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ABSTRACT

This report reviews the role of technological factors in metalworking and the training required to adapt to new metalworking technologies. Focus is on whether firms that have adopted the new technologies have encountered obstacles in training and developing the skills of their work forces. The report is organized in three parts. Parts I and II draw upon several public and private surveys and studies plus telephone and written contacts with persons in industry, unions, trade and professional associations, and training institutions. Two recent innovations, programmable controllers and programmable hand calculators, are considered, along with the more familiar numerical control, in part I. Part I also briefly discusses powder metallurgy and "nontraditional" machining. Part II deals with training requirements and sources of training. It describes several programs in educational institutions outside the industry. The third part, four case studies in training in metalworking, considers different firms of varying size and technology. Two of the case studies deal with sources of, and needs for numerical control (NC) training. The other two describe training for powder metallurgy and electrochemical machining. Implications are drawn for productivity and the quality of working life in the metalworking industries. References and descriptions of federal government publications related to training and technology are included. (CT)

NEW TECHNOLOGIES AND TRAINING IN METALWORKING

Summer 1978

National Center for Productivity
and Quality of Working Life
Washington, D.C. 20036

The 94th Congress created the National Center for Productivity and Quality of Working Life on November 28, 1975, as an independent Federal agency. The Center's enabling legislation (P.L 94-136) establishes a national policy encouraging productivity growth consistent with needs of the economy, the natural environment and the needs, rights and best interests of management, the work force, and consumers. The Center's purpose is to stimulate national efforts to implement this policy.

The Center's small staff of productivity specialists supports the Board of Directors in pursuit of seven main objectives

- Document and recommend policies to satisfy the Nation's capital investment needs from a productivity standpoint
- Encourage labor-management cooperation to enhance productivity and the quality of working life
- Without compromising legislative intent identify and recommend changes in government regulation which will improve productivity
- Stimulate and support industry task forces formed to conduct programs for industrywide productivity improvement
- Develop and recommend more effective approaches to improving productivity in the public sector
- Improve the review coordination and integration of productivity enhancement efforts of other Federal agencies
- Develop a better understanding of the concept of productivity and encourage better techniques for measuring productivity changes

The Board of Directors may contain up to 27 members representing business, labor, the Federal Government, State and local governments, institutions of higher education and others from the private and public sectors. The directors determine the Center's role and activities through committees formed to deal with substantive issues defined in an October 1975 policy statement.

The Center is located in Washington, D.C. It seeks to identify the various points of view affecting productivity growth, determine which of these views can be reconciled to further productivity improvement and encourage within and among various groups cooperative efforts toward productivity growth.

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LIST OF ACRONYMS USED IN METALWORKING

CAD	Computer aided design
CAM	Computer aided manufacturing
CNC	Computer numerical control
DCS	Diagnostic Communication System
DNC	Direct numerical control
ECM	Electrochemical machining
MAC	Manual Adaptive Control
NC	Numerical control
PC	Programmable controller
P/M	Powder metal
VCC	Variable Cycle Controller

PREFACE

The General Accounting Office has targeted manufacturing technology--especially small-batch manufacture of parts--for examination by the National Center for Productivity and Quality of Working Life. Small-batch production involving mainly metal cutting and machining is economically critical because of (1) the metalworking sector's significance to other manufacturing industries; (2) the apparent lag in introducing numerically controlled machines and other appropriate technologies in many U.S. machine shops; and (3) the possibility of achieving impressive productivity gains through a large-scale shift to newer metalworking technologies.

This report reviews the role of technological factors in metalworking and the training required to adapt to new metalworking technologies. A basic question is whether firms that have adopted the new technologies have encountered substantial obstacles in training and developing the skills of their work forces.

The report is organized in three parts. Parts I and II deal with technology and training and draw upon several public and private surveys and studies, plus extensive telephone and written contacts with knowledgeable persons in industry, unions, trade and professional associations, and training institutions. Part III consists of four case studies of training in metalworking.

The Center acknowledges, with deep appreciation, the frank and thoughtful accounts of technological adjustment and training that were shared by corporate and union representatives. Thanks also are extended to officials at the General Accounting Office, Bureau of Labor Statistics, the National Science Foundation, several editors of technical journals, members of consulting organizations, and officials of various professional and trade associations, all of whom were extremely cooperative and provided useful data and insights.

The report was prepared by A. Harvey Belitsky, a consultant to the Center. Edgar Weinberg, Assistant Director for Policy at the Center, provided direction in its preparation.

SUMMARY

Two recent innovations--programmable controllers and programmable hand calculators--appear to meet the recommendation in a General Accounting Office report to develop metalwork technologies that will be "cost effective in the environment of small- and medium-batch plants." These innovations are considered, along with the more familiar numerical control, in Part I of this report.

Programmable controllers have long been associated with mass production. But they can also be used in small-batch production with stand-alone machines and as interfaces for numerical control, and they can dramatically reduce downtime.

The introduction of new control devices has reduced training requirements for controller operators and maintenance personnel because machine failures occur less frequently and the time needed to repair breakdowns is usually shorter than that for earlier models. Operators can "program" in their normal language after an average of only 3 days training. Because operators are actively involved with the controllers, job satisfaction appears to be high. The feasibility of in-house training on controllers is another attraction for some firms.

No major capital investment is needed to achieve the productivity increase that results from using programmable hand calculators. The calculators enhance the role of machine operators by making more use of their abilities and judgment. An engineer or even a college freshman or sophomore with a good mathematics background can prepare programs for storage on magnetic tape, enabling an operator to compute machining costs per part on a calculator and move toward an optimum cost level. Technical experts believe programs can be mass-produced for use in small machine shops. Widespread use of the calculators could yield substantial cost savings in machining.

Part I also briefly considers powder metallurgy and "nontraditional" machining--additional technologies that can be used in making metal parts. Brief consideration also is given to other innovations that may be the links between the machining of today and the even more advanced machining of tomorrow.

Part II deals with training requirements and sources of training and shows that skills present in the work force may affect the kind of technology that is adopted. Training to adapt to some of the newer (and even conventional) technologies has been lagging, even though the skills needed to operate such innovations as numerical control (NC) do not exceed the learning capabilities of the current work force and of new entrants into metalworking. Highly skilled technicians are needed for parts programing on advanced NC tools, and personnel with high maintenance skills are needed

to keep the costly and complicated equipment in working order. However, machine operators on all but the most advanced equipment make fewer decisions than do operators on traditional equipment.

Most training has been provided by the metalworking firms. Manufacturers' associations, machine-tool builders, and software firms that provide programing for machining have also provided some training. Educational institutions outside the industry are other sources of training. Part II describes some of these programs:

- Only about 15 percent of the metalworking firms surveyed by the Bureau of Labor Statistics provide structured training; the rest use only informal training. The metalworking industry prefers hands-on training on a firm's own equipment.

- The training provided by NC machine manufacturers takes 2 to 5 days and is considered an important aspect of marketing the machines.

- More than 25,000 people have taken a basic 1-day NC training course provided by John A. Moorhead Associates at various sites. An intensive 1-week course for NC coordinators, also provided by the Moorhead firm, is sponsored by the National Machine Tool Builders' Association.

- Manufacturing Data Systems Inc., the largest provider of time-shared NC-tape preparation systems, offers to train, in a 1-week course, any "good machinist" without programing experience.

- The Machinability Data Center has trained representatives from numerous companies and some government agencies in a 2-day seminar on practical machining principles for shop application.

- Training has also been furnished by several trade and professional associations. The Society of Manufacturing Engineers sponsors various conferences and teaching materials to keep members abreast of improvements in technology. The Numerical Control Society holds occasional conferences and seminars for its members. The Metal Powder Industries Federation also sponsors conferences and intensive 2- and 3-day seminars.

- A survey of NC technology instruction provided by postsecondary educational institutions revealed that insufficient instruction is given in "new technology, particularly in the area of computer-aided manufacturing." Also, practical application has generally been absent in colleges. Less than 10 percent of the personnel employed in NC received their training from educational institutions.

- Hennepin Technical Center, located in a suburb of Minneapolis, is unique, because it accommodates the technical requirements of several powder metallurgy firms in its own area and also of some firms in other States.

- Some private vocational schools offering NC-related training found that employers place new, inexperienced employees on their oldest machine tools; therefore, their training concentrates upon such machines. Other schools provide NC instruction because they have identified employers who seek graduates with such training.

The third and final part of this report considers different forms of training within four metalworking firms of varying size and technology. Two of the case studies deal mainly with sources of, and needs for, NC training. The other two cases describe training for powder metallurgy and electrochemical machining.

- Kearney & Trecker Corporation has pioneered in introducing NC machines and machining centers. The firm also manufactures a programmable cycle controller and equipment that minimizes maintenance (and therefore training) requirements. Training programs for purchasers of Kearney & Trecker machines are short but include responsibility for studying course materials sent out 1 month before the start of courses in programing or machine maintenance.

- The focus in this case study is on training needed by employees adapting to NC machines within a large metalworking firm classified mainly as a job-order shop. As for most technological changes at the firm, affected personnel were given considerable advance notice of the shift to NC, and workers did not resist its introduction. Employment and training changes were probably similar to those in other firms adopting NC. Employment did not change much: fewer machine operators and somewhat more maintenance personnel are needed and some employees have been shifted to the new occupation of programing. The adjustment of machine operators to NC was facilitated by using several tracing machines, or duplicators, in training. About one-third of the firm's electricians, including some with 20 to 30 years' experience with the firm, enrolled in and completed four electronics courses on NC equipment maintenance.

- A new technology may present a considerable challenge to a work force. Such was the case with Lehr Precision Tools, Inc., whose experience offers some lessons in the learning needed to enable employees to adjust to technical innovations. The president of Lehr and the firm's other engineers work "shoulder-to-shoulder" with their workers to provide training in challenging aspects of the job and to teach employees about the economic problems of producing parts by the electrochemical process.

- Merriman Inc., in the absence of outside capabilities to provide instruction in powder metals technology, has had to furnish much of its training internally. Because the set-up specialist is of central importance in manufacturing powder metal parts and must have considerable skill, labor and management have recognized standards for qualifying training in a 3-year apprenticeship.

PART I. CURRENT AND EMERGING TECHNOLOGIES IN METALWORKING

Mechanical material removal was used with man's first identifiable tool--the chipped flint knife. Now--2 million years later--new mechanical material removal processes are still emerging. [4]*

Machine tools, also called the "master tools of production," are used to manufacture a tremendous variety of parts and components for end products.

Machining is the largest industry in the manufacturing sector; it accounts for more than 40 percent of the labor-hours expended in manufacturing. Moreover, because machine tools and the parts they supply are basic to producing other durable goods, changes in the machine tool industry eventually affect virtually all other manufacturing. "Production shortages in [metalworking] can cause rippling effects in other sectors of the economy." [55]

A 10-year projection by the U.S. Department of Commerce stresses the need for modernizing machine tools to raise productivity and thus enable the U.S. metalworking sector to compete in international markets. [61] A General Accounting Office (GAO) survey of metalworking recommends that the productivity of the technology used in manufacturing should be made a "national priority." [10] According to the GAO survey, although highly productive metalworking technologies have been pioneered in the U.S., most of the newest technologies have been applied only by a comparatively few large American firms--those in high-technology or capital-intensive industries such as aerospace.

Metalworking industries consist of many small- and medium-size firms. Even the largest machine tool builders are not large by American standards. Among the users of machine tools, less than 25 percent of metalworking parts are manufactured by mass production. It is widely accepted that some three-quarters of all parts are manufactured in lots of less than 50 pieces. Nearly 90 percent of the firms currently represented by the National Tool, Die and Precision Machining Association have 45 or fewer employees. Nevertheless, the many small metalworking firms that produce only in small runs or batches account for more than one-third of the manufacturing portion of the gross national product.

Numerical Control

Numerical control (NC), developed largely under U.S. Air Force sponsorship in the 1950's, has turned out to be a much more productive manufacturing technology for the metalworking sector than the more widely used, traditional, manually operated machine tools.

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*Numbers in brackets refer to the numbered list at the end of this report.

