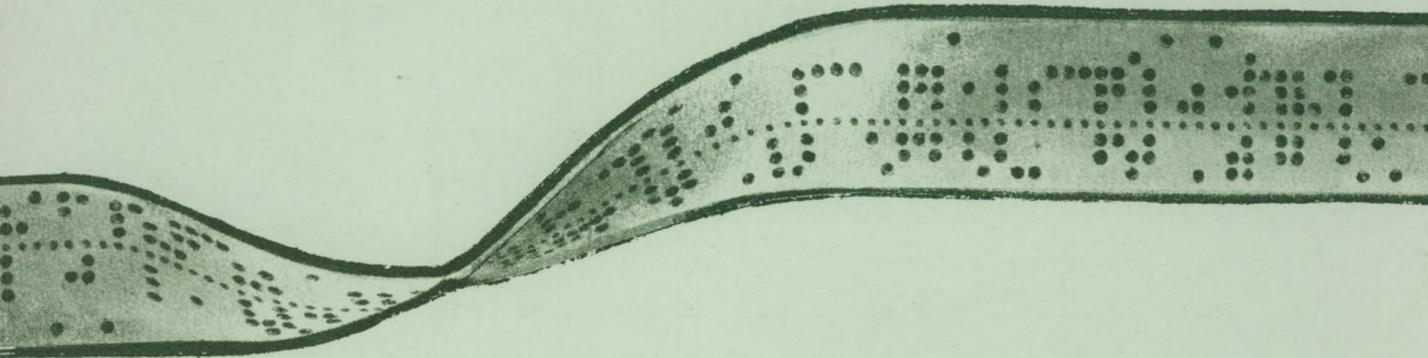


2.3:
1437

OUTLOOK FOR NUMERICAL CONTROL OF MACHINE TOOLS

MAY 28 '65



A Study of a
Key Technological Development
in Metalworking Industries

Bulletin No. 1437



UNITED STATES DEPARTMENT OF LABOR

W. Willard Wirtz, Secretary

BUREAU OF LABOR STATISTICS

Ewan Clague, Commissioner

OTHER BLS PUBLICATIONS ON AUTOMATION AND PRODUCTIVITY

Manpower Planning to Adapt to New Technology At an Electric and Gas Utility--A Case Study
(Report No. 293, 1965).

Techniques used to facilitate manpower adjustments. Covers three technological innovations affecting more than 1,900 workers.

Case Studies of Displaced Workers (Bulletin 1408, 1964), 94 pp., 50 cents.

Experiences of workers after layoff. Covers over 3,000 workers from five plants in different industries.

Technological Trends in 36 Major American Industries, 1964, 105 pp. Out of print, available in libraries.

Review of significant technological developments, with charts on employment, production, and productivity. Prepared for the President's Advisory Committee on Labor-Management Policy.

Implications of Automation and Other Technological Developments: A Selected Annotated Bibliography
(Bulletin 1319-1, 1963), 90 pp., 50 cents. Supplement to Bulletin 1319, 1962, 136 pp., 65 cents.

Describes over 300 books, articles, reports, speeches, conference proceedings, and other readily available materials published primarily between 1961 and 1963.

Industrial Retraining Programs for Technological Change (Bulletin 1368, 1963), 34 pp. Out of print, available in libraries.

A study of the performance of older workers based on four case studies of industrial plants.

Impact of Office Automation in the Internal Revenue Service (Bulletin 1364, 1963), 74 pp. Out of print, available in libraries.

A case study highlighting manpower planning and employment impacts during a major conversion to office automation in the Federal Government.

Impact of Technological Change and Automation in the Pulp and Paper Industry (Bulletin 1347, 1962), 92 pp., 50 cents.

General industry survey and three case studies highlighting implications of technological change for productivity, employment, and industrial relations.

Technological Change and Productivity in the Bituminous Coal Industry, 1920-60 (Bulletin 1305, 1961), 136 pp., 65 cents.

Trends in technology and productivity and implications for employment, unemployment, wages, prices, and profits.

Adjustments to the Introduction of Office Automation (Bulletin 1276, 1960), 86 pp., 50 cents.

A study of some implications of the installation of electronic data processing in 20 offices in private industry, with special reference to older workers.

Studies of Automatic Technology (Free).

A series of case studies of plants introducing automation. Describes changes and implications for productivity, employment, occupational requirements, and industrial relations.

A Case Study of a Company Manufacturing Electronic Equipment.

A Case Study of a Large Mechanized Bakery (Report 109).

A Case Study of a Modernized Petroleum Refinery (Report 120).

A Case Study of an Automatic Airline Reservation System (Report 137).

Sales publications may be purchased from the Superintendent of Documents, Washington, D. C. 20402, or from regional offices of the Bureau of Labor Statistics at the addresses shown below. Free publications are available, as long as the supply lasts, from the Bureau of Labor Statistics, U.S. Department of Labor, Washington, D. C. 20212.

Regional Offices:

New England Region
18 Oliver Street
Boston, Mass. 02110

Middle Atlantic Region
341 Ninth Avenue
New York, N. Y. 10001

East Central Region
1365 Ontario Street
Cleveland, Ohio 44114

North Central Region
219 South Dearborn Street
Chicago, Ill. 60603

Southern Region
1371 Peachtree Street, NE.
Suite 540
Atlanta, Ga. 30309

Western Region
450 Golden Gate Avenue
Box 36017
San Francisco, Calif. 94102

OUTLOOK FOR NUMERICAL CONTROL OF MACHINE TOOLS

**A Study of a
Key Technological Development
in Metalworking Industries**

Bulletin No. 1437

March 1965

**UNITED STATES DEPARTMENT OF LABOR
W. Willard Wirtz, Secretary
BUREAU OF LABOR STATISTICS
Ewan Clague, Commissioner**

**For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price 40 cents**

Preface

Under the Manpower Development and Training Act of 1962, the Secretary of Labor is required to establish techniques and methods for detecting in advance the potential manpower impact of automation, technological progress, and other changes in the structure of production. This type of early warning system could be of great assistance to management and union leaders, educators, government officials, economists, and others in planning policies to cushion the impact of change.

This bulletin deals with the outlook for and implications of a key technical innovation in the metalworking industries, still in a very early stage of application. Widespread adoption of numerical control of machine tools could have significant effect on productivity, occupational requirements, training programs, employment, and industrial relations.

The study was based on information obtained through review of trade and technical publications, attendance at conferences and seminars, and discussions with producers and users of numerical control and with union officials. The Bureau of Labor Statistics is grateful to the many individuals in various companies, unions, trade associations, educational institutions, research establishments, and government agencies who furnished valuable information and reviewed and commented on the draft of this report. Special acknowledgment for providing photographs is due to Cincinnati Milling and Grinding Machines, Inc., Giddings and Lewis Machine Tool Co., Kearney and Trecker, Pratt and Whitney, and Westinghouse Electric Corp.

The bulletin was prepared by John Macut in the Bureau's Division of Technological Studies under the supervision of Edgar Weinberg, Chief, and under the general direction of Leon Greenberg, Assistant Commissioner for Productivity and Technological Developments.

Contents

	Page
Summary and highlights -----	1
Automatic control by coded tape instructions -----	1
Extent of use still limited -----	2
Metalworking industries affected -----	2
Favorable prospects for rapid diffusion -----	2
Reduced unit labor requirements -----	2
Important operating advantages -----	3
Changes in occupational pattern -----	3
Numerical control generates new training needs -----	3
Need for changes in training programs -----	5
Significance of numerical control to metalworking industries ----	5
Possible employment changes in some machining occupations ---	5
Employment impact depends on economic growth -----	6
Labor-management adjustments may be needed -----	6
Chapter 1. Introduction -----	7
Evolution of machine tools -----	7
Present trend toward automation -----	8
Chapter 2. Numerical control in machine-tool technology -----	9
Relation to conventional machine tools -----	9
Development of numerical control -----	9
Two types of numerical control -----	10
Future directions of numerical control -----	12
Chapter 3. Status of numerical control applications -----	15
Number shipped -----	15
Types of numerical control used -----	16
Applications in metalworking industries -----	17
Chapter 4. Outlook for numerical control -----	21
Supply of equipment -----	21
Potential demand -----	21
Market for numerical control -----	22
Government programs -----	25
Price and demand -----	26
Chapter 5. Impact on labor requirements per unit of output -----	29
Reduction in unit labor requirements -----	29
Operating economies -----	31
Saving in capital requirements -----	31
Chapter 6. Changes in occupational requirements -----	33
Greater importance of planning and programing -----	33
Part programmer -----	36
Changes in content of machine tool operator jobs -----	37
Changes in maintenance jobs -----	38
Changes in tooling jobs -----	40
Changes in drafting and designer jobs -----	40

Contents--Continued

	Page
Chapter 7. Training for numerical control -----	41
Company training for numerical control -----	41
Implications for vocational education -----	42
Apprenticeship training program -----	42
Adult education for retraining machinists -----	43
Professional seminar sessions -----	43
Chapter 8. Implications for employment -----	47
Labor displacement and expansion -----	47
Implications for equipment producers -----	48
Employment in the metalworking industry group -----	48
Employment changes in specific machining occupations -----	50
Chapter 9. Labor-management adjustments -----	53
Method of determining skill level and wage rates -----	53
Methods of adjusting to displacement -----	54
Appendix. Selected bibliography on outlook for numerical control of machine tools -----	57
Tables:	
1. Domestic shipments of numerically controlled machine tools, selected years, 1954-63 -----	15
2. Number of numerically controlled machine tools shipped and on order, by type, 1954-63 -----	17
3. Distribution of manufacturers' shipments of numerically controlled machine tools, by major industry group, by type of control, 1954-63 -----	18
4. Percent of four categories of metal-cutting machine tools at least 10 years old, 1963 -----	22
5. Distribution of four categories of metal-cutting machine tools at least 10 years old, by industry, 1963 -----	23
6. Capital spending plans of metalworking manufacturing companies, 1964-67 -----	24
7. Spending for automated machinery by metalworking industries, selected years -----	25
8. Value of shipments and average unit values of numerical controlled machine tools, by type, 1954-63 -----	26
9. Reported labor and other cost savings of numerically controlled versus conventional machining -----	30
10. Operational flow under conventional and numerical machine tool control -----	34
11. Three comparative case studies of man-hour require- ments: conventional and numerically controlled machining -----	35

Contents--Continued

Page

Tables -- Continued

12. Description of duties and knowledge and ability required in numerical control positions at one aircraft parts producer -----	39
13. Content of training courses on numerical control open at a U.S. Government metalworking installation -----	44
14. Average weekly hours and overtime hours of production workers in metalworking industries, 1964 -----	49

OUTLOOK FOR NUMERICAL CONTROL OF MACHINE TOOLS

Summary and Highlights

Numerical control (N/C) of machine tools is a relatively new technique of advanced automatic machining which opens possibilities for a faster rate of growth in productivity within the important metalworking sector of the economy. Numerical control is particularly suitable for the manufacture of a variety of different metal parts in small volume--the job shop type of production which comprises a large part of the metalworking industry. The techniques and equipment now used generally in this type of production lag considerably behind the high degree of mechanization in mass production of standardized metal parts.

