center for Manufacturing Engineering
	Engineering's Automated Manufacturing Research Program	Dr. Dennis A. Swyt Deputy Director
2:00 p.m.	AMRF Film	
2:15 p.m.	Coffee with participants' feedback on interests, programs	Drs. Simpson, Swyt, Albus, and Hocken
2:30 p.m.	Industrial Systems Division (Control Hierarchy-Robotics)	Dr. James S. Albus, Chief Industrial Systems Div.
3:30 p.m.	Automated Production Technology Division (Machine Accuracy, Sensors, CAD/CAM, and IGES)	Dr. Robert J. Hocken Chief
4:30 p.m.	Departure	

THURSDAY, OCTOBER 11, 1984

8:30 a.m.	Welcome, Foundations of the AMRF	Dr. John A. Simpson
9:00 a.m.	AMRF as it is in October 1984	Dr. Philip N. Nanzetta Project Manager, AMRF
9:30 a.m.	Theory of Hierarchical Control	Dr. James S. Albus

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* The participants in this project comprised a small part of a much larger group attending these briefings.

10:00 a.m.	Real-Time Robot Control Systems	Dr. Donald Myers Real-Time Controls Systems Industrial Systems Div.
10:30 a.m.	Break	
10:45 a.m.	Robot Integration and Safety	Mr. Harry G. McCain Automation Sensors Group
11:15 a.m.	Sensory Interactive Robotics	Dr. Ernest W. Kent Sensory-Interactive Robotics Group
11:45 a.m.	Work Station Control Horizontal Work Station	Ms. Kathleen Strouse Manufacturing Systems Group
12:15 p.m.	Cell Control	Mr. Charles R. McLean Production Management Systems Group
1:00 p.m.	Lunch	
1:45 p.m.	Data Preparation: Process Planning	Mr. Charles R. McLean
	Smart Sensors for Automated Manufacturing	Mr. Donald S. Blomquist Sensor Systems Group
2:15 p.m.	Emulator	Ms. Cita Furlani Software Systems Group
	Robot Metrology	Mr. William Haight Robot Metrology Group
2:45 p.m.	Communications	Mr. Edward J. Barkmeyer Software Systems Group
	Accuracy Enhancement	Mr. James Shaver Machine Tool Metrology
3:15 p.m.	Break	
3:30 p.m.	Data Base	Ms. Mary J. Mitchell Software Systems Group
4:00 p.m.	Data Formats: IGES and Others	Dr. Glen M. Castore Manufacturing Systems Group
4:30 p.m.	Departure	