All NC machines--including the basic NC machine tool, which is controlled by (or receives instructions from) punched tape or other media--introduce automatic control into metalworking. Although automatic control is usually associated with large-scale production runs, NC is suitable for small runs, because it significantly reduces set-up time compared to manually controlled machines and allows different parts to be machined merely by changing a tape and resetting the tools. Thus, the economic break-even point is reached at smaller lots than with conventional machines.

Conventional machine tools use only about one-third of available cutting time, but because NC allows high-speed tool positioning, some two-thirds of available cutting time can be used. Additional economies are achieved with NC machines equipped with automatic tool changers that hold different types of cutting tools. These machining centers, as they are called, improve productivity by minimizing set-up time at the machine and by enabling an operator to control more than one machine.

NC also produces parts with greater reliability and repeatability than do conventional methods. Most errors are eliminated, so time and materials are saved. NC is especially effective in those situations in which human error occurs most frequently: machining complex parts of high quality that require many precise operations with various tools. In fact, some complex parts can only be produced with NC. The economies resulting from NC can reduce unit labor costs by 25 to 80 percent. Human drudgery on repetitive jobs is also reduced by using NC machines rather than manual methods.

Improvements in NC.

Adaptive control, an important innovation in NC technology, can increase machine productivity. It offsets such factors as material and process variations and permits optimum cutting. The programer or operator formerly performed some of the functions now carried out by adaptive control.

Hardwired NC, with a special-purpose computer, has also been united with the general purpose computer, a combination many authorities consider to be as important as the introduction of the assembly line and interchangeable parts. This innovation has taken several forms. One is Computer Numerical Control (CNC), in which a minicomputer controls a single machine. Another is Direct Numerical Control (DNC), in which [a computer] normally controls several different machine tools so that more machine time is available for metal cutting than is the case with tape. Both CNC and DNC electronically store NC data and, consequently, tend not to need a tape reader to put the program for the part into the machine tool. Because less electronic hardware is involved in computerized systems, initial investment and maintenance costs are lower than for conventional systems.

NC is considered the beginning of an evolutionary process in manufacturing technology:

> [NC is the] primary and most prevalent function found in the overall concept whereby the complete preplanned and programmed design and production functions will be processed, stored, and finally executed with the aid of a computer. CAD (Computer Aided Design)

and CAM (Computer Aided Manufacturing) will be the eventual outcome, and NC is just one phase in the overall application of the computer in the manufacturing and marketing process. [21]

At a recent conference sponsored by the American Defense Preparedness Association and the Society of Manufacturing Engineers to review the Defense Department's manufacturing technology program, more than two-thirds of the participants identified CAM and CAD as the manufacturing technologies most likely to raise productivity during the next 10 years.

Utilization of NC.

Despite its advantages, NC is not widely used. The aircraft industry uses NC more than any other industries, but in 1973 less than 5 percent of the industry's machine tools were numerically controlled. CAM is used primarily by medium- and large-size concerns but most small firms have not adopted even the basic NC machines. Less than one-fifth of the firms responding to the 1975 GAO survey had one or more NC machine tools, and NC tools represented less than 1 percent of all the machine tools they used. The GAO also found that approximately half the firms surveyed did not use a computer in any way, and less than 25 percent had a computer on site. [10]

According to a recent American Machinist survey, only about 3 percent of the metalcutting machine tools in the nonelectrical machinery industry, which represents about one-third of metalworking, were numerically controlled. However, it is estimated that about one of every eight metalcutting tools installed during the past 3 years was NC. The impact of the NC machines on industry productivity is much greater than their number suggests, however, because they are much more productive than manually operated tools. [25]

The steady decrease in the size and price of computers is accelerating progress in NC technology, and much of the new NC capacity being installed is computerized. Microcomputers (also called microprocessors), for example, sometimes have their central processing unit on a single chip. Because of their low cost, microcomputers have been incorporated in a large share of computerized NC systems; they also have been applied to some very simple, low-cost machine controls involving manual data input. [25] Despite these technical advances, some experts consider the hardwired NC better for some applications than the computerized systems, which require operating programs or software. [25]

The GAO report, assessing the prospects for application of more advanced automated technology in the mid-1980's, concluded, "...the conditions, methods, and processes of metalworking...may not differ drastically from those found during [the GAO] mid-1970's survey." [10] Although the introduction of NC machines is likely to expand at a moderate, steady pace, many small firms feel intimidated by the new technology. These firms will probably continue to use manually controlled machine tools, at least until they overcome their apprehensions by learning what is involved in operating, maintaining, and repairing NC machinery. [65] One authority is convinced that NC can be successfully applied in companies employing as few as six persons, but he advises that NC should not be adopted without careful study and planning--fear of competition and a hunch that NC will succeed are not sufficient reasons to convert. [40]

Programmable Controllers

The GAO study called for developing "new methods" and refining "much existing technology...so that it will be cost effective in the environment of the small and medium batch plants." [10] Programmable controllers are among the innovations that deserve to be considered, though they may not be directly competitive with the more established NC. The programmable controller (PC), also called a programmable logic controller, is an improvement over previous hardwired control systems. PC is defined by the National Electrical Manufacturers Association as

> a digital electronic control apparatus using a programmable memory for the internal storage of instructions which implement specific functions such as logic, sequencing, timing, counting, and arithmetic to control through digital or analog input/output modules various types of machines or processes. [57, 58]

PCs vary considerably in sophistication. The simplest are sequence (or cycle) controllers with a stepping switch, which permits one step to be taken at a time. With a drum-type stepping switch, several steps can be taken at a time. Operators may "program" in their own language or that of a pegboard. Sequence is not a problem with modern solid-state controllers, which may be considered minicomputers. A "hidden digital computer-like device" relieves the user from having to learn how to program a general purpose computer.

Labor Factor in PC Development.

The modern-era PC, with its programmable logic, was introduced in 1969. Relays, which were costly because considerable labor was required for wiring, debugging, and maintenance, were replaced by first-generation PCs. Because PC failures occur less often and the time to repair a breakdown is usually shorter, firms using PCs realized savings by reducing downtime and by eliminating costly training for operators and maintenance personnel. Declining electronics costs and greater computer use later led to the acceptance of second-generation PCs. Some PCs have had two additional benefits: Operators remain actively involved in the machining process, and the level of job satisfaction is felt to be improved.

According to Professor Terry Taebel of the General Motors Institute, only minimal training is needed for operators to adapt to PCs. Minicomputers are programed at the factory to accept the graphical language formerly used on relay systems; unlike NC, the controller has only a few buttons. Engineers who have worked with a relay system can be trained in 1 day. Those without recent relay experience require about 3 days of training. According to 32 PC manufacturers, training ranges from 1 to 5 days, with 3 days the most common period. Training, in most cases, is held at the controller manufacturer's site. [51]

Major Types and Uses of PCs.

There are "two parallel trends...in the PC market: one [is] toward smart PCs to handle the increasingly complex demands of installations like transfer lines and materials-handling systems, and the other [is] toward PCs aimed at low-cost, stand-alone relay-panel replacement." [50] Controllers can be used for mass production, as well as for batch production with small, stand-alone machines. Programing for either is easy and flexible.

PCs are primarily used in automobile manufacturing, but they are also important in processing industries, and recently they have been used in energy management. PCs have been used in metalworking to manufacture some rather complex parts, but they are sometimes resisted on the grounds that one machine is as good as another as long as the machine makes parts. This view ignores the contribution that controllers can make to metalworking productivity. For example, downtime on traditional machines is high, and this is accepted as a natural condition. controllers, however, can reduce downtime by as much as 95 percent.

In some metalworking firms, PCs have been used as programmable machine interfaces for NC systems. In one machine tool application, "each tool in a synchronous metalcutting machine with 85 tool groups can be changed at different intervals and at different times. A PC keeps track of how close each tool was to required replacement based on number of parts made." [16]

One firm prefers to apply PCs to small machines by using a standard size controller for several machines, because PCs offer more features, greater reliability, and cost much less than a minicontroller for each machine. "We have put controllers on welders, die cast machines, punch presses, boring machines, batch processes, and other types of equipment." [31] A Detroit firm with more than 12 NC machines plans to introduce its first PC on a non-NC grinder.

Cincinnati Milacron, a major machine tool manufacturer, decided that allying a hardwired, solid-state controller with some conventional machines would have substantial advantages. Its first controllers--the Cincinnati Milacron Variable Cycle Controller (VCC)--were delivered in 1974. The VCC is identified generically as a memory logic controller. In contrast to the PCs, which are designed for longer runs, the VCC contains a memory that can be set up for any number of pieces requiring two or more axes of movement.

Among the benefits Cincinnati Milacron claims for the VCC is that it can bridge the gap between conventional and NC machining. Like NC, it automates a machine, but it does not upgrade a machine; as a result, none of the inherent flexibility of manual operation is lost. VCC provides manual machines with speed (reduced times for set-up and part cycle) and accuracy comparable to NC, but it costs less. VCC-produced parts are more consistent in quality than those produced by manual machining. VCC is effective in making parts that require from one to three machine tools, with movements done sequentially, and in making parts that are simple to medium in complexity. Although VCC is not adaptable to complex parts demanding considerable tool changes, slopes, circles, and arcs, some VCCs have been bought by aircraft makers for low-volume production of parts.

VCCs are used to make a variety of hydraulic control valve stems for earthmoving equipment manufactured by the Caterpillar Tractor Company. The VCCs have a capacity of 96 events, and they are used for small production batches. Productivity has increased, an operator can now tend two milling machines instead of one. A Caterpillar machine shop foreman reported that he is most impressed by the improvement in the quality of the parts produced as a result of the repetitive accuracy possible with the VCC. [56]

According to an engineer at Cincinnati Milacron, the VCC can be useful in overcoming the problem of finding skilled operators for milling machines. With the VCC, operators do not have to write any programs and can use their normal language. The VCC can be depended on to "remember," after the machine has been "taught" the operator's skill.

PC Costs.

PC prices have decreased sharply, largely because of the introduction of microprocessors. Because some simpler controllers cost $2,000 or even less, it is feasible for training institutions to offer instruction in PC technology. [2; 32]

PC sales have increased substantially in recent years and are still growing. According to some observers, PC sales could soon greatly exceed those of NC. Others believe that PCs are more likely to continue as an interface with NC rather than as stand-alone machines, except where complex cycles have to be performed over and again. The argument is that PCs are not cost effective for small-batch production, but that NC is, because it is constantly reprogrammable to make engineering changes. An engineer at Bridgeport Machines indicated that NC's flexibility in making changes motivated his company to adapt a PC to a computerized NC machine, rather than offer a PC by itself or with a conventional machine tool.

Programmable Hand Calculators

Hand calculators are another low-cost technology with potentially wide applicability to metalwork machining. Dr. Milton C. Shaw and colleagues at Arizona State University and Carnegie-Mellon University recently developed a process, using programmable hand calculators, called Manual Adaptive Control (MAC), a form of adaptive control in which the operator is the sensor and interface between calculator and machine. Because of the time and skill they demand, calculations for MAC need to be made by engineers. However, freshmen and sophomores with a good mathematics background, but little machine tool experience, are now being used in this exercise at Arizona State University and Carnegie-Mellon University.

MAC has shifted the emphasis in metalworking in two ways: Greater use is made of the operator's ability and judgment, and no major capital investment is needed. MAC is most easily applied to mass production, but shops of all sizes can benefit because the programs are simple, the calculators are inexpensive, and products that seem different can be grouped.

Each machining operation--whether it is turning, drilling, milling, or grinding--has an optimum production rate that leads to minimum machining cost per part. For example, in a turning operation, speed is the variable to be optimized with regard to cost. To minimize cost, the feed should be as large as feasible, taking into account surface finish, vibration, horsepower available, tool breakage, etc. Many other operations require optimization for only a single variable. Often, the operator needs only three or four trials to optimize cost for a single variable.

Low-cost, magnetic strip, programmable calculators could result in considerable savings. The economy and accuracy of MAC were supported by an experiment which involved determining an optimum course by independent calculations made by MAC and by a much costlier computer program based on testing. Although large shops could generate their own programs, relatively general programs could be mass produced for use in smaller shops. The Machinability Data Center in Cincinnati sells programs for machining-cost and production-time analyses at a modest price. [54; 8] With a handheld Hewlett-Packard calculator, a user (typically an engineer) can input cut, time, and cost data and evaluate the effect of speed, feed, and tool life on machining cost and production time.