Although use of numerically controlled machine tools is still limited, the prospects for rapid diffusion over the next few years are highly favorable.

The same operations necessary to conventional machining are required for numerical control, but different tasks and skill requirements are created, especially for the occupations of planning, machine operator, and maintenance. It creates a new occupation of "part" programmer. Since the procedures and operation of numerical control are new to the machining work force, workers must be trained to utilize this technique.

As long as the economy is expanding, the introduction of numerical control may not result in extensive labor displacement, but labor-management adjustments to provide for orderly changeover will be required.

Automatic Control by Coded Tape Instructions

Previous changes in machine-tool technology involved largely improvements in power, speed, and specialization. Numerical control permits automatic operation of machine tools by such means as a system of electronic devices (control units) and changeable tapes. The control unit interprets coded tape instructions (prepared in advance by the programmer) and can direct the machine tool automatically through the programmed sequence of machining operations (drilling, milling, boring, turning, etc.) while controlling machining speeds and feeds, distance and direction of movement of the tool or workpiece, flow of coolant, and even the selection of the proper preset cutting tool for each operation. In operating most conventional machine tools used in the small lot manufacture of metal parts, such machine setup and control conditions are largely determined and manually arranged by the operator. In addition, expensive fixtures, jigs, and templates to hold the work in place and to guide the cutting tool are needed.

Extent of Use Still Limited

Numerical control is still in an early stage of development and commercial use but the growth rate has increased in recent years. A total of 3,365 units were shipped by producers to domestic users between the beginning of 1954 and the end of 1963; but 64 percent of these were shipped in 1962 and 1963, and 611 (including a small number for export) more were on order at the end of 1963.

Metalworking Industries Affected

About 55 percent of all numerically controlled machine tools were shipped to six major industries engaged in small batch metalworking production: aircraft, metalworking machinery, special industrial machinery, general industrial machinery, machine shop, and construction equipment. Every major metalworking industry, however, has at least one numerically controlled tool. The motor vehicles and parts industry, are adopting increasingly this technique of machining to replace the costly and time-consuming methods of producing the large amount of tools, dies, and fixtures needed in operating their highly specialized production machines.

Favorable Prospects for Rapid Diffusion

Numerical control is likely to be adopted increasingly over the next few years. The proportion of machine tools, 10 years old and over, which may be fully depreciated and hence economically replaceable by numerically controlled units is high throughout metalworking. Some industry experts foresee 12,000 installations of numerical control by 1967. Even this optimistic estimate, however, leaves N/C machine tools in a limited stage of use--about 1 percent of all machine tools presently installed. Diffusion is being speeded by increased familiarity with the use of numerical control and greater knowledge of its economic advantages, increased outlays for plant and equipment (particularly automated) planned by metalworking industries, tax provisions favorable to new investment, and the Federal Government's encouragement of the use of numerical control in defense work. The high price of numerical control relative to conventional equipment is an obstacle to its rapid adoption even though capital requirements per unit of output are probably significantly lower for numerical control. A few simplified, less expensive models of several types of N/C machines have become available recently, and as a larger variety of models are marketed this may increase.

Reduced Unit Labor Requirements

Numerical control makes possible substantial reduction in unit labor requirements relative to conventional machine tools. The amount depends on the complexity of the design of the part, number of parts produced, number and type of operations, type of machine tool (s) formerly used, etc. Some examples disclosed unit labor savings of 25 to 80 percent over conventional methods. Such savings result from many factors--one

numerically controlled tool can replace several conventional tools and their operators, tooling and setup time is reduced because tape controls virtually replace the use of jigs and fixtures, machining time is shortened since the operator no longer has to interrupt the work cycle to readjust the machine or to recheck the blueprint information, and time to repair rejects and inspect parts is greatly reduced because of the greater consistency of accuracy in reproduction of parts. Although maintenance, planning, and programming (which is not incurred in conventional machining) result in increased man-hours, they are usually more than offset by labor savings in the other operations.

Important Operating Advantages

Cost savings on certain operations, though usually difficult to determine, are frequently cited by users and producers to justify numerical control. Shortening of lead time in production is particularly advantageous, for example, in aerospace work, because it affords opportunities to incorporate last minute design changes in a fast changing field. Because of the greater accuracy and flexibility of numerical control, parts formerly uneconomic or technically impractical to produce are often feasible. Fewer tools mean less floor space needed, and savings in storage space can be considerable since significantly fewer jigs and fixtures are needed.

Changes in Occupational Pattern

Although occupations necessary under conventional machining--part designers, method planners, tooling men, and machine-tool operators--are still required under numerical control, their functions, relative level of skill requirements, and decisionmaking responsibilities change. Maintenance becomes more important in terms of skill requirements and responsibility. Numerical control requires additional knowledge of servomechanisms, electronics, and numerical control systems--and responsibility for much more highly priced equipment. Much of the work in developing control data and instructions by machine-tool operators and tooling men under conventional techniques is transferred to the planning stage and to programming. The operator of a conventional machine must set up the machine, including indexing of table or workpiece; selecting the cutting speed and feed; and adjusting the machine settings to achieve part specifications. Under numerical control, these duties are automatically carried out by coded tape instructions. The work of an operator of a numerically controlled machine tool tends to become monitoring or watching but with added responsibility for much more costly equipment.

Numerical Control Generates New Training Needs

The tasks and skills associated with numerical control require development of new training efforts, particularly for jobs in machine operation, programming, and maintenance. It is estimated that more than 50,000 persons will have had to be trained between the end of 1963 and 1967.

Some Major Steps In Numerical Control Machining

Design and Drawing of Part



Programing and Preparation of Control Tape



Combining Control Tape and Machine



Operator Starts Automatic Operation of a Numerically Controlled Drilling and Milling Machine

Conventional machining workers require specific retraining, but are generally readily transferable to related jobs under numerical control. Training programs already underway usually provide formal classroom instruction at company expense and on-the-job training for programing and maintenance; on-the-job training alone is generally considered sufficient for operators. The length of classroom training for programers with a skilled knowledge of machining, and for maintenance men with conventional maintenance skills and some knowledge of electronics is usually less than 5 weeks. The on-the-job training for these two jobs may vary from 3 weeks to 6 months. A machine-tool operator usually learns to operate a numerically controlled tool in a few weeks.

Need for Changes in Training Programs

While producers and users of equipment are currently the principal sources of training, instruction in numerical control could be incorporated into the curriculums of vocational schools, apprenticeship programs, technical institutes, and other institutions from which machining workers learn their skills. Examples of training programs already provided by a government installation, a State board of education, and a professional society point up the variety of possible approaches.

Significance of Numerical Control to Metalworking Industries

Since three-fourths of all metalworking production is estimated by industry experts to consist of lots numbering less than 50 pieces, the employment and other economic impacts of numerical control could be quite significant. Metalworking industries--ordnance, fabricated metal products, machinery, electrical machinery, transportation equipment, instruments and related product producers--employed 6.6 million persons in 1964, accounting for close to two-fifths of total manufacturing employment in the United States. The workers most directly affected by the introduction of numerical control will be 1.1 million machining workers (in all sectors of manufacturing and nonmanufacturing) who, in early 1963, were employed as all-round machinists, machine-tool operators, tool and die makers, instrument makers, and setup and layout men.

Possible Employment Changes in Some Machining Occupations

Growth in employment in each machining occupation could be slowed by widespread use of numerical control. The extent of the impact would depend on how fast industry adopts this new technology; and some occupations are likely to be affected more than others. Employment of machine-tool operators is particularly sensitive to change and likely to be curtailed. Machinists and instrument makers--many of whom work in repair shops and research and development laboratories--where numerical control is not likely to be used extensively--may not experience any serious curtailment in employment. Highly skilled craftsmen, such as toolmakers and setup men, are likely to be affected adversely since fewer jigs, fixtures, and

machine setups will be required. The net effect on the employment of the various occupations will depend on a number of factors including the future levels of metalworking output, the changing unit labor requirements made possible by numerical control, and the extent to which disemployed workers can be utilized in other occupations in the industry. For example, decline in the level of employment of skilled machine-tool operators and toolmakers could be partially offset by the demand for programmers.

Employment Impact Depends on Economic Growth

Reduced labor requirements per unit of output made possible by numerical control could result in decreased employment if the output of metalworking plants and industries is declining, constant, or increasing relatively slowly. In plants and industries where output is expanding, numerical control could slow the growth of employment. The impact of numerical control may fall more heavily on marginal plants which do not introduce numerically controlled machine tools and may be unable to compete with the more automated metalworking plants. Employment among producers of electronic control systems may expand because of sales increases induced by the emergence of numerical control. Because of the probable decreasing demand for conventional machine tools, the net result of the emergence of numerical control on future employment in the machine tool industry is difficult to determine.

Labor-Management Adjustments May be Needed

Changes in manufacturing practices stemming from widening introduction of numerically controlled machine tools may pose a variety of questions for collective bargaining, notably determination of wage levels and wage criteria for new jobs, necessary revisions in incentive plans, jurisdictional problems, and means and standards of selection of personnel for new jobs. As the diffusion of numerical control affects wider areas of employment, unions and management may find it necessary to give greater attention to measures for advance notice and preparation; for avoiding layoffs; for easing the burden of displacement; and for facilitating new employment.

Chapter I. Introduction

Metalworking industries employed 6.6 million persons in 1964 or about 38 percent of total employment in manufacturing in the United States. Over 70,000 plants in these industries produced the consumer and producer durable goods that characterize a highly industrialized economy.

The basis of metalworking technology is over 2.1 million machine tools. Because they are basic in the reproduction of themselves and the production of all other machinery--from textile looms to turbines--machine tools are described as "master tools" of the economy.

In this study, the term "metalworking industries" is used to categorize those industries where metalcutting operations are basic to the production technology of the primary end products. Essentially, the term includes the following six major Standard Industrial Classification industries: Ordnance and accessories (SIC 19); fabricated metal products (SIC 34); machinery, except electrical (SIC 35); electrical machinery (SIC 36); transportation equipment (SIC 37); and instruments and related products (SIC 38). A few other industries, such as primary metals (SIC 33), where metalcutting operations are present but are not primary to overall activity are included in some of the data and analyses.

Evolution of Machine Tools

The evolution of machine tools began in the first days of the Industrial Revolution. The "American System of Interchangeable Parts Manufacture"--the principle of all mass production--was ushered in by such developments as Eli Whitney's jigs, fixtures, and milling machine by which operating and control functions were transferred from the skilled handcraftmen to the machine tool and significant improvements in precision of operation were achieved. The "American System," soon adopted by industry universally, makes it possible to produce a specific part of a machine, in large numbers, each part so precisely like the other that any one part can be freely used in assembly of the final product. First used in making muskets and revolvers, the method was extended in the first half of the 19th Century to the making of clocks, farm machinery, sewing machines, and other durable goods.

The latter half of the 19th Century saw the introduction of a wide range of special tools. A variety of tools were designed to perform one or more of the five basic arts of metalcutting--drilling, turning, milling, grinding, and planing. The introduction of hydraulic, pneumatic and electric controls led to greater degree of automatic operation. A key advance was the use of individual electric motors in place of the belt, shaft, and steam engines. Speeds, feeds, horsepower, and auxiliary equipment such as carbide tipped cutting tools were continually improved.

Largely because of such cumulative developments, machine tool productivity has increased steadily. For example, studies conducted by American Machinist found machine tools of 1958 design to be, on the average, 54 percent more productive (output per machine hour) than those designed 10 years earlier. And 1950 models were found to show a 40-percent improvement over those produced in 1940.

Present Trend Toward Automation

The word "automation" was coined in 1946 to describe highly automatic production techniques first introduced in the mass production of automobile parts. This development consists essentially of the integration of machine tools with one another by conveyors to enable the automatic processing and handling of a workpiece in, between, and out of the machines. Such transfer lines, which are used to perform scores of different machining operations on a part with a minimum of human assistance, have been introduced into many metalworking plants producing on a mass production basis.

Improvements in machine-tool technology clearly have far-reaching implications, not only because of the large number of workers whose employment may be directly affected, but also because of the stimulus to mechanization that could come eventually from cost savings in producing industrial machinery. Cheaper machinery could ultimately create opportunities for a faster pace of technological change and for greater productivity in many sectors of the economy.

Numerical control represents the latest major development in making machining more automatic. Used primarily for automatically producing parts in small quantities, this innovation draws on advances in electronics that have developed out of postwar research and development. The nature of this innovation, the extent of present and prospects for future usage, and some of its probable implications for productivity, occupations, training, employment and industrial relations are covered in subsequent chapters of this study.

Chapter 2. Numerical Control in Machine-Tool Technology

Numerical control of machine tools is a technique of automatic operation by means of numerical instructions expressed in code. These instructions or program are prepared in advance. Recorded on punched cards, magnetic or paper tapes, these coded instructions can control the sequence of machining operations; machine positions; speed, distance and direction of movement of the tool or workpiece; flow of coolant; and even the selection of the proper preset cutting tool for each operation. The tapes are placed on a control unit--a system of electronic interpreting devices. When the control unit is activated, it can drive the machine tool through the programmed operations and movements without any human intervention. The machine operator's role is limited largely to starting, stopping, loading and unloading, and observing the tool. The operator can change instructions easily after each job by replacing the roll of tape on the control unit with another, containing a different program.

Relation to Conventional Machine Tools

Numerical control can be best understood by comparison with the two conventional types of control generally used in the operation of machine tools. In general purpose machine tools--the most common type--instructions about direction, speed, and distance the tool must travel in cutting a particular part are established manually by an operator who rearranges various elements such as cams, bars, and sequencing and cycle timers according to the needs of a particular job. The machine operator consults blueprints and other data to get his instructions. In the second type--the specialized machine tool--instructions about sequencing, positioning, and tool travel are built into the machine through mechanical-electrical devices but these are restricted to a fixed set of operations for mass production of parts of one specific design. This type of control is found in types of specialized automatic machine tools used for making long runs of the same item. This second type of control also results in a high degree of automatic operation.

Both conventional systems require a considerable time (compared to numerical control, as will be shown later) for setting up the controls and making expensive tooling such as templates, jigs, and fixtures to guide the cutting tool in its operation. In addition, operation of conventional machine tools does not achieve the high degree of coordination and precision inherent in numerical control.

Development of Numerical Control

Research and development on numerical control--which got underway after 1947--was accelerated by the need of the aircraft industry for new machining techniques that could produce the many intricately designed parts of high-speed planes cheaper, faster, and more accurately than was possible with conventional techniques. Advances in communication engineering, servomechanisms and electronics, perfected during World War II for directing

antiaircraft fire, provided the basis for making numerical control technically practicable.

Early developmental work on this innovation was carried forward through joint research efforts of universities, the Air Force, and aircraft industry. An initial study was conducted in 1948 by a small airplane parts manufacturer under a contract for the U.S. Air Force. Later the Massachusetts Institute of Technology undertook an extensive Air Force sponsored project and by the fall of 1952, MIT engineers and scientists had successfully developed the first numerically controlled milling machine, establishing the concept of numerical control practicable for industrial use. Refinement of principles and techniques was continued at MIT and begun by numerous machine tool builders and producers of electronic control and computer equipment. In 1955, the first few commercial models of numerically controlled machine tools were displayed at the National Machine Tool Show and placed into factories for operational use. By 1957, numerically controlled machine tools were installed and used in production in various Air Force contractor plants located across the country, providing an important impetus to industrial application.

Since their commercial introduction, research and development have advanced numerical control significantly. Reliability of control components has been increased, special systems for a variety of specific machine applications have been devised, and a wide range of competing systems featuring varying combinations of electronic, electrical, hydraulic, optical, pneumatic, and mechanical control devices have been made available to choose from. At the present time, more than 40 different numerical control systems are available.

Two Types of Numerical Control

Numerical control systems are classified under two basic functional types--positioning and continuous path. Positioning systems are used to control machine tools such as the drill and jig borer which perform operations only at specified points on a workpiece. In drilling, for example, the drill spindle is positioned at a single specific point; the proper drill size, speed and feed selected; the drill advanced to cut a hole to the proper depth; withdrawn when completed; and repositioned to cut at the next point of work. Compilation of the required instructions for operation of a positioning system--programming--can almost always be easily performed by a programmer with only the aid of a manual desk calculator.

The continuous path system is used to control such machine tools as the lathe and milling machine. Such tools remove metal continuously over the surface of a workpiece as in milling a propeller blade. The problem is to control continuously a cutting tool which requires frequent changes in movement along two or more machine axes simultaneously and is in constant contact with the workpiece.

The continuous path system is more complex and requires a far greater input of detailed instructional information than a positioning system. Although direct programming with a desk calculator is also possible for

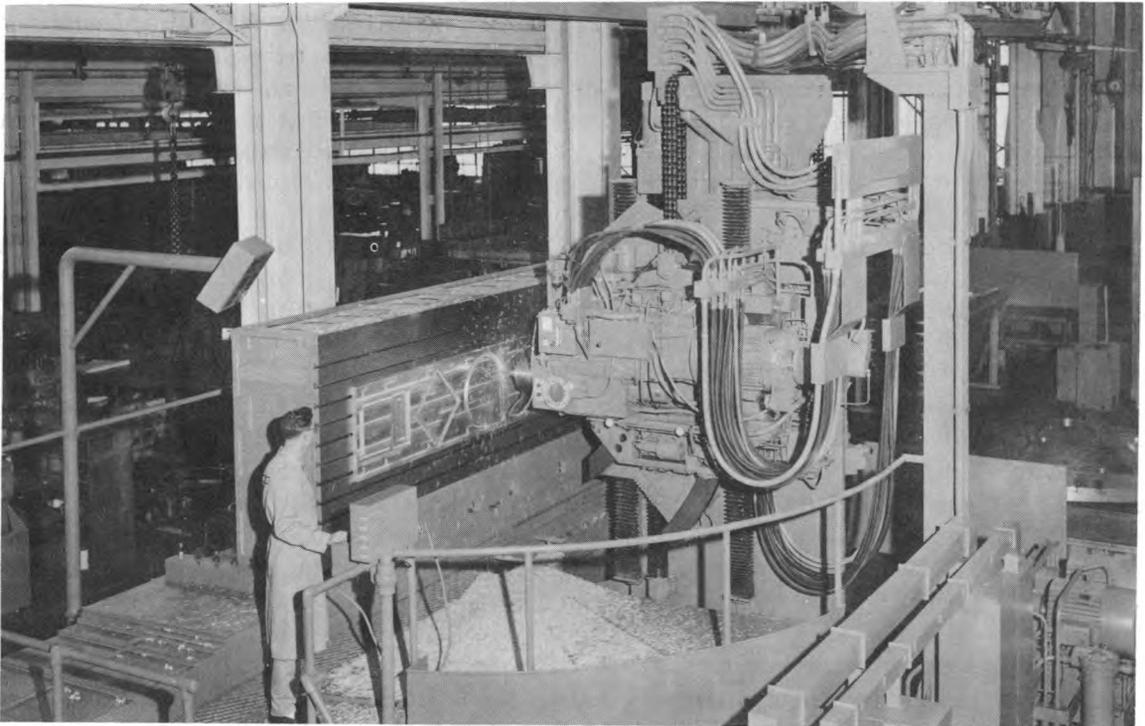
While operator monitors, a tape automatically controls a:



ENGINE LATHE



DRILLING MACHINE



MILLING MACHINE

continuous path systems, it would be too time consuming for practical use of the system. Therefore, the use of an electronic computer has become practically indispensable as a computing tool for the programmer preparing instructions for machine tools controlled by a continuous path system.