In two case studies, Dr. Milton Shaw and his associates found MAC saved up to 25 percent in machining operations. If MAC were applied to one-third of the estimated $60 billion spent annually in machining, nationwide, an average saving of only 5 percent would total $1-billion per year.

MAC also benefits workers by allowing machine operators to take part in the decisionmaking process during optimization, thus leading to more job satisfaction. MAC could also lead to the development of a work-incentive system based on the number of parts produced per unit of time and on the value of consumable tooling required to produce them.

A National Science Foundation grant made possible two successful MAC applications involving grinding. Another NSF-funded project will apply in 14 cases in small and large companies. These applications will cover a wide range of machining operations and industries, and results will be recorded in a casebook of typical MAC applications. This casebook ultimately will serve as a textbook to introduce manufacturing engineers to MAC. It is anticipated that a training organization will be set up to offer 1 or 2 weeks of training to prepare engineers to write specific programs. Machine operators would need only minimal on-the-job training.

Additional Technologies for Making Metal Parts

The new methods of controlling machine tools can raise the productivity levels of NC machines and traditional machine tools. Some other new technologies that are developing use nontraditional methods to make metal parts.

Powder Metallurgy.

Unlike other metal-forming techniques, powder metal (P/M) parts are shaped directly from metal powders. In the P/M process, metal powders are blended and the mixture is pressed under great pressure, in a precision die, at room temperature. After the part is ejected, it is sintered (heated) at temperatures of more than 2,000 degrees Fahrenheit to bond the particles.

Although metals in powder form have been used for centuries, "modern powder metallurgy came into its own during World War II and has since been growing more rapidly than other metal-fabricating processes." Although some P/M parts do not need to be machined, some are machined or are otherwise treated. P/M has a strong productivity advantage because it eliminates major secondary machining and trim and machining waste, an especially important factor with high-priced superalloys and titanium. [38]

P/M is a fast, high-volume production method; it produces several hundred to several thousand parts per hour. Although labor input is rather low, some skilled machine operators are required, as well as highly skilled set-up and maintenance personnel.

Most P/M parts weigh less than 5 pounds; however, parts weighing more than 1,000 pounds can be produced by special techniques. More than 60 percent of all P/M parts are used in making automobiles. These parts are being substituted for castings and stamped assemblies. P/M is also used in the appliance, agricultural equipment, business machine, electrical, electronics, and machine tool industries. In addition, P/M parts have markets in aerospace (with its relatively low production quantities), nuclear, and still other industries. Because P/M can produce complex and unusual shapes that are impractical to make by other processes, P/M parts are promising for surgical implants.

Nontraditional Machining.

Nontraditional machining has been defined by Guy Bellows as "new material removal techniques that have emerged since the early 1940's." [4] Although nontraditional processes change rapidly, Bellows identified 26 of them on the market in 1976. These can be grouped by the kinds of energy they use--mechanical, electrical, thermal, or chemical.

Some of the factors that sparked the demand for P/M parts also led to the development of nontraditional processes. These processes use less material from tougher and more costly alloys to make better and more durable parts in more complex shapes. The alloys used are more difficult to fabricate and have only a small fraction of the machinability rating of the alloys used with other methods. Nontraditional material removal processes make it possible to manufacture economically component parts that are difficult, if not impossible, to make otherwise.

The aerospace industry initially exploited these new processes, but they are now common in the automotive industries and, to a lesser extent, in appliance manufacturing. Broader industrial application is anticipated for some of the processes.

More Innovations and the Future.

Other important innovations may be the links between the machining of today and the more advanced machining of tomorrow. A recent issue of Manufacturing Engineering highlighted the following new technologies: horsepower monitoring, signature analysis, the Caterpillar Tractor (CAT) adapter, and improvements in tool materials. [15]

Horsepower monitoring is used for adaptive control, and it also has non-NC applications, especially in cases in which tool breakage is a serious problem. For example, horsepower monitoring can replace the human ear in listening to a gun-drilling operation for likely difficulties and breakage.

Signature analysis is a "form of status recognition based on trends." Acoustical signature analysis, for example, can be used to detect bearing failures at their onset. The process works best if the signature is kept in microprocessor memory.

The CAT adapter is a simple device, but its long range impact may be as significant as that of numerical control. There were formerly more than 30 adapter makes, but now the machine tool industry is standardizing on the CAT adapter. The CAT adapter significantly reduces cutting-tool inventory requirements; this is especially beneficial to the small user of NC equipment. [15]

Newly developed tool materials are an exceptionally important area of technological improvement. Though a single, universal cutting tool would be ideal, this goal will undoubtedly never be realized, and choosing appropriate tool materials will continue to be essential. When one recognizes that the performance of an extremely expensive machine tool largely depends on its $30 end mill, the importance of the "right" material becomes apparent. [46]

- Although cemented tungsten carbide inserts will continue to be used, the price of tungsten is rising. This will make the coated carbides, which were introduced in 1969, increasingly attractive because they increase productivity and potentially save downtime and inventory costs.
- Given their many applications, coated carbides would be more widely accepted if there were not a confusing array of different coatings and combinations of coatings and substrates. In addition, many machine tools lack the speed-and-feed capability or the rigidity to benefit fully from coated inserts.

- Ceramic inserts also have certain advantages over tungsten carbide: They can be applied to nonferrous materials, nonmetallics, and super alloys, as well as to steel and cast iron.

- COMPAX tool blanks--industrial diamond blanks produced by General Electric--also are available for machining nonferrous alloys and nonmetallic workpieces. The longer tool life, higher machine productivity, better part quality, and reduced scrap rates of diamond tools have reduced manufacturing costs. [18]

- There are also new work materials, including advanced composites such as boron/epoxy and graphite/epoxy. Because the new materials can be formed into components requiring fewer fasteners than metals do, they are economical in design and labor. Moreover, these materials are both strong and lightweight; they can take considerable abuse and still require less maintenance than metal. Although most applications have been in the aerospace industry, as prices decline material producers expect to see more applications in the production of leisure items and in such industries as automobile manufacturing. [64]

Toward the Computer-Automated Factory.

According to a survey of the American and foreign scientists and engineers of the International Institution for Production Engineering Research (CIRP), computer-automated factories "...will be a full-blown reality before the end of this century." [39] The ultimate objective--the automated factory--will be approached by the industrialized nations of the world through such "viable, economic steps" as "integrated manufacturing software systems, group technology, cellular manufacturing, computer control and multi-station manufacturing systems."

CIRP has explored economic and social incentives for establishing automated factories for batch-type metalwork manufacturing. Economic incentives include the higher productivity to be realized by reducing the time that parts are in process in the shop and by increasing the time that machines are used. Social incentives include the upgrading of job quality. The international experts in CIRP feel that automation would provide safer, healthier, and more satisfying jobs, with greater employee participation in decisionmaking.

CIRP recommends education and training to prepare for the automation of factories: keeping workers and educators informed as the evolution toward the automated factory proceeds; educating and training management on the technical, economic, and social aspects of implementing the new technology; providing more worker training in repair and maintenance; and providing more and better formal education about computers, software, and automation which emphasizes the versatility students will need to meet changing career situations. [17]

PART II. TRAINING REQUIREMENTS AND SOURCES OF TRAINING

The kind of metalworking technology that a firm adopts will be partly determined by the skills of its work force. For example, an Air Force logistics center decided against NC equipment, simply because most of the center's machine operators were experienced with conventional tools. Another obstacle to change is the inadequate supply of manufacturing engineers trained in nontraditional methods.

The skills required to operate innovative machines such as NC do not exceed the learning capabilities of either the existing work force or new entrants into metalworking, but training in both new and conventional technologies has been inadequate.

Skill Requirements for NC

Except for the most complex NC machines, NC tools eliminate the need for highly skilled machine operators. In fact, shortages of skilled machinists and machine operators have, to an extent, actually accelerated the introduction of NC machinery in both this country and Japan. [61] According to the training coordinator for the National Machine Tool Builders Association, some firms, in the past, used their best toolmakers or most skilled machinists when introducing an NC machine, because they incorrectly believed that workers of the highest caliber were needed for such expensive and productive machines. Certain facilities probably still are failing to benefit from NC's ability to use less skilled operators.

This does not mean that using NC will eliminate the need for trained personnel. Highly skilled technicians are required to maintain and service NC equipment, and trained programers are needed to write NC programs; some observers even feel that graduate engineers are needed to prepare the computer programs. [53]

Part Programer Skills.

According to the U.S. Department of Labor, the new technical position of part programer for NC requires mathematics, the ability to visualize objects and motions in three dimensions, and an understanding of cutting and tooling principles. [62] A General Accounting Office survey found that programers must be able to derive, from engineering drawings, the data "to program the numerical calculations to control machine movements." [10] Skill requirements vary, however. Programing for the simplest form of NC, which involves a point-to-point machine tool, is relatively simple and requires only the ability to read engineering drawings and to understand machining. But toolmakers being retrained today on advanced NC tools do need more knowledge of programing, mathematics, and computer sciences than they would have needed in the early years of

NC. (At least one firm which is applying Cincinnati Milacron's Variable Cycle Controller utilizes its work standards personnel to write programs. The job, which is much simpler than that of NC programer, is performed by employees who are not college graduates.)

Machine Tool Operator Skills.

A trade journal report on NC ascribed the revolutionary nature of NC tools to the replacement of machining methods which draw upon precise "operator [motor] skill and intuition" with "an entirely conceptual documentation [through programing] of all machine motions and functions needed to machine a workpiece." [21]

A 10-year-old study that compared the skills of machinists on NC with those of workers on conventional machines also concluded that NC operators could be less skilled than conventional operators. [26] Although operators had the manual dexterity to operate NC machines, it was found that certain operators might benefit from specialized training in tape language, display codes, and program sheets to increase their perceptual skills for machine monitoring and conceptual skill to handle much more symbolic information. It was also found that NC operators had to make substantially fewer decisions than do operators of conventional machines. According to the U.S. Department of Labor, NC machine tool operators need less knowledge because tapes are programed to control speeds, feeds, and width and depth of cut.

However, operators need new skills for advanced NC equipment that allows functions which previously could not be performed practicably. Thus, the job of a worker who operates two NC lathes (and thereby raises productivity eightfold) is not like that of a conventional lathe operator. According to the president of a firm that manufactures sophisticated machine tools, such a worker is less a machinist than a "machine manager." [6] Workers in capital-intensive automated systems must be able to deal very quickly with unexpected and varied difficulties; individual initiative is needed, rather than the usual form of supervision. In fact, initiative may even be the most important "skill" operators should have.

Maintenance Skills.

NC machines are expensive and have complex control systems; preventive maintenance is necessary to assure their optimum use. Preventive maintenance mechanics should be trained in the technology of electronics and have a working knowledge of hydraulics, pneumatics, and, of course, mechanics. Preventive maintenance is simplified if hardwired systems, with their many printed wiring boards, are replaced by microcomputer NC systems, which allow "...resident, pushbutton-actuated, boardlevel self-test circuits with direct visible feedback...of circuit integrity." [19] (Preventive maintenance and reliability control will be on the agenda of the Fifth World Congress on the Theory of Machines and Mechanisms in Montreal, Canada, in July 1979.)

It is noteworthy that an engineer who has applied programmable controllers to small machine tools believes controllers can be simply maintained, if, in the design of the control system, the program placed into a machine takes maintenance into account by making it feasible to troubleshoot the machine easily if it is not operating properly.

Shortage of Skilled Workers

According to an Industry Week survey of manufacturing industries, 80 percent of the responding nonelectrical machinery manufacturing plants reported shortages in skilled workers. [13] The most severe needs were for machine operators, mechanics, electricians, and tool and diemakers. More than half of the 152 respondents reported shortages in skilled workers, but none reported major problems in finding computer operators or programers. A GAO study confirmed shortages of skilled machinists for conventional machine tools. Qualified maintenance personnel for NC equipment are also in critically short supply: In 1976, 35 percent of the job listings in NC COMMLINE were openings of this type.