Future Directions of Numerical Control

The significance of numerical control lies in the possibility of its becoming a major means of making more automatic the production of items that are manufactured in small batches rather than on a mass-production basis. Since industry experts estimate that about three-fourths of all metalworking production consists of items manufactured in quantities of less than 50 pieces, the economic impact of numerically controlled machining could be quite significant. Such jobbing production is common to all sizes of firms--from small machine shops employing only a few persons to the large plants employing thousands of workers. Moreover, even those firms which produce primarily on a mass-production basis also have numerous departments engaged in jobbing production.

Current research and development are directed to advancing numerical control to the most automatic, universal, and flexible type possible. The future may see, for example, more equipment featuring "adaptive control"--a control refinement that combines automatic machining with constant monitoring of the results. This concept permits a continuously automatic adjustment of the machine and programmed feeds, speeds or other instructions to compensate for such uncontrollable factors as vibrations, cutting-tool wear, and temperature changes.

Another increasingly important development is "the machining center," also called multioperation machine, capable of performing a number of operations in machining a whole part under numerical control. A number of machining centers are already on the market and in operation. Such machines are expected to become available in various sizes and capabilities. Some machining centers can be complete machine shops in themselves.

Further important advances, through the use of the computer, are also being made toward simpler, faster, and more automatic preparation of the machine instructions and control tapes that command the machine. Computer assisted programming consists essentially of a specially devised symbolic language capable of transmitting a brief, simple description of the machining operations and shape of the workpiece to a computer. In turn, the computer calculates and translates these brief directions into the detailed machine instructions and coded language of the control tape. Computerized programming has become essential in the applications of the continuous path type of numerical control where manual programming proves too slow, time consuming, and uneconomic. Its use, however, has been extended to the less complex positioning type of numerical control.

The current advanced state of automatic programming has been due in large measure to the continuing efforts of the users and producers of the numerically controlled machine tool and computer. At the present time,

numerous systems are available, including the well advanced and widely used Automatically Programmed Tool System (APT), largely developed by the Aerospace Industries Association on the basis of earlier work started at MIT under contract to the U.S. Air Force.

The possibility of extending the principle of numerical control to other types of production machinery is also being tested. Operations most frequently mentioned as already being successfully adapted to this type of control include drafting, assembling, riveting, welding, inspecting, testing, tube forming, molding, wire wrapping, and steel rolling. In these applications, tapes or cards, on which numerical data about the dimensions, sequence and timing of operations are recorded, are used to control production equipment. Numerical control thus has far-reaching implications for other operations in metalworking and for other industries.

Chapter 3. Status of Numerical Control Applications

Numerically controlled machine tools are used at present only to a limited extent. They are being accepted increasingly, however, as a practical method in metalworking industries.

Number Shipped

Although the number of numerically controlled tools is still relatively small--less than 1 percent of the total number of machine tools installed--the number increased markedly in recent years. Approximately 64 percent of the total was shipped in 1962 and 1963. The number of all types, shipped to domestic users between January 1954 (the first year of commercial prototype usage) to December 31, 1963, totalled 3,365. (See table 1.) An additional 611 units were reported on order, including a small number for export. These figures were reported to the Department of Commerce by metalworking equipment producers. A total of 60 companies reported shipments of numerically controlled equipment in 1963.

In the American Machinist 1962 survey of a national inventory of machine tools, about 4.5 percent of all companies responding reported having numerical control, compared to 1.5 percent in a small study made in 1960.

Table 1. Domestic Shipments of Numerically Controlled Machine Tools, Selected Years 1954-63

Period	Number	Percent of total
Total, 1954-63.....	3,365	100.0
1954-58.....	181	5.4
1959.....	178	5.3
1960.....	366	10.9
1961.....	496	14.7
1962.....	997	29.6
1963.....	1,147	34.1

Source: U. S. Department of Commerce, Bureau of the Census and Business and Defense Services Administration.

Types of Numerical Control Used

Drilling machines lead the list of specific types of numerically controlled machine tools shipped, accounting for 47 percent of the total (table 2). They also comprise about half of those on order.

The next most numerous type is the boring machine, with about 18 percent of the total. The milling machine, the first to be adapted to numerical control, constitutes the third most important type comprising 15 percent. Lathes accounted for about 11 percent of the total.

About 9 percent of all numerically controlled tools reported by the Department of Commerce's survey of shipments are in the miscellaneous category, including grinding and polishing machines, punching and shearing machines, and certain types of metal-forming tools such as presses, forges, and bending machines.

Some types of metalworking operations are considered less suitable for application of numerical control because of certain technical difficulties. Abrading or grinding, where surface dimensions must be measured, are in this category. Also, certain simple metalcutting tools such as saws and polishing and threading machines are less adaptable to numerical control.

The Commerce Department survey categorized numerically controlled machine tools under three headings: point to point positioning (as described above), accounting for over 66 percent; continuous path type, comprising about 12 percent; and the dial or plugboard type; accounting for about 20 percent. The latter type consists of machines equipped with numerical program control systems in which "positioning" or "continuous path" are automatically commanded by numerical programs fed into the systems by means of dials, plugs, or switches, or by playback of prerecorded operations programs.

Table 2. Number of Numerically Controlled Machine Tools Shipped and on Order, by Type, 1954-63

Type	Number of machines	
	Shipped (1954 to December 31, 1963)	On order (December 31, 1963)
Total.....	13,583	1611
By type of machine:		
Drilling machines.....	1,690	271
Boring machines.....	636	126
Milling machines.....	540	78
Lathes.....	402	91
Grinding, polishing, and other.....	315	45
By type of numerical control:		
Point to point positioning.....	2,478	374
Continuous path.....	441	132
Dial or plugboard type.....	664	105

¹ Includes export shipments. Information not available on shipments by type of N/C to domestic users only.

Source: U.S. Department of Commerce, Bureau of the Census and Business and Defense Services Administration.

Applications in Metalworking Industries

Numerical control appears to be adaptable to operations in a wide range of metalworking industries. About 55 percent of the numerical controlled tools shipped went to six industries: aircraft, metalworking machinery, general industrial machinery, special industrial machinery, machine shops, and construction equipment. But at least one tool was shipped to every major metalworking industry. (See table 3.)

Numerical control is particularly adaptable to the aircraft and machinery industries and these industries will probably remain the most important users. Plants in these industries typically manufacture small batches of a wide variety of parts, and tooling time constitutes a high proportion of the total cost of production.

Table 3. Distribution of Manufacturers' Shipments of Numerically Controlled Machine Tools, by Major Industry Group, by Type of Control, 1954-63

Description	Shipments			
	Total number, 1954-63	Number with point-to-point positioning controls	Number with continuous path controls	Number with dial or plugboard type or prerecorded motion program controls
Total -----	3,583	2,478	441	664
Ordnance and accessories -----	135	75	43	17
Primary metal industries, total -----	29	(¹)	(¹)	(¹)
Fabricated metal products, total -----	273	191	35	47
Metal cans; cutlery, hand tools, and hardware -----	127	(
Heating apparatus, structural metal products, screw machine products, metal stampings -----	103	{ 191	35	47
Fabricated wire products, not elsewhere classified, fabricated metal products, not elsewhere classified -----	43	(
Machinery, except electrical, total -----	1,543	1,189	93	261
Engines and turbines -----	94	(
Farm machinery and equipment -----	52	{ 586		
Construction and like equipment -----	171	(
Metalworking machinery -----	490	{		
Special industry machinery -----	221	(
General industrial machinery -----	248	{ 419	93	261
Office machines, not elsewhere classified --	63	(
Service industry machines -----	26	{ 184		
Machine shops -----	178	(
Electrical machinery, total -----	335	293	16	26
Electric distribution products -----	29	(
Electric industrial apparatus -----	82	{		
Household appliances; electric lighting and wiring devices -----	39	{ 293	16	26
Radio, TV, receiving equipment -----	12	(
Communication equipment -----	113	{		
Electronic components; electrical products, not elsewhere classified -----	60	(
Transportation equipment, total -----	859	485	222	152
Motor vehicles and equipment -----	194	(
Aircraft and parts -----	629	{ 485	222	152
Ships and boats -----	19	(
Railroad equipment -----	17	(
Instruments and related products, total -----	68	55	(¹)	(¹)
Scientific instruments -----	31	(
Mechanical measuring devices -----	24	{ 55	(¹)	(¹)
Optical, surgical, and medical instruments; photographic equipment; and watches -----	13	(
All other, including exports -----	341	(¹)	(¹)	(¹)

¹ Withheld to avoid disclosing figures of individual companies.

Source: U. S. Department of Commerce, Bureau of the Census and Business and Defense Services Administration.

Aircraft industry experts estimate that numerical control could be applied to 20 to 40 percent of all machining. Making airframes for jet aircraft requires such a technique of machining parts to meet the demand of high strength to weight and close tolerances. Experts in this industry anticipate a fourfold increase by 1972 in the number of numerical controlled machine tools in use.

A major firm producing electrical and nonelectrical machinery reports that about 50 percent of its machining operations are suitable for numerical control applications. This includes machining in job lot production shops, tool and die shops, and repair-replacement and parts shops. At the present time, this firm has adapted only about 2 percent of its machining to numerical control. It expects to achieve conversion of all machining suitable for numerical control within the next 10 to 20 years, with an estimated tenfold increase in the number of numerically controlled machine tools in use.

Numerical control is also being introduced in the motor vehicles and parts industry, which are the major purchasers of machine tools and leaders in development and use of automation machinery for mass production. An important use is in the fabrication of tooling, including dies, needed in operating the industry's highly specialized machines.

Not only is numerical control being adopted by additional firms and industries but once its advantages have been determined, some firms extend its applications to a variety of operations. One company producing printing machinery, for example, uses more than 30 different types of numerically controlled machine tools. A major multiproduct firm whose various job lot machinery producing plants were using approximately 50 units in 1961, reported having about 280 machine tools with numerical control in the fall of 1964.

Chapter 4. Outlook for Numerical Control

Prospect for a substantial increase in sales of numerical controlled machine tools in the immediate future appears to be favorable--reflecting the generally favorable business outlook in the metalworking sector of the economy. Some industry experts expect sales of numerical control to increase rapidly over the next few years and speculate that by 1967, they may comprise 30 to 50 percent of all machine tools sold. The possibility of 12,000 numerical controlled units by 1967 is also foreseen. Several economic factors may affect the outlook.

Supply of Equipment

A variety of numerical control equipment for industry's diverse needs is becoming available as the machine-tool industry gives increasing attention to the production and marketing of this type of machine tool. At the 1955 National Machine Tool Show, only seven companies exhibited such equipment. In 1964, over 50 companies were selling numerically controlled tools. Among these were the largest machine-tool producers.

Since manufacture of numerical control devices involves application of specialized skill and knowledge of modern electronics, machine-tool builders have generally limited themselves to the construction and assembling of the machine tools themselves, purchasing control systems from 40 producers or more of electronic control equipment. Only about 12 machine-tool builders are currently engaged in production of controls for their own use.

Domestic and world competition may induce U.S. producers to participate in the manufacture and marketing of numerical controlled tools to a greater extent than hitherto. Japanese and German machine-tool producers have already begun to offer such tools for sale in U.S. and foreign markets, but so far only a few units have been sold in the United States. Generally, foreign machine-tool producers are behind the U.S. in experience and background in numerical control.

Potential Demand

The potential demand for new machine tools, including numerical control is asserted by many experts in the field to be high because of the high average age of machine tools in use. The most recent American Machinist inventory of machine tools (1963), shows that more than 1.3 million units, or 64 percent of the machine tools installed in metalworking establishments (as compared with 60 percent in 1958), are at least 10 years old and therefore many are presumably fully or substantially depreciated and subject to replacement. Of this number, more than 782,500 fall into the four categories of machine tools--drilling, lathes, milling, and boring machines--which, at present, are being most frequently adapted to numerical control (table 4).

Table 4. Percent of Four Categories of Metal-Cutting Machine Tools At Least 10 Years Old, 1963

Category	Total number (units)	Tools at least 10 years old	
		Number	Percent of total
All metal-cutting machine tools -----	2,137,497	1,364,792	64
Total four categories -----	1,210,291	782,514	65
Drilling machines -----	446,618	281,524	63
Lathes -----	447,179	301,037	67
Milling machines -----	236,346	148,546	63
Boring machines -----	80,148	51,407	64

Source: American Machinist, June 10, 1963.

The potential market for numerical control, on this basis, is not confined to a few industries but is widely distributed throughout all of metalworking. In 18 of the 29 metalworking industries, the number of overaged machine tools equals or exceeds the national average of 65 percent. Included in the 18 are the construction and mining machinery, general industrial equipment, farm machinery, and special machinery industries--all of which produce primarily in small and medium sized quantities for which numerical control is considered most adaptable (table 5).

It is important to keep in mind, however, some limitations in equating precisely the average age of machinery and the extent of obsolescence. A single unit of a new, more efficient model, for example, may be equivalent in capacity to a number of older machine tools, some of which do not lose their economic usefulness and are retained on the inventory. Furthermore, other old units may be removed from first line production, but retained for production of spare parts or reserve capacity. Also, it is not uncommon for companies to rebuild rather than replace an old machine tool with the current manufactured model. The average age of machine tools may, therefore, rise over time but this does not necessarily imply that the extent of obsolescence is rising to the same extent.

Market for Numerical Control

Widespread adoption of numerical control depends also on overall investment plans, either for modernization or expansion; the outlook for sales, profits, and taxes; and willingness of firms to scrap obsolete equipment with which they are familiar and which still can be used economically.

Table 5. Distribution of Four Categories of Metal-Cutting Machine Tools At Least 10 Years Old, by Industry, 1963

Industry	Machine tools, all ages ¹		Machine tools, 10 years and over		
	Number	Percent of total ²	Number	Percent of total ²	Percent or industry total
All metalworking industries -----	1, 210, 291	100	782, 514	100	65
Fabricated metal products -----	212, 203	18	140, 929	18	66
Cutlery, hand tools, etc. ----	23, 745	2	15, 857	2	67
Heating apparatus -----	12, 598	1	10, 160	1	81
Fabricated structural metal products -----	41, 929	4	27, 735	4	66
Screw-machine products ----	65, 569	5	43, 697	6	67
Metal stampings -----	20, 621	2	12, 908	2	63
Miscellaneous fabricated metal products -----	33, 308	3	21, 657	3	65
Other fabricated metal products -----	14, 433	1	8, 915	1	62
Machinery, except electrical --	483, 048	40	323, 408	41	67
Engines and turbines -----	24, 243	2	19, 978	3	82
Farm machinery and equipment -----	23, 161	2	17, 300	2	75
Construction, mining, and material handling equipment -----	45, 341	4	34, 139	4	75
Metalworking machinery ----	107, 452	9	66, 597	9	62
Special industry machinery --	61, 409	5	44, 196	6	72
General industrial equipment -----	76, 905	6	53, 505	7	70
Office, computing and accounting machinery ----	19, 649	2	11, 787	2	60
Service industry machinery --	19, 597	2	14, 189	2	72
Miscellaneous machinery, except electrical -----	105, 291	9	61, 717	8	59
Electrical machinery and equipment -----	144, 902	12	77, 424	10	53
Electrical equipment -----	73, 085	6	43, 357	6	59
Household appliances -----	12, 815	1	10, 628	1	83
Communication and electronic equipment -----	59, 002	5	23, 449	3	40
Transportation equipment ----	190, 560	16	127, 154	16	67
Complete motor vehicles ----	10, 320	1	8, 000	1	78
Automotive parts -----	66, 009	6	46, 824	6	71
Complete aircraft -----	21, 154	2	13, 772	2	65
Aircraft engine and parts ----	84, 754	7	51, 352	7	61
Ships and railroad equipment -----	8, 323	1	7, 206	1	87
Precision instruments and mechanisms -----	68, 745	6	39, 308	5	57
Ordnance and accessories ----	16, 590	1	11, 276	1	68
Furniture and fixtures (metal only) -----	9, 125	1	5, 417	1	59
Primary metal industries ----	60, 521	5	42, 807	6	71
Miscellaneous manufacturing industries -----	24, 597	2	14, 791	2	60

¹ The four categories of machine tools are: drilling machines, lathes, milling machines, and boring machines.

² Because of rounding, columns may not add to totals.

Source: American Machinist, June 10, 1963.

Actual sales of machine tools, a durable good for which purchases intended for modernization of plant capacity are postponable, fluctuate widely with business conditions and the outlook in metalworking industries. Since the postwar peak level of 1952 and 1953 (during the Korean crisis), shipments of metalcutting machine tools have fluctuated widely. In 1956, shipments (industrial types with unit values \$1,000 or more) were at a peacetime peak of \$834 million. By 1958, the level had fallen by 49 percent, to \$422 million. By 1963, value of shipments had risen to \$622 million, 47 percent above the 1958 low but still below the 1956 level. Preliminary reports for 1964 indicate a 28-percent increase over 1963. Reasons given for the depressed state of machine-tool sales until recently include the large unused metalworking capacity, increasing use of plastics, and the substitution of other types of metalworking processes for metalcutting.

Machine-tool sales are expected to continue to increase over the next few years. A Department of Commerce estimate indicates a substantial increase in shipments in 1965 over 1964. According to the 1964 McGraw-Hill report on industry's capital spending plans, metalworking industries planned significant increases in expenditures for plants and equipment. Expenditures were to rise by about 22 percent, from \$4.7 billion in 1963 to \$5.7 billion in 1964. All metalworking industries except aerospace planned increases. (See table 6.) Preliminary plans for the 1965-67 period indicate a continued high level of investment in these industries. The major part of planned spending is for replacement and modernization of machinery and equipment.

Table 6. Capital Spending Plans of Metalworking Manufacturing Companies, 1964-67

(Billions of dollars)

Metalworking industries	Actual, 1963	Planned		Preliminary plans, 1965-67	
		1964	Percent change from 1963	Annual average amount	Percent change from 1963
Total -----	4.70	5.71	+21.5	5.64	+20.0
Machinery -----	1.24	1.40	12.9	1.30	4.8
Electrical machinery ----	.69	.71	2.9	.76	10.1
Autos, trucks, and parts--	1.06	1.61	52.9	1.66	59.6
Aerospace -----	.39	.38	- 2.6	.35	- 7.7
Other transportation equipment -----	.14	.18	28.6	.15	7.1
Fabricated metals -----	.90	1.11	23.3	1.15	27.8
Instruments -----	.28	.32	14.3	.27	- 3.6

Source: 17th Annual Survey of Business Plans for New Plants and Equipment, 1964-67. McGraw-Hill Co., Department of Economics.