Various explanations are offered for these shortages. One is that experienced machine operators are leaving their craft to be trained as part programers. Industry Week cites manager resistance to on-the-job training, relating costs for this to the 1974-75 recession. According to spokesmen for the National Tool, Die and Precision Machining Association, large companies in other industries have for some 20 years been pirating employees from the smaller, skill-intensive toolmaking firms. Apprentice training is lagging, and it has been maintained that, if minority members and women would forego high current earnings in production-line jobs in order to train as machinists, ultimately they could realize a greater payoff as skilled journeymen. The state of the labor market also has other economic implications. Because of the lack of skilled personnel, one aircraft manufacturing supervisor estimated that he must hire 20 percent more people to get the job done. Moreover, as journeymen have been "deskilled" by splintering their responsibilities, pride in the job and productivity have suffered.

Training: A Response to the Worker Shortage

The shortage of skilled workers, rather than impeding technological change, can be dealt with by training and/or retraining. Several European metal firms, for example, prefer to train local workers in the firm's plant in another country, rather than adapt their production methods to the skills of available workers. [29]

Training is necessary for NC programers--who, because of nonstandard equipment, must learn several languages and machines--and for maintenance workers. One user of NC tools estimates that controls have changed so radically that many maintenance personnel are 3 years behind the latest technology. Firms that must subcontract their maintenance because they lack in-house trained personnel incur costly downtime. The Oilgear Company of Milwaukee specifies similar controls and spindles on its NC machines to standardize spare parts, servicing, and tooling and thus simplify maintenance. The electrical engineers, electricians, and mechanical supervisors trained to service the machines are taught the fundamentals of maintenance by NC tool builders.

Training is offered by the industry itself. Metalworking firms offer on-the-job training to update present employees and apprenticeship and other training for new employees. Machine tool builders, software firms (in programing), trade associations, and educational and training institutions outside the industry are also a source of training.

Structured Training.

The Bureau of Labor Statistics during 1974 surveyed structured training programs for 14 skilled manual occupations in four metal industries: fabricated metal products, nonelectrical machinery; electrical machinery; and transportation equipment. [63] Excluded from the survey were the most common forms of training: learning through work experience and informal and casual training. The statistics should be viewed with caution because standard errors (which measure variations that arise by chance) were high and the survey was unable to identify important changes in training methodology that some firms adopted. Only 15 percent of the surveyed establishments provided structured training in one or more of the 14 selected skilled occupations. Of the nonelectrical machinery establishments, 18 percent offered training--the highest percentage among the four industries. The greater the number of employees, the more training was offered. Of those in training, 71 percent were in qualifying programs; only 29 percent were enrolled in structured, skill-improvement programs. Of the establishments that offered structured training, three-fourths evaluated their programs periodically, usually by supervisory feedback. Trainee followup, examinations, and outside evaluations were used much less frequently. Nearly 85 percent of the establishments with structured training did not have a specific training budget.

The reason most often given by employers for providing training was that this is the best way job skills can be learned, and (according to an official of the National Machine Tool Builders Association) there is a definite industry preference for providing in-house, hands-on training on a firm's own equipment. Another reason was that employees had inadequate educational and/or training backgrounds. The sufficiency of informal training was the main reason for not offering structured training; the small number of skilled jobs to be filled was another important reason; other firms preferred to recruit workers who were already trained (by others), and one-fourth of the establishments lacked the capability to provide structured training.

In 1977, The Conference Board, Inc., published the results of its survey of industry's training methods. [34] More than 600 companies, from industries accounting for about half the total private employment in the United States, responded to the survey. The results indicate that corporate training efforts are characterized by practicality and a concern for minimizing educational outlays. Corporations prefer to use short-term courses (including learning modules), self-study materials, and operating specialists and managers, rather than professional educators.

Training Modules at Cincinnati Milacron.

Many aspects of training at Cincinnati Milacron may typify education and training programs by corporations with 500 or more employees. Cincinnati

Milacron has recognized that training must be cost effective and adaptable to changing needs. The firm's training effort has also been influenced by expansion and improvements in public vocational education within the firm's central manufacturing area. Milacron's training is responsive to changes in machine-tool technology and to such new technologies as minicomputers, microcircuitry, and NC systems, which are related to the firm's diversification into other fields, including plastics.

The firm shifted away from general training in toolbuilding, because it could mean training would "go on forever." It also was not considered economical to continue using a centralized training facility owing to the rapid changes in equipment and techniques. Milacron's shift from "vestibule" training to the use of existing, in-place equipment during downtime was not permanent. During the middle of 1977, in response to a need for more workers to accommodate demand for much higher production, Milacron resumed vestibule training on surplus or third-shift equipment. The firm also wanted to be able to accept more women and minorities into machine operator and assembly positions. The vestibule setting has served to introduce inexperienced persons into the shop environment and to raise their retention rate as regular employees. [34]

Milacron's training is based on careful diagnosis of and prescription for individual training needs. An important training tool is the module, which is a "unit of needed information and/or skill that has been translated into a unit of study." Milacron is building a library of modules, adding new modules and removing others according to its continuing redefinition of need. Milacron's training modules meet this requirement by including behaviorally defined objectives and a specific performance standard as an evaluation device. [47] According to a report of the National Center for Productivity and Quality of Working Life, evaluation is an important feature of training programs, because it is likely to engender a greater commitment to training. [41]

The modular technique is used both for new hirees and for current employees who are receiving technical training, especially in machine operation; it will be extended to management development and education. Milacron's Personnel Development Department, which is responsible for training, continuing education, and customer training, operates with a much smaller staff since the shift to module training.

To reduce high turnover among new employees, Milacron developed a machine operator shop-learning program, which gives hirees a better understanding of what they are doing and of its relationship to the other work of the company. Formal training lasts for about 4 weeks; however, an operator may be in a learner category until the required performance level is attained, sometimes as long as a year. Continuing education and training are considered important for all company personnel; supervisors are heavily involved in day and evening programs, which usually last a week.

Apprenticeship and Other Qualifying Training.

The National Machine Tool Builders Association favors apprenticeship, because many skilled tool and diemakers will soon retire (their average age in the St. Louis area, for example, is 55) and because many graduate apprentices ultimately become supervisors. Apprenticeship and other qualifying training are costly and, of course, do not immediately alleviate shortages of skilled workers.

Some firms have cut back on apprenticeship training on the grounds that many machinists work almost exclusively on only one or two machines and that apprenticeship, which usually takes 4 years, is not cost effective. The Federal Bureau of Apprenticeship and Training can (in its approved apprenticeships) shorten the period if trainees are shown to be able to progress more quickly than in the prescribed periods. Apprenticeships have increased in Illinois since several firms got the training period for machinist apprentices reduced to 3 years.

Cincinnati Milacron's machine-trades apprenticeship is listed as a 4-year program, but it carries the equivalent of a 2-year associate degree in evening school. Two-thirds of the program is job related; the other third is academic. Milacron has also had college cooperative students. These students generally develop into technicians, but also may become journeymen and supervisors after they receive their associate degrees.

Detroit has considered instituting a joint-employer approach to apprenticeship and other forms of qualifying training in order to meet the need for machine builders, machinists, and machine operators with traditional skills. The program, which would resemble the cooperative training ventures the construction industry has undertaken in response to its highly fluctuating employment, would be conducted by the Detroit Machine Tool Personnel Association, a group of 16 firms. Eonic, Inc., is typical of these firms. It is a job shop with about 180 employees. The firm does not have a major product line, which makes it difficult to predict production loads and to support a formal apprenticeship program (although the company did have one in the past). The association may try to deal with the problem by sponsoring a program as a concerted effort.

The multiemployer approach to training has also made some progress in DuPage County, Ill., a suburban area west of Chicago. Employers have actively supported the machine tool operation program offered to high school students by the area's public vocational education center. The program reflects some employer preference for moving away from a formal apprenticeship program, which one employer claims "only teaches experience, not knowledge." It is hoped that cooperation between the school and employers can expand this program to include adult trainees.

Since 1964, preemployment training programs, conducted by the National Tool, Die and Precision Machining Association and funded by the U.S. Department of Labor, have enrolled nearly 12,000 economically disadvantaged, unemployed, or underemployed trainees. The programs consist of two 12-week phases. During the first phase, trainees spend 35 hours a week (five 7-hour days) in school. Three hours a day are devoted to acquiring background skills--shop math, blueprint reading, shop theory, and so forth; the remaining 4 hours are spent learning to operate machines--drills, mills, lathes, grinders. Trainees receive $65 weekly, plus a nominal travel allowance.

During the second phase, trainees work for local metalworking plants. Trainees are registered under State apprenticeship regulations and receive on-the-job training during the day and related training in the evening. Some employers give trainees who successfully complete the program a 24-week credit on a 4-year apprenticeship.

Training for Machine Tool Purchasers.

According to one survey, 66 percent of the persons working with NC systems were trained in-house. [3] One out of five of the workers was trained by manufacturers--16 percent by equipment manufacturers and 4 percent by control manufacturers--who view training as a very important aspect of marketing their machines.

Training costs to purchasers vary. Initial maintenance training is included in the purchase price of NC machines. Charges for training programers, planners, and liaison personnel vary with the policies of suppliers and in-house capabilities. [11] Travel expenses and wages paid to employees during the training period are major cost items.

According to a survey by American Machinist of some 50 suppliers who provide most of the NC systems in North America, training ranges from a half day, in a small number of cases, to 14 days for maintenance training, in one instance. Programers' training averages 3 days; operators', nearly 2-1/2 days; and that of maintenance persons, 5 days. In general, training periods on hardwired systems were very short; more sophisticated systems took longer. In only a few instances was training provided on a purchaser's site; apparently, most training is provided at the factories that make the systems. [25] The distributors of Bridgeport machine tools (and probably other distributors as well) send out factory-trained instructors when a purchaser cannot attend the manufacturer's training sessions or when enrollment is at a maximum.

The vice president of marketing of Kearney & Trecker Corporation feels that, in the case of a large NC system, machine installation should occur in planned phases along with intensive training. He suggests that NC machines, which can be operated with a punched tape, be installed one at a time, so that employees can gradually become acquainted with the machine's capabilities. A semiautomatic materials handling system could be introduced next, and finally, direct numerical control. [43]

Some thought and effort have been devoted to the problem of distributing information on the characteristics and operations of NC machines. Until about 3 years ago, a Connecticut concern used a few mobile displays and mobile machine shops with NC machines to demonstrate its product to small machine shop owners and their personnel; this was very costly. Many managers of smaller firms learn about NC through seminars, but the training available from manufacturers of NC equipment is primarily for actual rather than prospective purchasers.

Jack Williams, of the Illinois Institute of Technology Research Institute, is among those who have been trying to secure support for a national demonstration site, which would be an economically feasible means for small companies to learn about the new and different technologies of many manufacturers. The Society of Manufacturing Engineers and the Robot Institute of

America have discussed establishing a site modeled after European trade centers, where manufacturers could display equipment and offer training.

Training Programs of John A. Moorhead Associates.

This organization, at its Lawrence, Kans., facility and other sites, has provided NC training to more than 25,000 persons from more than 7,500 private firms and government agencies. Many trainees have been managers and supervisors responsible for a major part of a plant; personnel from tool rooms, sales, programing, and purchasing also have been trained. Recent enrollees have been machine operators learning the entire NC process, including programing.

Moorhead's basic NC course is only 1 day long. Large companies can arrange for two classes, with 30 people in each, which can also include employees from another company. Clients have been firms of all sizes, from General Motors and General Dynamics to plants employing as few as 40 people. Some universities also have used the course. These classes have been attended mainly by people from industry; occasionally, faculty members attend but only rarely do students. A general knowledge of machining is a requirement.

Moorhead also conducts an "NC coordinator course," sponsored by the National Machine Tool Builders Association. The course, which is described as a "unique combination of training and private consulting services," has been likened to a "... Berlitz language school approach that force feeds NC concepts for 5 days straight." [66] No prior NC knowledge is assumed. The course could be worthwhile to a firm contemplating the use of NC equipment or to one trying to improve its present NC use.

The course begins by identifying the specific production needs of enrollees, and is conducted in a highly individualized way. Enrollment averages 6 and never exceeds 12 persons. Evenings are devoted to study with preparation for the following day's class. The textbook for the course is in looseleaf form, so that it can be readily revised: Enrollees keep the 600-page book as a useful reference, and it is kept up to date with mailouts. Follow-up services to graduates also include free consultation by telephone or mail, useful information--for example, on the training of programers, their job functions, and the types of people who make the best programers--and guidance in choosing maintenance personnel. About 70 percent of the requests from NC coordinators are for technical information; most of the remainder are for advice on the purchase of NC machines.

Training Programs of Manufacturing Data Systems, Inc.

Manufacturing Data Systems, Inc. (MDSI), of Ann Arbor, Mich., is the largest provider of time-shared NC tape-preparation systems and related training for its customers. Time-sharing, which was first offered in the summer of 1969, is on a pay-as-used basis, making it accessible to small and large firms alike. Some 2,000 metalworking firms, using more than 10,000 NC machines, are served by MDSI.

The shift from manual programing to some form of computer-assisted programing can be made after a firm acquires from one to four NC machines; the shift is invariably made after the fifth machine is acquired, when writing workpiece programs by hand becomes too time consuming. Time-sharing services allow metalworking companies to move into computer-assisted programing with the smallest possible investment and in the shortest possible time.

MDSI runs 1-week training courses throughout the year for its COMPACT II processor language customers. Classes are small, averaging 10 persons. Written materials sent to trainees prior to their arrival for the course are not only to instruct but also to remove concern over working with a computer on a time-sharing basis. Classroom instruction is partly in learning the COMPACT II language and system use and partly in actually communicating with a computer to develop programs for test parts. Each trainee has a graphics plotter that is used to simulate a machine tool and detect errors in cutter-path programing and costly tool collisions. Purchase of such a plotter for in-plant use is also an option. Instructors have devised special ways of working with unusually fast or slow students.

MDSI has trained about 4,500 people from metalworking; approximately 2,000 of these have returned for an additional course. About 85 percent of the enrollees have a high school education, and some also have college credits. About 80 percent of those receiving MDSI training become involved in programing. Of these, three-fifths have had experience in manual programing or another programing language. The remaining two-fifths--machinists or machine operators--have had no previous programing experience. The 20 percent who do not become programers are supervisors, managers, and owners. Half of the trainees are in the 25 to 34-year age group; the remainder are about equally distributed within the under-25, 35 to 44, and 45-year and above age groups.

Courses are conducted in Ann Arbor, Dallas, Houston, and Los Angeles. If desired, training for six or more employees is also offered at customers' sites. MDSI also conducts training in "group technology" at customers' plants. This consists of 5 days of training and 1 or 2 days a week of followup for as long as 60 days.

MDSI also provides an advanced 3-day programing course on a scheduled basis. In addition, low-cost time-sharing for educational institutions with NC programing training is furnished, and includes up to $200 a month free use, and a 50 percent discount thereafter, on a terminal at any time after 5 p.m. More than 90 institutions have already signed up for this service.

Some firms have found it cost effective to move from NC time-sharing to in-house programing. For example, Eonic, Inc., now uses only a salaried programer and its own computer to make tapes and corrections. Eonic continues to use MDSI for backup, and it still uses MDSI's training service.

Machinability Data Center Seminars.

The Machinability Data Center in Cincinnati, which is sponsored by the Department of Defense, collects, evaluates, stores, and disseminates information on all phases of machining technology. The purpose of the center is to reduce the cost of machining and to increase the productivity and dependability of machined products produced for various Federal agencies and their contractors; machining data are also available to private industry. The center's information is transferred to users through technical inquiry services, preparation and sale of reports on machining data on new materials and new machining methods, and a seminar program.

MDC has conducted more than fifty 2-day seminars. Seminars are scheduled for the middle of the week to accommodate small firms whose personnel must set up production on Monday and on Friday, when materials are usually shipped. Normally, no more than 40 students are enrolled at a time. Topics are introductory, although NC, computer-aided design and manufacturing, and nontraditional machining processes are considered. Attendees also learn about the availability of machinability data from the center. These data can be very important, for instance, in deriving--from very hard materials--parts that are thinner and of higher quality than is possible with older mechanical processes. It was pointed out during the seminar that even a simple milling operation involves 23 different variables, and the fastest machining rate may not produce the best production rate.

Nearly 2,000 representatives from more than 800 companies and government agencies in 40 States have attended the MDC seminars; most are degree and nondegree engineers, but others are shop supervisors, NC programers, estimators, manufacturing managers, production planners, or machinists. Attendance counts as 12 credits toward the Society of Manufacturing Engineers' recertification program.

Professional and Trade Association Training Programs.

The Society of Manufacturing Engineers emphasizes the importance of continuing education. It sponsors seminars, conferences, and short courses. It also makes available educational materials, such as technical reports and videotapes, on NC machining, material forming, electrical and electronic manufacturing, nontraditional machining, energy conservation, industrial robots, and lasers. One of the technical reports is entitled "Training People for Manufacturing Jobs."

The Numerical Control Society holds occasional conferences and seminars both for its members and for nonmembers. In 1978, a 2-day seminar on numerical-control tooling was planned for presentation at six locations.

The Metal Powder Industries Federation sponsors conferences and intensive 2- and 3-day seminars on such subjects as basic powder metallurgy (P/M), P/M tooling/compacting, and copper and copper-base P/M materials.

Training in Educational Institutions.

According to one study, postsecondary educational institutions do not provide sufficient instruction in "new technology, particularly...in computer-aided manufacturing."[3] In 1974 only 9 percent of all NC personnel had been trained by educational institutions--3 percent in universities, 2 percent in vocational-technical schools, and 4 percent in junior and community colleges.

College Training. Significant course offerings in NC were provided by universities in only eight States and by junior or community colleges in only five States. Most of the training time was devoted to manual part programing, and little time was spent on computer programing for NC. Only a few universities provided instruction in economics, equipment selection, justification, and similar management-oriented aspects of NC.

Although NC machine tools were introduced in the 1950's, public education did not deal with the technology until 1965, when Automatically Programmed Tool (APT), a standard computer language for NC tools, was introduced. Colleges have been discouraged, by equipment costs and/or a lack of technological information, from teaching NC-related courses. NC programing practices, techniques, and languages differ widely among industrial and educational institutions, and practical application generally has been missing in college-level instruction. Some engineering schools have dropped shop and hands-on training, and some engineers attending the Machinability Data Center seminar were so unfamiliar with machine tools and machinery that they did not know the difference between a drill press and a lathe.

Instruction in NC technology could be made more relevant. Controlled teaching experiments have shown that NC manual programing and NC control maintenance could be taught with about equal effectiveness by using simulated NC equipment instead of the much more costly actual NC equipment.

Hennepin Technical Center--A Special Case. A training program set up in 1971 at the Hennepin County (Minnesota) Area Vocational-Technical Center, a public education institution, may still be the only one in the country that is geared to meet the manpower requirements of powder metallurgy firms. The center is located in Brooklyn Park, a suburb of Minneapolis-St. Paul.

The program, which produces technicians rather than operators, consists of 2,640 hours of instruction during a 2-year period. During the first year, students work with actual equipment and learn how P/M parts are produced. Almost any P/M part can be produced at the center's metallurgy testing laboratory with its four different presses and two sintering furnaces. The center also teaches students to set up and maintain equipment. Training takes place in an environment as close to an actual plant as is possible, and each student works for several weeks, in turn, as press operator, furnace operator, set-up person, inspector, expediter, and foreman. During the hours not spent in the shop, students study mathematics, technical writing, drafting, electricity, hydraulics, machine-shop familiarization, and basic metallurgy.

During the second year, most of a student's time is spent in more technical areas, including tool design, advanced metallurgy, metallography, chemistry, statistical analysis of data, manufacturing problems, material testing and specification, failure analysis, and static mechanics. Supervisory training is also offered. Each student chooses a major project related to materials, processes, or chronic difficulties associated with P/M and produces a report of publishable quality. (Selected papers have been printed and are available from Precision Metal Magazine or A.O. Smith Company in Milwaukee, a manufacturer of powder metals.)

Most of Hennepin's students are not yet in the labor force, although some are sent by their employers. Because Hennepin is unique in P/M training, employers from all over the country come to interview its graduating students. Competition for graduates is so keen--some get more than eight job offers--that students hesitate to accept initial offers at graduation time. More than 90 percent of the center's 60 graduates have been placed as set-up personnel, supervisors, and planners, and in engineering, research and development, sales, and production control jobs.

Private Vocational Schools.

These schools are keenly concerned with placing their graduates in jobs. Enrollees, for the most part, are young--usually recent high school graduates. Training is concentrated on older machines, because those are the ones to which graduates are most likely to be assigned when they are first hired, and because of the minor percentage of NC machines in operation. An informal telephone survey and examination of catalogs of schools accredited by the National Association of Trade and Technical Schools disclosed that some offer training only on conventional or basic machines; others provide at least an introduction to NC machining.

- The 26-week machine shop program at the Industrial Trade School in Dallas does not deal with NC because school officials are convinced, on the basis of discussions with potential employers, that people trained in basic machine operations are in greater demand. NC machinery varies from one make to the next, so employers prefer to provide their own training on their own machines.

- The Allied Careers Institute in Hazel Park, Mich. (a suburb of Detroit), has a 28-week program which is "not at all into NC." Its experience has been that graduates who are provided with the basics can be trained on more sophisticated machines by their employers.

- The Ranken Technical Institute in St. Louis provides computerized NC training because it considers these skills "basic to the modern plants" in which their graduates are placed.

- At the ITT Technical Institute in Dayton, Ohio, about 4 percent of the credit hours in a 100-week associate degree program in tool-engineering technology deals with NC.

- The J.M. Perry Institute in Yakima, Wash., has a 2-year machine technology program. Students spend 2 hours a day in the classroom and 5 in the shop. The shop is run like a business and accepts a limited amount of job-order work. The school has one NC machine and plans to acquire another smaller, simpler machine for training purposes. It has no computer because it feels that students only need to learn NC basics to prepare them for more extensive training on their employers' machinery. Graduates have been placed in jobs throughout the State, including both small shops and larg installations such as the Hanford Atomic Energy facility. Because graduates are considered to be better trained than the typical apprentice, unions often grant them 1 to 3 years credit on an apprenticeship, and some become journeymen directly.

- The National Technical Schools in Los Angeles offer machine shop programs without NC, a 6-month program in general machine shop with NC, a 5-month program in NC and tool and diemaking, and a 2-month program in NC machine operations.

- The Williamson Free School of Mechanical Trades in Media, Pa., offers a 3-year machinist program. In the final year, students (accepted at a minimium age of 16) are introduced to point-to-point programing. The school has facilities for making tapes, and although it has no computerized equipment, students get into continuous-path programing.

The "World of Manufacturing" Program

More than 5 years ago, the Society of Manufacturing Engineers (SME) became involved in an industrial technology program in the public schools as a way of helping to maintain an adequate supply of trained personnel in manufacturing, including metalworking. Preparatory studies for the program were begun in 1965 by industrial arts experts at Ohio State University.

The "World of Manufacturing" program (as well as a "World of Construction" program) was developed for the junior high schools, using a $2.5 million outlay from the U.S. Office of Education. The SME contributed $25,000, plus resource and advisory personnel. The program did not require large initial outlays because already-existing shops and hand and measuring tools owned by the schools could be used.

Unlike vocational education, which aims to prepare some students for entry-level jobs and advancement in a particular occupation, the World of Manufacturing program is designed to provide young people with the technological literacy they will need to cope with change. It was also felt that students might plan their careers more intelligently by exploring the intrinsic and monetary rewards of various blue-collar occupations. (A public school survey in Milwaukee disclosed that less than 3 percent of the high school students chose factory work as their first choice. The careers of machinist or machine operator ranked rather low, even though Milwaukee is known as the Machine Tool Capital of the World.) [60]

By conservative estimate, 400,000 students in more than 1,000 junior high schools completed the World of Manufacturing program between 1971 and 1976. [9] Most of the programs last 1 school year (185 hours) or 1 semester (90 hours) but shorter (6- and 10-week) programs have also been provided.

In view of the promising beginning in junior high schools, SME decided to try to get a more sophisticated version of the course introduced into high schools. SME hopes that all high school students can be exposed to a program of at least five 1-hour classes per week for one semester. Many school systems in Michigan already have a 1-year program in high school, as well as the 1-semester program in junior high school.