Information is not available on specific plans for purchasing numerically controlled machine tools. The McGraw-Hill reports, however, cover expenditures for all automated machinery--defined as the "use of advanced mechanical equipment, especially in combination with self-regulating controls and/or high-speed computers in manufacturing, accounting, distribution, and all other operations." For metalworking industries, this definition would cover numerically controlled machine tools, among other types of automated machinery.

Table 7 shows an increase in the proportion of spending for automated machinery from 1959 to 1963 in each metalworking industry. Since the total amount of capital spending by these industries has been increased markedly, the increase in the amount for automated equipment (some part of which is presumed to be N/C) becomes even more significant.

Table 7. Spending for Automated Machinery,¹ by Metalworking Industries, Selected Years

Industry	Percent of total capital spending		
	1959	1963	Expected, 1964-67
Machinery -----	9	18	17
Electrical machinery -----	18	36	38
Autos, trucks, and parts -----	18	23	28
Other transportation equipment---	4	14	12
Fabricated metals and instruments -----	6	15	15

¹ For the purpose of this survey, automation was defined as "the use of advanced mechanical equipment, especially in combination with high-speed computers and other self-regulating controls in manufacturing, accounting, distribution, and all other operations."

Source: 17th Annual Survey of Business Plans for New Plants and Equipment, 1964-67. McGraw-Hill Co., Department of Economics.

Government Programs

Recent Government tax and procurement programs providing special stimuli to industrial modernization probably have an important effect on the outlook. Two measures--7 percent income tax credit for new investment in machinery and equipment and accelerated depreciation rules--are intended to increase the attractiveness of investing in new equipment. These actions were designed partially to encourage capital expenditures for modern machine tools, including numerically controlled units.

Furthermore, the Federal Government is continuing its purchase of numerically controlled machine tools. The U.S. Air Force, for example, is planning a modernization program that is expected to replace a large number of conventional machine tools with numerically controlled units by 1971. This and similar programs will result in placing a substantial number of such machine tools into weapon plants, naval shipyards, air force depots, and numerous private plants working on defense contracts.

Price and Demand

Because of the larger capital outlays needed to install numerical controlled machine tools compared to conventional tools, many firms, particularly small ones, may be cautious in purchasing numerical control. Table 8 shows average unit values of machine tools shipped between 1954 and 1963, ranging from \$31,200 for drilling machines to \$160,800 for milling machines, with the overall average at \$77,800. The cost of controls constitute about 30 percent of the average total value. Prices for specific models of numerically controlled machine tools, however, can range from under \$10,000 for a drilling machine to as high as \$650,000 for a multi-axis milling machine. And the price of the continuous path type of control of a milling machine can be many times that of a positioning type of control of a drilling machine.

Table 8. Value of Shipments and Average Unit Values of Numerical Controlled Machine Tools, by Type, 1954-63

Type of tool	Number	Total value (in thousands of dollars)		Average unit values (in thousands of dollars)		
		Machine tools and controls	Controls only	Machine tools and controls	Controls only	
					Amount	Percent of total
All types....	¹ 3,583	278,917	83,900	77.8	23.4	30.1
Drilling -----	1,690	52,648	20,031	31.2	11.9	38.1
Boring -----	636	65,549	20,350	103.1	32.0	31.0
Milling -----	540	86,839	30,192	160.8	55.9	34.8
Lathes -----	402	22,483	8,387	55.9	20.9	37.4

¹ Include domestic and export shipments.

Source: U.S. Department of Commerce, Bureau of the Census and Business and Defense Services Administration.

A more rapid diffusion of numerical control is expected as high development costs cease to influence prices; as economies of larger scale production of numerical control equipment permit reductions in their manufacturing costs and prices; and as a larger variety of more simplified, less expensive machine-control models become available. Recently a few simplified models of several types of N/C machines have become available at lower prices, and as a larger variety of models are marketed this may increase.

One factor governing the demand for numerical control is the minimum rate of return that industry requires for investment in new equipment. According to a 1964 McGraw-Hill survey, about half of the companies in metalworking industries answering reports indicated that they needed a minimum return (before taxes) of 20 percent or more for replacement and modernization expenditures. The proportion specifying 20 percent or more ranged from 45 percent of the companies in the automobile industry to 62 percent of the companies in aircraft and other transport equipment. Under these conditions, it may be calculated that an expenditure of \$77,800 (the average value of numerical controlled machine tools), would need to yield annual savings over a 5-year period at least equivalent to 2 to 3 man-years of employment (estimated at \$6,400 per man-year). This calculation does not take into account costs incurred in establishing programming, maintenance, and other indirect activities. Although expressed in terms of labor savings, the return can also be realized through savings from other sources.

Chapter 5. Impact on Labor Requirements Per Unit of Output

Among the possible economic implications of numerical control are reductions in labor requirements per unit of output, in operating economies, and in savings in capital investment per unit of output.

Reduction in Unit Labor Requirements

A review of published reports on the experience of users of numerically controlled machine tools shows substantial reductions in unit labor requirements in machining operations. Examples from various industries of reported applications and some description of the savings achieved, ranging from 25 to 80 percent are shown in table 9. Aerospace and other metalworking firms report large savings in the machining of complex parts where contours require the continuous path type of control. Significant labor savings are also reported by firms using the positioning type of numerical control to produce parts of relatively simple design in small quantities.

The amount of savings in any particular case depends upon such factors as specific design of parts, quantity of parts produced, ingenuity of management and types of machine tools formerly used. Estimates of savings, therefore, vary over a wide range. Although complete measurement of all the advantages of numerically controlled over conventional machine tools is not possible, the available data from a large number of cases indicate that average savings in labor requirements per piece were substantial.

Labor savings come from various sources. Tooling and setup time is significantly reduced because of the substitution of the tape controls for conventional jigs and fixtures. Numerically controlled machining is more continuous since the machine-tool operator does not have to check and re-check against blueprints. Tool operation, moreover, is more uniform since the operator need not slow up as the work approaches completion. Since numerical control results in more accurate machining, less work has to be redone. While equipment maintenance reportedly required more labor time, the increase was rarely sufficient to offset reported operating labor savings.

Labor savings in machining operations as a result of numerical control are not necessarily reflected in commensurately reduced unit labor requirements for the metalworking plant as a whole. Numerical control does not affect the entire machining operation, but is usually limited to boring, drilling, etc. Finishing, grinding, etc., are usually not done by numerical control. Moreover, machining is only one of many operations in such plants. A Bureau of Labor Statistics study of the electronics industry shows that machining occupations comprised about 20 percent of the total production worker employment in the defense sector in 1962. Materials handling, assembling, inspection, finishing, and shipping absorb a major part of the employment and labor time in electronics and other metalworking plants.

Table 9. Reported Labor and Other Cost Savings of Numerically Controlled Versus Conventional Machining

Industry	Machining operations and type of numerically controlled machine tool	Reductions in labor requirements	Other resulting economies
Aircraft -----	Eleven separate machining operations including milling, boring, drilling, tapping, and spotfacing on each of 35 parts. Multipurpose (mill, drill, bore, etc.) machine.	Reduced number of machine-tool operators from 5 to 1.	Replaced 5 conventional machine tools. Reduced number of jigs and fixtures from 5 to 1. Total cost per part reduced about 10 percent.
Aircraft -----	Two numerically controlled turret drills for aircraft engine parts such as carburetors, fuel pumps, and fuel regulators.	50 percent reduction in labor costs.	Cut scrap losses by 13 percent. Lowered overall tooling cost by about 40 percent. Downtime for design changes reduced to time needed to program and splice tape instead of lengthy period formerly needed to rebuild or build fixtures.
Electrical equipment ----	Milling and grinding of 3 dimensional steam turbine buckets on numerically controlled profiling machine.	Saved 78 man-hours in machining time per piece.	Reduced lead time from 144 hours to 24 hours or 83 percent.
Electrical equipment ----	Drilling 109 holes in a printed circuit board.	43 percent reduction in direct labor cost.	Saved 82 percent in tooling costs. Eliminated hand-feed drilling of hole patterns.
Machine tool -----	Numerically controlled versus tracer lathe to face, turn, and bore lot of 12 parts.	Setup and machining labor costs reduced by 57 percent per part.	Tooling cost, including programing cost, reduced by 55 percent.
Auto parts -----	Drilling over 100 different patterns of holes in suspension brackets.	57 percent saving in cost per unit.	Eliminated use of fixtures and hole pattern plates; and storage, maintenance and setup of same.
Machine tool -----	Drilling, milling, facing, tapping, and spotfacing of motor base on numerically controlled multipurpose machine in lot size of 15.	Reduced number of machine-tool operators from 6 to 1. Total machining time reduced by 65 percent, from 1.86 to 0.65 hours per part.	Replaced 6 conventional machines. Cost of tooling reduced from \$2,350 to \$835.
Special machinery -----	Boring, drilling, and tapping of 328 holes in each of 9 parts on numerically controlled boring machines.	Machining time reduced to 1/4 of former time.	Total cost reduced from \$389 to \$90 for 9 parts, with tolerances held to 0.001 inch.

Sources: Various trade publications.

Numerical control reportedly resulted in laborsavings in such operations as assembling and inspection because of greater consistency of quality and reproduction, but such savings are not necessarily commensurate with those in machining.