SME contracted with the same Ohio State group that prepared the World of Manufacturing textbook, [35] to produce a feasibility study on implementing a high school manufacturing education program. No U.S. Office of Education funds have been made available for this program or for an adult education version in which Federal educators had also shown some interest in 1975. SME chapters have aided several communities--including, among others, Indianapolis, South Bend, Fort Wayne, Evansville, Akron, Cincinnati, and Dayton--in establishing a career exploration program by financially sponsoring teachers who wished to attend workshops.

The "Open Road" Program.

The National Tool, Die and Precision Machining Association has suggested that public high schools along with employers should assume responsibility for skills training, particularly apprenticeship training. The Association proposed to the Department of Labor a program designed to provide a long-term solution to unemployment in the United States. The program would be aimed at 11th- and 12th-grade high school students not intending to go directly to college.

Under the proposal, an industry advisory committee would make an annual survey of job needs in communities. Aptitude testing and counseling would be used to guide students in their career choices. Prospective metalworking students, for example, would need "...high math ability, above average powers of visualizing spatial relationships, above average mechanical aptitude, [and] a normal or above I.Q." Counselors would remain involved with selected junior and senior year students, who ideally would be broadly representative of all students, including women and minorities.

The program would also provide for oversight committees, made up of employer and labor representatives, to work with the schools, monitor the program, and--during the summer before the 12th grade--place students in curriculum-related jobs. Before graduation, a faculty committee and an industry advisory committee would consider student test results and other evaluation criteria, and then offer students permanent positions starting at the level determined by the evaluators. Students who pass all program requirements would receive credit for 2 years of apprenticeship, and other students would get appropriate credit. Students who fail to qualify for apprenticeships in the higher skilled trades would be placed in machine operator positions.

Initially, the program would not offer instruction in NC technology because it is considered too advanced and not needed by high school graduates starting their careers in metalworking. Furthermore, most schools have no NC equipment. This is not a real deterrent, however, because at least some experiments indicate that using a simulator to teach NC concepts in a high school industrial arts program is not significantly different in result from conventional approaches to teaching numerical control. [3]

Loan of NC Equipment to Schools.

The Defense Industrial Plant Equipment Center, Memphis, Tenn. makes a very limited amount of industrial equipment, including NC machines, available on a loan basis to nonprofit schools, mainly technical-vocational centers and community colleges. Although the machines are useful to teach NC theory, they are usually behind the state-of-the-art. Even so, an official of the center knew of instances in which persons trained on simple NC machines were unable to secure jobs because small shops had not converted to NC machines, even simple ones.

Some manufacturers of advanced NC equipment lend it to educational institutions and occasionally provide instructors, particularly when they want to train people on machines that the manufacturers expect to sell to private firms.

PART III. CASE STUDIES IN TRAINING

These four case studies describe training programs in four metalworking firms that vary significantly in size and technology. The studies report on the following:

1. Training provided by the Kearney & Trecker Corporation for purchasers of its NC equipment and machining centers.

2. Training provided in a sizable metalworking concern when it converted its workers to NC machines.

3. Measures taken by Lehr Precision Tools, Inc., a small job order shop, to assure stable employment and motivate its workers to train in traditional and electrochemical machining.

4. Measures taken by Merriman Inc., to train its work force in-house in powder metals technology.

Kearney & Trecker Corporation: Machine Tools and Training

Operations.

Kearney & Trecker (K&T) was founded about 80 years ago in Milwaukee. It manufactures and sells such metalcutting machine tools as milling machines, NC machining centers, special purpose machines, flexible manufacturing systems, and computer-aided manufacturing systems. The company also remanufactures older machines. K&T machine tools are used to produce parts for products ranging from hand calculators to earthmoving wheel loaders.

Standard milling machines and NC machining centers (including special products) usually account for more than 85 percent of K&T's total sales and revenues. In recent years, K&T has sold at least twice as many NC products as standard milling machines. K&T's NC machines range in price from less than $125,000 to more than $250,000, its flexible manufacturing systems can cost several million dollars.

Product Innovation.

K&T was an early force in the development of NC machining. In 1957, it produced the first NC machine tools for use in high-speed aircraft production. In 1958, the company developed the first NC transfer line. That same year, it introduced the "revolutionary" Milwaukee-Matic machining center; less than 10 years later, it delivered its thousandth machining center. In 1965, K&T produced the first NC high-horsepower vertical profilers for hard metals.

During the 1970s, K&T placed on the market two models of its Milwaukee-Matic machining center featuring computerized numerical control (CNC). The smaller model is considered especially suitable for small job shops; it produces small- to medium-size workpieces. The larger model can accept production workpieces of nearly 1 cubic meter.

In 1976, the MM-200 machining center, which was first introduced in 1972, was adapted to a five-axis work capability. In the same year, K&T brought out an unmanned machining system consisting of individual machining centers capable of operating virtually unattended under computer control during nighttime or other hours when skilled operators are unavailable. The first such system, involving six machines, was sold to a Swedish firm; a second system, involving two machines, will be delivered to another Swedish firm in 1978.

The firm offers instruction in the operation and maintenance of its complete machining center systems. Such training is important because substantially higher costs are incurred when something goes wrong with NC machining centers than with conventional machine tools.

Trainee Qualifications.

K&T advises prospective purchasers of NC systems to choose personnel with the following qualifications:

Operators:

A knowledge of good machining practices.
A knowledge of tooling and tool geometry.
Proper use of machinist tools.
A knowledge of general inspection procedures and methods.

Programers:

General education - High school graduate, including 2 years of mathematics, preferably algebra and trigonometry.
General machine shop background and familiarization with machining procedures.
Ability to read drawings.
Knowledge of tooling, tool design, and process engineering.
Ability to plan and organize work.
Good attitude and strong interest in the NC method of manufacturing.

Maintenance (mechanical and hydraulic):

General education - High school graduate or trade training.
Minimum of 3 years performing machine tool maintenance.
A good working knowledge of hydraulics as applied to machine tools or equivalent.
The ability to read assembly prints and hydraulic schematics.

Maintenance (control):

General education - High school graduate, plus trade training in a technical school or college.

A good understanding of AC-DC electricity.
A good working knowledge of industrial electronics.
Electrical and electronic experience as gained by working with machine tools or equivalent application.
Basic understanding of the principles of digital logic.
Basic knowledge of the proper use of test equipment, including oscilloscopes, high-speed pen recorders, and volt/ohmmeter.

Experience in programing is not required, but experience in machining is necessary. K&T cannot (in a very short course) impart the metalcutting know-how required by operators or the general machine shop background and familiarity with machining procedures suggested for enrollees in the programing course.

During the period of an NC machine warranty, purchasers can send two employees to each form of training offered by K&T. Because separate total support groups are required for NC, which can be viewed as a "factory within a factory," smaller--and occasionally larger--companies send managers and supervisors to learn how to coordinate the machines so as to minimize interruptions, and to find out what types of support personnel are required. Occasionally, K&T tests its customers' job applicants to help fill maintenance positions. Customers assume travel and living expenses for trainees, and K&T makes the living arrangements. No tuition is charged; presumably, the cost of training is included in a machine's selling price.

Customer Training.

About 1 month before a course begins, K&T sends out course materials, which trainees are expected to learn and on which they may be tested. With the exception of audio cassettes, course materials are retained by the trainees.

Instruction is offered in manual parts programing, machine (or mechanical) and hydraulic maintenance, and control and electronic maintenance, including machine interface. Classes ideally consist of 8 to 16 trainees. Each course runs for 5 days. To the extent feasible, hands-on instruction is provided, along with videotapes that show "how things work." The control course has a control in the classroom, making possible hands-on troubleshooting and operation with the computer. Trainees in the part programing course actually program a part. The videotapes allow trainees to see assembly and disassembly procedures of parts and components being machined at various stages of completion.

K&T has 10 instructors. They are also technical writers who produce manuals, videotapes, and other materials for both training and machine maintenance. Trainees evaluate the instruction, as do their employers, once the trainees are back on the job.

In-House Training.

According to one local union official, senior workers at K&T initially were reluctant to post for NC machine jobs, and they remained on conventional machines by using their seniority to bump younger men. As more of the newer jobs opened up, however, and the tasks required became known, older workers were attracted to them. Although the new jobs are more demanding mentally, they are not as demanding physically.

The machinists' business representative believes it is easier to maintain the newer metalworking machines because of their solid-state construction; the machines often can be made operable merely by installing a new circuit board. He believes that maintenance personnel ought to be trained to diagnose electronic, mechanical, and hydraulic difficulties, however, in order to avoid costly downtime incurred when specialized repair personnel (who must wait for a correct diagnosis) are used.

The machinists' union encourages members to enroll in training, in order to keep up with changes in technology. K&T pays the tuition for machinists who enroll at various vocational schools in the Milwaukee area. K&T also offers on its premises continuing instruction in blueprint reading, shop math, and electrical and hydraulic applications. Instructors come from public schools, and equipment not in operation is used for hands-on instruction.

Machine Design To Accommodate Worker Skills.

According to one product manager, K&T tries to take into account the availability of skilled workers by designing machines simply so that less training is need for their operation and maintenance. The computerized NC machining centers contain thousands of components, however, which makes it difficult to identify the source of system failure. [30] To help with this problem, K&T developed the Diagnostic Communication System (DCS) to diagnose abnormal machine conditions and to simplify preventive maintenance. With DCS, an electronic probe placed in contact with a customer's machining center uses the K&T computer that controls the machine to send back to Milwaukee oscilloscopic waveforms that are present at the point of contact. By reading the waveforms, it is possible to diagnose potential or real problems. This saves customers both time and money. DCS is used on all NC machining centers during the first year after their sale. Most purchasers continue to subscribe to the service.

K&T's programmable cycle controller, the Data Mill MDI Controller, has been on the market since 1976. The controller (with its microprocessor) is described as approaching NC capability without NC cost and complexity. Compared with NC, training on the controller is minimal: a worker who has used a milling machine can learn to operate the controller in 1 day, so K&T does not provide customer training. The controller "automates" a milling machine, but uses simple shop language--not a programing language--to accomplish part programing via pushbutton input on the shop floor. According to K&T, the controller can raise milling machine productivity by about 25 percent compared to manual operations productivity.

One Metal Firm's Adjustment to Numerical Control

The firm which is the subject of this case study prefers to be anonymous; it is referred to here as MW.

Operations.

MW is a large firm that makes a part for the pipes used to transport natural gas. The firm is classified as a custom, or job order, shop because its customers dictate the parts and components it manufactures.

As a job shop, MW has short production runs. It began using NC 10 years ago and found that ~~NC improved~~ product quality, increased throughput as a result of improved "chip time," and helped reduce set up, handling, and downtime. The firm finds it cost effective to use more than 15 NC machines. These are mainly milling machines or turret lathes (with two or three axes), but NC drill presses are also in use. One NC is on adaptive control. Computer-assisted programing is used on all but three of the machines.

Worker Skills and Planning for New Technology.

According to MW's manager of industrial engineering, the skills of MW's work force have influenced the types of equipment the firm has purchased. Where highly skilled employees have been available (as in forging), the company has used more sophisticated equipment. Although this is nominally more costly than matching less skilled workers with simpler equipment, the firm is more productive with the more sophisticated equipment.

MW employees are given notice considerably in advance of technological changes so that they can become familiar with new equipment before it is placed in production. A foreman, department head, supporting departments, and engineers all may become involved in informing and assisting the affected workers.

The firm's initial adoption of NC involved rather simple NC drill presses. This did not meet with any resistance among workers who shifted into programing--a new occupational field for the firm. The move into NC machining had little to do with worker capabilities. Once it was determined that certain technical skills were needed, a number of employees, including some senior industrial engineers, "simply had to do some learning." There were no marked differences between younger workers and those 45 years and older in capabilities or in resistance to technological innovations.

Initially, programmable controllers were not considered as an alternative to NC. MW now has two of these, but not for the reason that minimal training of personnel would be involved.

Machinists selected for NC programing had to have a knowledge of mathematics to understand spatial relationships and geometric patterns and had to be able to read blueprints. Most of the early programers were new hires with machining backgrounds. Some of the newly hired machinists and MW' own engineers and machinists received 2 weeks of training in programi g for the NC machines at the Illinois Institute of Technology. NC was con idered such a challenge that the manager of industrial engineering did some programing himself to acquire firsthand knowledge.

Skills, Employment, and Training for NC.