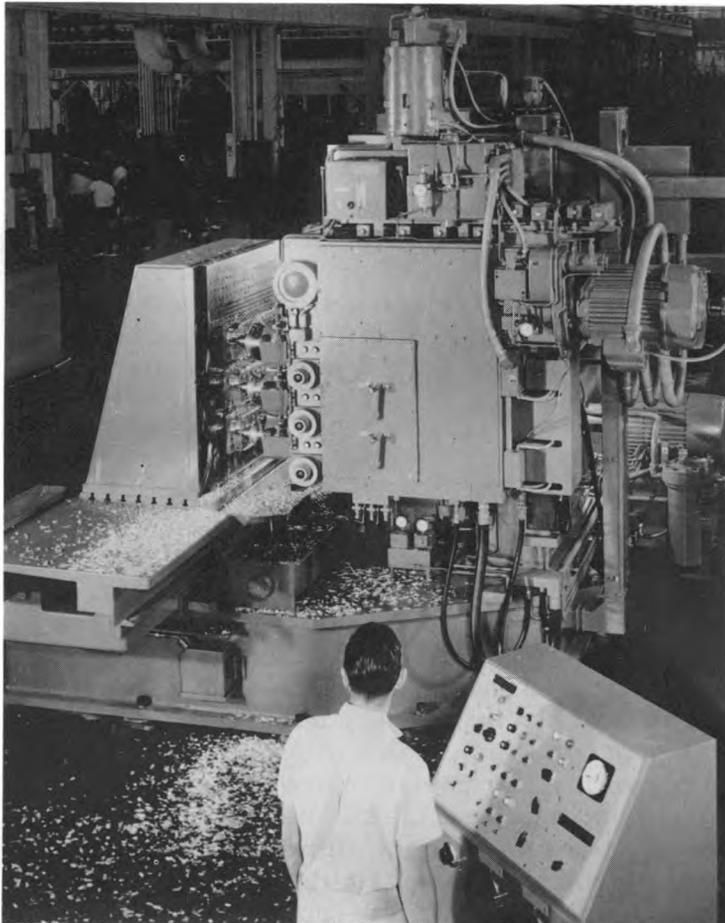
The implications of numerical control for productivity advances in metalworking industries as a group are difficult to determine. Speed of adoption by individual firms and growth in proportion of production to which numerical control is applied will affect industrywide trends. (Because of the diversity of production, numerous changes in product design and related factors, it is difficult to construct valid indexes of output per man-hour for metalworking industries.)

Operating Economies

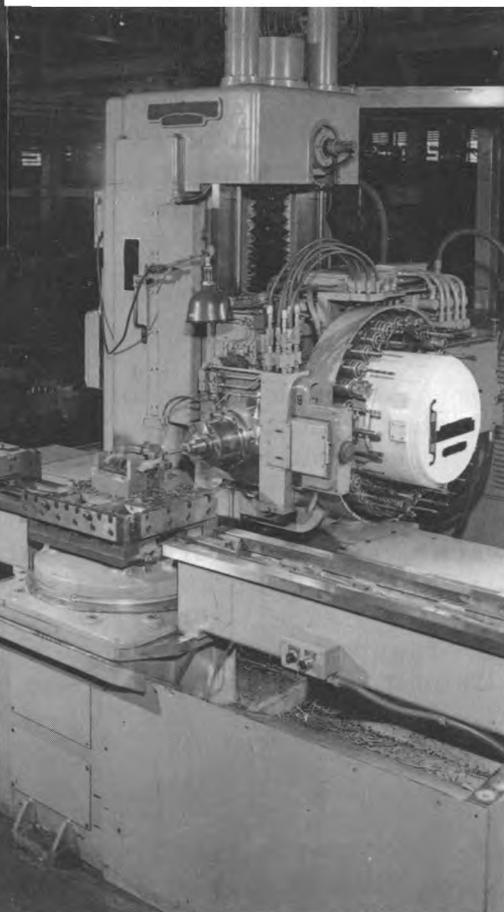
Certain operating advantages of numerical control, for which statistical data are difficult to compile, are almost always cited by users and producers to justify its use. Scrap and inventories of jigs and fixtures are reduced, resulting in cost and space savings. Because they can produce small quantities--quickly and economically--some users report that they are able to reduce inventory of spare parts. Another important advantage is the possibility of producing cheaply and quickly intricately designed shapes to very close tolerances. Numerical control thus allows much greater freedom in design of parts and products formerly too costly to manufacture are now practicable. Experts in the aerospace industry claim that some parts used in space equipment are impossible to make without numerical control. Finally, the shortening of leadtime in production is particularly advantageous, for example in aerospace work, because it affords opportunities to incorporate last minute design changes in a fast changing field.

Savings in Capital Requirements

Although outlay for a numerically controlled machine tool is generally higher than for conventional tooling, capital expenditure per unit of capacity is probably lower. Lower unit capital requirements result from greater utilization of productive capacities, reduced idle time for equipment in making changeover to different parts, and reduced need for plant space. However, since capital savings are realized only if the equipment is fully utilized, ability to plan a continuous flow of small job lot production becomes essential. Hence, a higher degree of managerial efficiency and improved plant organization, as much as engineering efficiency, become important in realizing the potential savings in capital requirements per unit of output.



Machine tool operator monitoring a numerically controlled milling machine performing under the automatic control of coded tape instructions.



Machine tool operator loading a part on a numerically controlled machine tool capable of automatically selecting proper cutting tool and performing a continuous series of milling, drilling, boring and related operations.

Chapter 6. Changes in Occupational Requirements

Because numerical control is a new field where procedures in most of the operations still are being developed, occupations, job titles, and duties do not yet follow a well-defined pattern. Some broad tendencies, however, can be outlined. Implications for occupational requirements can be discussed under three types of changes reported by users--changes in relative importance of the various metalworking operations, creation of a new occupation, and changes in content of old jobs.

Greater Importance of Planning and Programing

The use of numerically controlled machine tools, in general, still requires the operations found under conventional machining--part design, methods planning, tooling, setup, and machine-tool operation. But these operations are performed somewhat differently and are changed in their relative level of importance as control activities in the machining process. Table 10 presents the types of operations required and describes, in general terms, the flow of work.

Tooling, setup, and machine-tool operation are substantially less important as critical production decisionmaking activities under numerical control. Virtually all of the functions of developing control data and instructions of these operations are now transferred to the planning stage and programing. Maintenance usually becomes more important not only because of the more complex equipment but also because to be economical and to result in adequate return on the higher capital investment, a numerically controlled machine tool should run the maximum possible hours without breakdown.

Numerical control still requires the same function of design engineering but permits more freedom in the design of the shape and dimensional tolerances of parts. Some programing systems require conversion of conventional blueprint dimensions into cartesian coordinates; others are used with conventional drawings without any dimensional modifications. But in the future, the time consuming task of conventional drawing (blueprint) may be eliminated, since precise visual representation of the part to be manufactured is not necessary. For positioning control systems only a sketch containing dimensions in cartesian coordinates could be substituted. For control systems used in conjunction with computers, various computer oriented techniques of design are actively being worked on to greatly simplify the transmittal of design information.

Table 11 presents examples from published case studies illustrating some of these changes in terms of comparative man-hour requirements. Although planning and programing result in increased man-hours, they are usually more than offset by the reduction of man-hours in the other operations, particularly tooling, setup, and machine-tool operation.

Table 10. Operational Flow Under Conventional and Numerical Machine Tool Control

Operation	Conventional	Numerical control
Design and drawing of part.	Presentation of engineering data in form of drawing of part with dimensions expressed in conventional blueprint form.	Conversion of engineering blueprint data in form of sketch of part with dimensions expressed in rectangular coordinate form.
Planning of methods.	Selection and general description of machining operations and tooling. Preparation of general setup instructions.	Selection of parts or portion of parts for numerical control machining and general descriptions of machining operations and tooling.
Tooling-----	Design and fabrication of jigs and fixtures---	Design and fabrication of jigs and fixtures.
Programing-----	Programing is not done under conventional control.	Preparation of manuscript and control tapes. Use of computer as aid for continuous tape control. Preparation of specific setup instructions. (Determining and coding detailed manufacturing steps and instructions which describe in sequence exact cutting operations, machine motions and functions such as feeds, speeds, and direction and distance of table travel.)
Machining machine-tool setup.	Planning and setting up correct sequence of machining operations according to blueprints or other general instructions. Selection and manual adjustment of speeds, feeds, direction and distance of table travel and other machine controls. Mounting tooling.	Mounting tooling and control tape specified by setup instructions.
Machine-tool operation--	Loading workpiece into machine. Tending and adjusting machine during work cycle. Unloading workpiece.	Loading workpiece into machine. Tending and observing the machine during work cycle. Unloading workpiece.

Table 11. Three Comparative Case Studies of Man-Hour Requirements: Conventional and Numerically Controlled Machining

Case Study 1. Multiple operation of drilling, reaming, and tapping, 914 parts.

Operation	Conventional methods		Numerical control		Percentage difference in man-hours, numerical control vs. conventional
	Man-hours	Percent	Man-hours	Percent	
Total -----	3,424	100.0	818	100.0	-76.1
Planning -----	(na)	(na)	(na)	(na)	(na)
Tooling -----	485	14.2	83	10.1	-82.9
Design -----	149	4.4	15	1.8	-89.9
Fabrication -----	336	9.8	68	8.3	-79.8
Programing (control data and tape preparation) -----	0	0	16	2.0	-
Machining (machine-tool setup and operation) -----	2,939	85.8	735	89.9	-75.0

Source: U.S. Army, Ordnance Weapons Command, Ordnance Corps Study of Numerically Controlled Machine Tools (Joliet, Ill., Headquarters Ordnance Weapons Command, 1960), p. 32.

Case Study 2. Skin milling, 4 parts.

Operation	Conventional methods		Numerical control		Percentage difference in man-hours, numerical control vs. conventional
	Man-hours	Percent	Man-hours	Percent	
Total -----	6,848	100.0	3,249	100.0	-52.6
Planning -----	320	4.7	960	29.5	200.0
Tooling -----	5,952	86.9	1,896	58.3	-68.1
Design -----	912	13.3	216	6.6	-76.3
Fabrication -----	5,040	73.6	1,680	51.7	-66.7
Programing (control data and tape preparation) -----	0	0	321	9.9	-
Machining (machine-tool setup and operation) -----	576	8.4	72	2.2	-87.5

Source: Tilton, Peter D., Retrofit Applications of Numerical Control for Machine Tools, (Calif., Stanford Research Institute, 1957), p. 61.

Case Study 3. Drilling, 40 parts.