MW's experience with skill requirements is probably typical of many firms adopting NC: machine operator skill requirements have gone down and maintenance personnel skill requirements have gone up. Software developments have gradually reduced skill requirements for NC programing; MW, along with all software users, has developed its own facilitating techniques, such as "canned programs" and "macros" (mathematical descriptions for machining steps that are smaller than an entire program and are used over and over again).

No formal job evaluations have been used to determine wage rates on the NC machinery; rate changes are negotiated in bargaining agreements. MW does not have enough workers on NC to affect its employment level significantly. The need for maintenance workers has increased somewhat and the need for machine operators has fallen somewhat; there is now a need for programers. On balance, employment has been quite stable.

Maintenance personnel still require some outside training, but generally only for a few days; often, equipment vendors provide instruction at the plant on MW's machines. When new machines are installed, machine operators are given one-time training on the job.

Training requirements for programers diminished when the company decided to reduce the number of computer languages that were used. One reason this policy was adopted was to minimize difficulties that result from switching to a language system that is incompatible with an important programing system already in use.

The firm's industrial engineers are encouraged to continue their education and training in order to anticipate and prepare for technological changes; they are then able to instruct operators and line supervisors, who are not involved with continuing training.

MW's manager of training feels it would be highly unusual for workers to undertake training on their own to prevent their skills from becoming obsolete because of technological change. Moreover, because workers are also union members (seven unions are represented at the firm), he believes it would be arbitrary for management to give workers tuition aid for enrolling in job-related courses. Such aid, he said, must be secured through collective bargaining. Generally, workers enroll in a training course only if their tuition is reimbursed; they may also want to be paid for time spent in school, as are apprentices and some other employees.

At least three of the seven unions at MW are generally favorable toward the measures to aid workers to adjust to new technology:

- The Machinists Union. Although MW has the right to introduce changes without giving the union any advance notice, the machinists union emphasizes its right to speak up or raise issues regarding new working conditions, including new wage rates. Normally, a union committee (with representatives from more than one of the unions) meets to discuss an innovation the firm has decided to adopt. Decisions are then made concerning jurisdiction. For example, if metalcutting equipment is installed, the machinists have jurisdiction; if the sinking of dies is involved, the diesinkers have jurisdiction.

Apprenticeships are not available to machine operators in the production machine shop. However, in-house training programs have been offered, including on-the-job training to upgrade operators into certain classifications. Training in the machine shop is achieved by a "piggyback" method, which resembles an apprenticeship: operators observe qualified machinists and ultimately try their own hands at a machine. Machine operators were helped to adjust to NC equipment by using the firm's several tracing machines or duplicators. Machinists working as machine repairmen and hydraulic repairmen encountered "no real problem" in adjusting to NC.

According to the machinists' training representative, continuing education or training is not yet necessary for members of his union. He observed that MW reimburses employees for completed job-related courses, and he considers the overall program to be excellent.

- The Electricians Union. Major changes in electrical maintenance--which is performed by members of the electricians union--took place following the introduction of NC machines. About one-third of the electricians voluntarily, over a 1-1/2-year period, completed four 50-hour electronics courses at a public technical college. MW worked with the college to develop customized courses to meet its requirements. These included two courses in logic and switching circuits, which require Boolean algebra. The union negotiated payment by the company of 80 percent of fees and book expenses.

Some, but not a majority, of electricians who had worked for the firm for 20 to 30 years took the courses; they experienced some difficulty with electronics mathematics. (Not everyone who took the courses had finished high school.) However, by studying together in the classroom, shop, plant, and even at home, all of those enrolled completed the courses.

The chairman of the electricians union also completed the four courses. He thinks it would be desirable for the college to conduct some evening sessions at the plant because some of the equipment is highly specialized; MW's spare equipment could be used to build up complicated circuits.

Although management recognizes that highly skilled journeymen will be needed for evolving technologies, it disagrees with the union over the number of apprentices needed to insure an adequate supply of maintenance personnel.

- The Professional and Technical Engineers Union. Only two programers in the engineers union are involved with NC machinery, but other technological changes have affected m[illegible]of the union local's more than 300 engineers and technicians. [illegible]ently, continuing education and training of engineers are encouraged through tuition refunds; it is largely left up to the individuals to take the courses. According to the chairman of the union, a joint labor-management committee could deal more effectively with engineering training than does the present effort.

Advanced Technology at Lehr, a Small Machine Shop

Like many American contract shops, Lehr Precision Tools, Inc., of Cincinnati, is small in terms of dollar volume of output and number of employees. Unlike most contract shops, however, Lehr applies the most advanced forms of machining technology. Lehr recently acquired an NC machine, and it is also involved in electrochemical machining in addition to its traditional machining operations.

Operations.

Many contract shops are captive to a handful of single-industry contractors, a pitfall Lehr has avoided by stabilizing its operations through five divisions. The precision tooling division, from which Lehr evolved, supplies injection mold cavities and other products for nationally known manufacturers of consumer products, including typewriters and safety razors. The Arnold Gauge Division, which Lehr purchased 5 years ago, produces gauges that are distributed throughout the country. It makes a center-type grinder gauge that provides continuous visual display and lowers costs through higher productivity, more consistent quality, and lower scrap loss. Another Arnold gauge provides a fully automatic grinding cycle. A third division makes air gauges used by a major automobile manufacturer to check diameters of components and parts. A fourth division does all repairs on the mechanical parts for gauges on the grinders produced by a major Cincinnati machine tool builder. The remaining division, electrochemical machining (ECM), is the most technologically advanced of the five, and it is the subject of this case study.

Cost and Labor Factors in Electrochemical Machining.

Very few concerns are involved with ECM. Lehr's president had more than 15 years of experience with a company that was a primary developer of the technology, and he was responsible for establishing this division at Lehr.

ECM equipment is in limited supply, and the cost for all equipment needed is prohibitive for a small contract shop. Lehr's president estimates that a typical 10,000-ampere machine costs nearly $125,000; the support systems necessary for electrolyte clarification and temperature control raise the basic machine price by three to five times. ECM machines also need extensive floor space, so machining firms must be able to construct, or at least modify, their equipment. Talented, all-around toolmakers are needed to design, construct, and operate the machines. Engineers who understand the mechanisms and have an extensive knowledge of electronics are also necessary. As Lehr's president wrote:

> The people directly involved with ECM must be dedicated and willing to devote the years necessary to understand the tooling and other

process requirements. This is not tremendously different from die designing or mold designing, but it is a lot more difficult than electrical discharge machining or conventional machining. [7]

Lehr is topheavy with engineering employees. Even so, it must ship components for repair to one of two Illinois firms that pioneered in the technology; it would prefer to maintain its own repair equipment in-house with its own electronics specialists.

Electrochemical Machining's Benefits and Problems.

ECM replaces the "brute force and violence" of traditional machining with the "cool, steady, non-deforming magic" of the highly focused deplating action of electrochemical machining. Ideally, the removal of material atom-by-atom puts no stress--and therefore no distortion--on a workpiece. ECM's capability for cutting on an entire surface at the same time increases machine productivity, and ECM performs some basic machining operations (shaping, planing, drilling, milling, and grinding) more efficiently. [4] ECM can make difficult cuts quickly in very hard metals, intricate formations, and small, odd-shaped, and deep holes, which may not be achievable by any other machining method. Lehr's president notes, however, that other emerging processes which have fewer problems also minimize machining. "If you get involved with ECM, you must want to make it work."

The first piece turned out by ECM requires more skill than is required in a traditional machining process because an operator must choose from more operating variables (10 or so). The process is not economical for less than 20 to 30 simple parts; 100 parts are typically needed to justify using ECM. ECM is marginally useful when it lowers costs by half; to be really cost effective, ECM usually needs to effect savings of three to five times. The process is most effective in mass-producing complex shapes from materials that are difficult to machine.

Downtime with ECM is high. To keep it no higher than 20 percent, Lehr must control the whole process precisely, handle tooling problems expeditiously, and control the conditions of electrolytes and several other variables. Extreme care must be taken to avoid metallurgical damage from the corrosive solution (salt water) that is used. ECM is not electricity efficient, and its profitability lies in maximizing time efficiency.

Innovations at Lehr.

Lehr exemplifies the belief of the Chief, Office of Invention and Innovation, National Bureau of Standards, that innovations usually arise within small companies. For example, Lehr proposed (to the Department of Defense) a prototype system with a programmable controller capable of handling all the variables that ECM must deal with. Lehr's president also hopes that the firm ultimately will be able to marry an NC control to ECM to increase the uptime of the process. He also feels that firms must be able to adapt to a possible push for shorter hours of work, with no reduction in pay; one way to do this is to make machining cyclea less dependent on operators by using programmable systems to control the cycles.

Work Force.

ECM resembles NC in that it is less labor-intensive than traditional machining. Lehr's main plant, where precision machining and ECM are performed, employs 40 people. The firm's president, his brother, and three others are mechanical engineers. The engineers, who are oriented to computers rather than to material removal, are usually involved in applied work. This, along with avoiding the "frustrations of getting things done" in a large company, makes Lehr attractive to its engineers. A Lehr draftsman who had worked for a large manufacturing firm with sizable defense contracts said he used to make drawings for numerous parts but saw few of them after they were built. At Lehr, he can follow the progress of a part on the shop floor and make slight changes or corrections to his design.

Because Lehr employees who work in ECM also work in traditional machining, they must have a variety of skills. The same earning scale prevails for workers in ECM and traditional machining, but ECM workers are paid somewhat more overtime. When the ECM division is busy, it has the exclusive use of five machine operators and eight toolmakers; the engineers also pitch in on operator tasks when special problems arise.

According to Lehr's president, some workers feel comfortable, secure, and content in repetitive work. He considers it a mistake to downgrade repetitive work and makes a point of praising employees who do such work well. After all, he observed, the firm makes its "real money" on items produced in large quantity (or in long production runs) because these are the conditions under which a firm "knows its costs." It is always uncertain whether making one or two so-called experimental items will lose or make money.

Training.

Training (and learning) at Lehr is an intensely interpersonal relationship that takes place over a long period of time. New employees have high school or post-high school educations that include good shop programs. Usually, they have not worked for large firms, where jobs are likely to be specialized. Specialization runs counter to the demands a small concern makes upon most workers. Once an employee in a small shop becomes proficient, however, he has more opportunities to advance into better paying positions than he would in a large firm.

The president of Lehr, who is still involved in all tool design along with another engineer, works closely with personnel before they are trained in ECM by "running through" the first groups of various types of parts with them. He observed: "Our people work best when we work shoulder to shoulder with them; then they understand the economic problems of getting parts right and shipping them." (This bears some relation to the reflection of the chairman of the National Commission for Manpower Policy regarding some of Japan's best managed firms: "I recall seeing plant engineers hold regular sessions with semiskilled workers to elicit their recommendations about materials, adjustment of the machines, and other details aimed at increasing the firm's productivity." [23])

All of Lehr's ECM training for toolmakers and machine operators occurs on the job. Toolmakers build upon extensive experience in conventional tooling. The best operators are those who have capabilities for observing and analyzing.

The actual learning process is in the doing--"a lot of cut and try, including errors." No special problems have been encountered in training older workers, but they are not assigned to ECM positions involving heavy labor.

Because the gauge manufacturing division often turns out hundreds of the gauges at a time with traditional tooling, workers are able to drill many holes. This provides a training ground for inexperienced young employees because "after drilling hundreds of holes, you learn the fine details of hole drilling."

Unlike some firms, Lehr plans to move right into computerized NC. Lehr will enroll selected employees in an NC course offered by a private concern in Cincinnati. According to Lehr's president, younger workers or those with recent mathematics are most likely to be interested in working with NC. Two or three key personnel--including the firm's president or his brother--plan to attend a training session on operation and maintenance offered by Bridgeport Machines, the NC manufacturer.

Because Lehr's president believes that the biggest challenge in developing a work force is not training people to do their jobs, but training people to work with other workers, about 10 of the company's group leaders will participate in an externally conducted program on interpersonal relations. In this way, Lehr hopes to build the larger supervisory and managerial base it will need to expand the firm. (Lehr's experience is supported by a Department of Labor survey of training in metalworking: "Relatively few employers provided training in leadership, communication skills, and labor and materials estimating." [63])

Merriman Develops Skills for Powder Metals

Merriman Inc., located in an industrial park in Hingham, Mass., became a part of Litton Industries in 1968. The firm has always depended upon a work force of craftsmen. It began by manufacturing megaphones and, at the start of the 20th century, produced an all-weather navigation fog-warning system for Boston's harbor islands. Merriman invented and patented an oil-less bearing called Lubrite, which was first used in yacht blocks. Today, the bearings are found on offshore drilling rigs and in components of the U.S. Space-Shuttle program.

Powder Metal Operations.

During the early 1930s, Merriman was among the first American firms to turn to the powder metals (P/M) process to manufacture parts. Ten years later, the concern began producing textile rings, which spin or twist fibers together and wind them into thread. By forming the rings by the P/M process, a level of oil could be maintained within the ring, this film of oil retards wear on a traveler that moves at speeds of 30,000 RPM as it guides yarn onto a bobbin. Certain parts, including self-lubricating bearings, can be made efficiently only by powder metallurgy. The heavy components division of Merriman produces objects weighing as much as 15 tons, but these require as much fine quality workmanship as parts weighing less than 5 pounds.

Because P/M is not used widely, Merriman must "educate" design engineers about the process' flexibility and economy. P/M-produced parts are much stronger than plastic or cast iron parts; it is designability that is the main advantage of the process. P/M allows parts that are functionally indistinguishable from machined parts to be fashioned with little or no machining. Merriman engineers were among the first--in the early 1940s--to learn the technique of forming helical gears, in which the teeth are at an angle; this is a feat still rarely duplicated in the industry. The firm also specializes in the manufacture of spurical gears, which combine the helical gear with a straight-tooth pinion gear. Merriman manufactures P/M parts in ferrous and nonferrous metals, primarily for power tool equipment and business machines, but also for automobiles (the major user of P/M parts, nationally) and garden equipment. All parts are made for non-Litton firms.

Monitoring P/M Technology.

The president of Merriman described P/M as "somewhere between black magic and a high-technology industry." P/M machines have become increasingly intricate, and the equipment that produces P/M parts needs continuous fine tuning, which cannot be done by NC or even programmable controllers.

The technology for making a P/M part has not changed radically during the past 20 to 25 years, with the exception of some improvement in powders, which has increased the scope of what can be produced. Merriman maintains a laboratory where powders are checked for strength and "growth," that is, changes that take place in the process. At least 30 percent of the parts produced by the P/M process require secondary operations such as oil impregnation, drilling, tapping, fine honing, and tumbling.

Merriman has 30 presses, of which 60 to 65 percent are in running order at any given time. The industry's standard is about 50 percent. Because P/M is a highly capital-intensive process--Merriman has several 100-ton presses that cost $250,000 each--whenever possible, three work shifts are needed to make the investment economically feasible. Hundreds to several thousand complex parts are mass-produced each hour. Although the P/M process produces little scrap, it does have problems--tool wear, breakage, and frequent preventive maintenance--because powder metals become lodged in the presses so they cannot operate at peak levels of performance.

Work Force and Skill Composition.

Because of the characteristics of P/M machinery, the demands of customers, and the increasingly complex applications, exceptionally skilled individuals are needed to set up the presses and keep them running. Merriman's P/M division employs 55 people, exclusive of engineers and managers. Although P/M division workers are members of a machinists local, they do not have the title of machinist. P/M employees include the following:

Machine or press operators	26
Set up specialists	9
Toolmakers	9

Furnace operators---------------------- 6
Furnace helpers (material handlers)----- 3
Maintenance persons--------------------- 2

Machine Operators. Machine operators in Merriman's traditional machine shop are trained to operate various machines, including drill presses, lathes, millers, and grinders, but P/M division operators handle P/M presses only. A variety of P/M presses exist, but the operator's job is considered much more "automatic" than that of the set up specialist. Press operators may or may not bid for higher skilled positions of toolmaker or set up specialist, when vacancies exist. Seniority plus a written test determine acceptance. Several women press operators were hired during a labor shortage in 1966. Six women now work on presses, and although they are not assigned heavy material-handling tasks, the firm is pleased with their performance.

Press operators must make sure that parts have the "correct integrity," but, as a rule, they do not make any adjustments in the process. To reduce costs, Merriman has sometimes coupled two presses that can be tended by a single operator. The possibilities for Merriman's automation operations are limited, however. The parts produced are quite intricate, and some of the presses are highly sophisticated (operating at different rates, while pressing out parts with about 35 tons of pressure per square inch).

Set Up Specialists. Unlike press operators, set up specialists must understand the P/M process. One set up person services four presses. A "really critical" skill involves placing tools or dies in a press. Tooling is carried out piece by piece; the pieces become part of the press. This is more complex than, say, a stamping process.

The set up specialty has been described as a craft requiring a sixth sense. The specialists can call upon a maintenance person when they sense that something is going awry in the equipment they monitor. Merriman's president suggested that it might make sense for presses to be operated by set up specialists, since they are more likely than press operators to detect anything unusual in the equipment's operation and have it repaired before a more serious difficulty occurs.

The union recognizes that set up specialists are needed to operate the presses when the work load is heavy; but if set up persons regularly operate presses, they would expect to be paid at their normal rate of pay, which is $1.50 higher than an operator's hourly rate. Merriman's president was not sure that specialists would be willing to operate presses on a permanent basis. The firm has a problem of holding onto set up specialists who desire better paying supervisory jobs but cannot be advanced to them. There is also the question of whether press operators could become proficient in the set up position.

Toolmakers. The highest paid, and presumably the highest skilled workers in the P/M division, are toolmakers and maintenance persons. Basically, toolmaking with P/M neither demands more skills nor is harder than ordinary toolmaking. According to a Merriman foreman, a toolmaker with basic skills should be able to adjust to the P/M process after about 3 months. Probably half the firm's toolmakers started out in non-P/M positions.

Furnace Operators and Helpers. Furnace operators and furnace helpers are responsible for giving a part "some integrity" by fusing the parts via sintering. Workers, who initially may be classified as material handlers, work under close supervision and train informally on the job. They progress into such responsible tasks as making temperature and atmospheric adjustments on the furnaces. Once they become competent in such monitoring functions as starting and proper loading of furnaces, they are classified as lead persons.

Maintenance Employees. Skilled maintenance persons are an important requirement for P/M operations: the equipment (by usual equipment standards) is considered frail. Piping and machining maintenance is carried out by Merriman's employees, but electrical and plumbing repairs, and even some mechanical maintenance, are done on a contract basis.

Formalization of Training.

Merriman's manager of industrial relations reports that internal training is the principal means of preparing and upgrading workers in this industry of only some 100 firms. More promising employees can be enrolled in set up specialist training programs that are provided by press manufacturers. Press operators do not require much training; it can be provided on the job.

Apprenticeship Program. The major formalization of training was initiated in May 1973. This was an apprenticeship program for the set up specialist position. The set up specialist apprenticeship requires 2,000 hours a year for 3 years. Technical instruction consists of at least 144 hours a year; it is considered regular worktime and is creditable to the 2,000 hours a year. The ratio of apprentices to journeymen is determined by Merriman's expected need for journeymen and, as a rule, does not exceed one apprentice for each set up journeyman.

As part of the regular bargaining agreement, Merriman and its union accepted Federal apprenticeship standards. A supervisor of apprentices insures that apprentices receive the variety of work experiences that are described in the apprenticeship standards. The union's business agent hopes that some of the admittedly busy technical managers at Merriman will be made available on a regular basis to explain the entire P/M process to apprentices.

Technical, or related instruction, which once was provided by public vocational schools, was discontinued because of the small number of workers. Now, instruction is carried out by correspondence courses covering such topics as mathematics and blueprint reading. Instruction in blueprint reading also is offered occasionally in the firm during nonworking hours.

Journeyman Training. Journeymen who have completed an apprenticeship continue to receive training informally through job experience. The union favors continuous but informal training and hopes that it will be extended to maintenance personnel so that more P/M equipment can be serviced by persons on the regular payroll. From the union's point of view, informal journeyman training may be more practical than a more structured program because operation, specialization, and problems differ among various firms. However, the union's preference for informal training may be partially motivated by a desire to exclude training from collective bargaining negotiations.

IMPLICATIONS FOR PRODUCTIVITY AND THE QUALITY OF WORKING LIFE IN THE METALWORKING INDUSTRIES

The New Technologies

- Manually operated machine tools will undoubtedly remain in competitive use, but American firms will have to adopt numerically controlled machines and other technologies if they hope to stay abreast of foreign manufacturers.

- Programmable controllers may offer a bridge between conventional and numerical control machining. Large-size firms have found them extremely productive, and they deserve consideration by small- and medium-size firms engaged in small-batch production. They appear to require less training and maintenance than numerical control.

  The programmable hand calculator is another low-cost technology with potentially wide applicability to firms of all sizes.

Employment Relations

- Small metalworking firms can stabilize their operations and employment by not becoming captive to a handful of contractors in one industry and by not being highly specialized in the products they make. Stable employment can encourage firms to undertake the expense of providing workers with ongoing training to adapt to new technology.

- Some American firms resemble the "best managed firms" of Japan, in which plant engineers elicit the suggestions of even semiskilled workers regarding materials, machine adjustment, and other factors which can lead to higher productivity.

- Activities concerned with productivity and job satisfaction can be dealt with by a joint labor-management committee, which handles issues not covered by collective bargaining agreements. A union leader in one case study thought that continuing education and training could also be handled more effectively by such committees.

- Most metalworkers within small firms are expected to perform multiple functions, but some jobs within even a small metalworking firm do involve quite limited, repetitive tasks. In some cases, these jobs provide certain workers with security and contentment. It may be a mistake to downgrade all repetitive work; instead, recognition should be given for all work well done.

Training New Metalworkers

- Certain educators and industry representatives maintain that an adequate supply of trained personnel will depend upon providing high school students with "technological literacy" and preemployment preparation. A "World of Manufacturing" program, developed with U.S. Office of Education funding, is designed to do this. The program has been widely applied in the nation's junior high schools. Extension of an advanced version of the course for high school students merits reconsideration by Federal education officials.

- Expansion of the preemployment training programs conducted for the Department of Labor by the National Tool, Die and Precision Machining Association deserves consideration as a means of assuring an adequate long-term supply of skilled workers in metalworking. These programs combine school instruction with on-the-job training for economically disadvantaged persons.

  A machine tool builder has raised its retention rate of women and minority employees with no prior job experience by placing them in vestibule training.

- A survey of company education and training programs showed major interest in devising practical programs involving minimal outlays. Companies prefer short-term courses, self-study materials, and use of operating specialists and managers, rather than professional educators. More firms within metalworking might become interested in expanding their training, if they were familiar with one form of the short-term course--the training module--which may be defined as a "unit of needed information and/or skill that has been translated into a unit of study."

  Additional firms might undertake to train apprentices, if the training period were shortened. Some firms have already found this to be cost effective. The Federal Bureau of Apprenticeship and Training has approved shorter apprenticeship programs if apprentices can be shown to learn faster than in the normally prescribed periods.

- It was noted in one case study that the greatest challenge is not in training people to do their jobs but in training people to work with other workers. This confirms the finding of a national survey that there is insufficient training in leadership and communication skills among the bulk of the metalworking firms.

Training Metalworkers for the New Technologies

- The know-how required by a skilled machine operator cannot be imparted through a short training course, but persons with a general machine shop background and only a modest mathematics background can be taught to program in a rather short period of time.

- Controlled teaching experiments have shown that manual programing and maintenance of numerical control equipment can be taught with about the same effectiveness on simulated numerical control equipment as with actual equipment, which is more costly.

- If workers are insufficiently trained, and therefore less productive, firms may have to hire more workers than they would if they had a skilled work force. Training and retraining are necessary to deal with the skilled worker shortage. Multiemployer cooperation in providing qualifying training within at least two large metropolitan areas is one means of achieving more training to help replace the many skilled workers who will retire.

- A work force must be ready to devote several years to learning the tooling and other process requirements for electrochemical machining, a method which is much more difficult than conventional machining. A small firm may also have to employ people who can construct or modify costly equipment.

The manufacture of powder metal parts is highly specialized; only about 100 firms use this process. Therefore, much of the qualifying and upgrade training for workers learning powder metals technology must be done by the firms themselves.

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