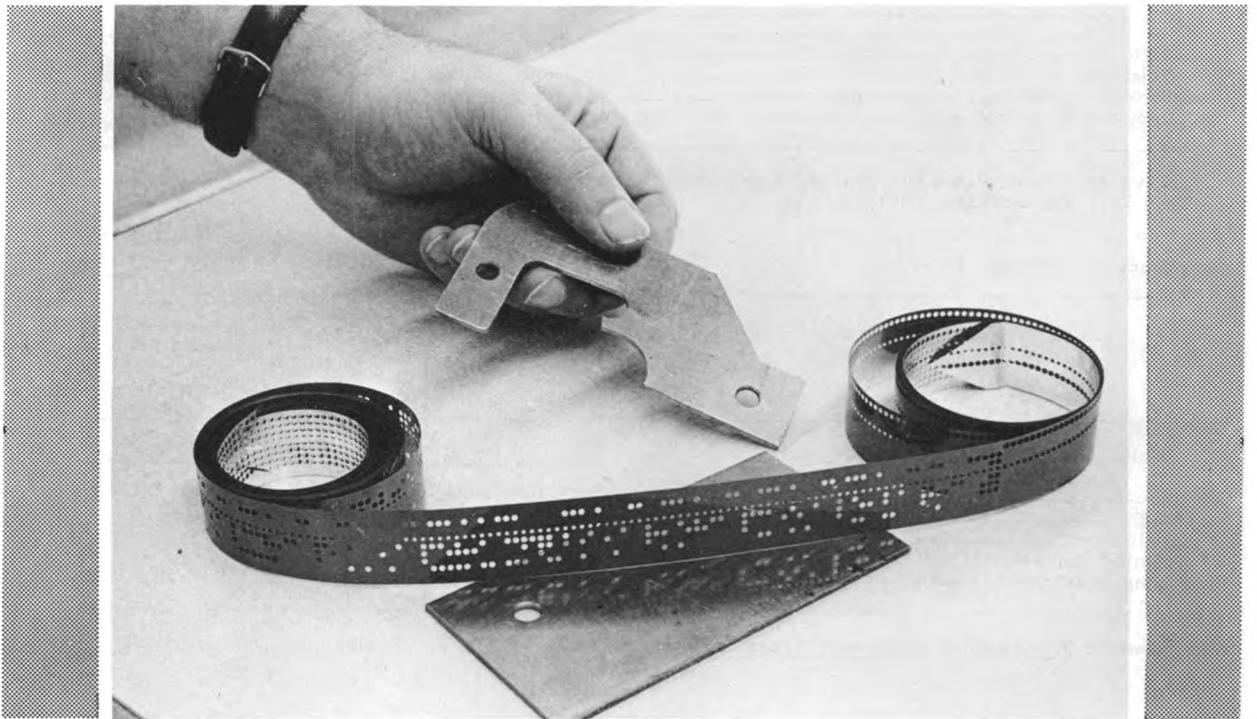
Operation	Conventional methods		Numerical control		Percentage difference in man-hours, numerical control vs. conventional
	Man-hours	Percent	Man-hours	Percent	
Total -----	41.8	100.0	20.0	100.0	-52.2
Tooling -----	27.1	64.8	12.7	63.5	-53.1
Design -----	2.7	6.4	2.7	13.5	0
Fabrication -----	24.4	58.4	10.0	50.0	-59.0
Programing (control data and tape preparation) -----	0	0	1.2	6.0	-
Machining (machine-tool setup and operation) -----	14.7	35.2	6.1	30.5	-58.5

Source: Friden Flexowriter for Numerical Control (Rochester, N. Y., Friden, Inc., 1961), p. 22.

Part Programmer

Part programmers determine the detailed manufacturing steps and instructions which are coded on the controlling tape and command the machine tool to perform automatically and in sequence such operations as position of work table, change of speeds and feeds and even change of tools. In effect, many decision, judgment and setup functions required of a highly skilled, conventional machine-tool operator are shifted to the part programmer's job. Since the coded tape instructions are substituted to perform many of the major functions of jigs, fixtures, and templates--i.e., locating, guiding, and measuring--programming takes over some duties of tooling men. Many of the basic knowledge requirements for part programming are, therefore, similar to these highly skilled conventional machining occupations: knowledge of cutting feeds and speeds; functions and use of cutting tools and fixtures; general shop and machining procedures; a thorough understanding of the various machine tools; and the ability to interpret engineering data, sketches, and blueprints.

In addition, programmers need certain new skills: a thorough knowledge of the capabilities of numerical control systems and procedures and methods of programming, including new techniques and languages. Skilled machinists and tooling men, who have an ability to solve problems



Control tape with punched instructions that automatically command a machine tool through the operations of machining the metal blank into a finished part.

by a systematic approach are generally reported to be able to acquire competency in these skills readily. Some companies prefer to employ engineers as programmers, particularly for the more complex contouring control systems. However, they usually work in collaboration with a skilled machinist or tooling man.

Specific requirements for programmers may vary with the complexity of the control system. For example, it usually requires less machining background and skill to program a drilling machine with a positioning control than a continuous path controlled milling machine. On the other hand, with the continuous path type, computers are almost always used to assist the part programmer in the time consuming, complex and numerous mathematical calculations involved. Initially, a knowledge of college mathematics was thought necessary. Today, a high school level mathematical background--arithmetic, extraction of square roots, algebra, geometry, and trigonometry is reported sufficient for programing both types.

In some large companies, several programmers at different levels of responsibility may work as a team on one problem. A senior programmer may have overall responsibility and may direct junior programmers. Junior programmers may be assigned to convert the senior programmer's completed manuscript of instructions into the special programing language or code. For positioning systems, this coded data is almost always converted onto tape by typist using an electric typewriter equipped with a special keyboard.

Although computers are used in programing and tape preparation for a continuous path type machine, numerical control does not necessarily result in creating new electronic computing system jobs. For those users of numerical control who have computers, the workload imposed upon existing computer operating personnel is only a small fraction of their total work time and duties. Some companies, however, create the position of full-time computer programmer for numerically controlled machine tools; he specializes in preparing the necessary computer instructions to process the data prepared by the part programmer.

Changes in Content of Machine-Tool Operator Jobs

Numerical control tends to change, to some degree, the content and skill requirements of machine-tool operator jobs. The machine operator working a conventional machine tool is required to setup a machine including indexing of table or workpiece; select the cutting speed and feed; and keep adjusting the machine settings to achieve part specifications. Under numerical control, these duties are automatically carried out by coded tape instructions. The operator of the numerically controlled machine tool is responsible for tending or watching a highly automatic, costly piece of equipment as it goes through a sequence of operations. He loads the control tape, fastens the part in the fixture, and verifies finished part dimensions. When finished part

dimensions do not conform to specifications, or an operating malfunction occurs, the operator of a numerical control machine is usually required to notify the supervisor or programmer rather than make the necessary adjustments himself.

Some companies assert that setup and control functions of numerically controlled machine operations are transferred largely to the part programmer or built into the machines; therefore, less emphasis is placed on the need for highly skilled machine-tool operators. Nevertheless, the operator of a numerically controlled machine still must have many of the basic skills common to an operator under conventional machining. These include, among others, a knowledge of general shop and machining procedures; the ability to read blueprints and other engineering instructions; use micrometers and other measuring instruments of the trade; and have a knowledge of shop mathematics (fractions, decimals, etc.). (See table 12 describing jobs and requirements.) In addition, some companies prefer that the operator be acquainted with programming techniques. Since the machine-tool operator must learn about and be responsible for the operation of much more expensive equipment, some companies prefer to use highly skilled and experienced machine-tool operators on numerically controlled tools.

Changes in Maintenance Jobs

For machine maintenance, the electrical, mechanical and hydraulic skills of the maintenance workers servicing conventional equipment are still required. The added responsibility and task of handling electronic systems and servomechanisms emphasizes the need for a knowledge of electronics, which is generally a new skill for maintenance personnel.

Maintenance functions at some companies are separated into two categories of jobs--maintenance for the machine tool itself and electronic maintenance for the control system. At other companies, one maintenance job category may include servicing both the machine tool and the control system.

A variety of patterns of maintenance are found. Some firms, particularly small ones with only a few machine installations, find it more economical to have their maintenance men trained to do all the servicing on the numerically controlled units. Because of traditional differences in maintenance job classifications, sometimes supported by union jurisdictions, some companies separate the maintenance responsibility for the machine tool from that of the control system. Other companies report that the basic knowledge and skill requirements for maintenance of the control system differ quite markedly from that for maintenance of the machine tool itself and can best be accomplished by separate maintenance men.

Table 12. Descriptions of Duties and Knowledge and Ability Required in Numerical Control Positions at One Aircraft Parts Producer¹

Job title	Description of duties	Knowledge and ability required
Operator: numerically controlled milling machine, "A".	Sets up and operates numerically controlled milling machine where operation sequences, tooling, speeds, and feeds are established by a program on tape or cards. Mounts holding fixture to work table; positions and fastens part into fixture, and mounts cutter. Loads machine control tape and makes required control settings. Observes milling process and notifies supervision of malfunctions. Checks cutter accuracy periodically. Operates machine to assist programming personnel in checking control unit for logical errors.	Knowledge of numerically controlled machine operation; mathematics, including trigonometry; interpretation of blueprints and sketches; machinability of various metals; use of precision measuring instruments.
"B" -----	Operates numerically controlled milling machine after the setup and initial part has been checked by higher classified employee. Duplicates additional parts by repeating machine cycle. Observes milling process and reports any malfunctioning. Assists milling machine operator "A".	Same as operator "A", except that in blueprint and sketch reading, only the ability to obtain easily identified information is required.
Numerical control parts programmer, "A".	Prepares numerical control machining programs for all types of machined parts involving undefined contours and varying radii and plans the sequence of machining operations. Advises on design of holding fixtures. Programs machining by preparing numerical control manuscript listing the location of reference and transition points and the commands to move cutter through its path. Calculates location of transition points and offset from center of cutter to obtain required cut in conformance with tolerance limits. May consult with machine operators during proof run of new or revised programs.	High school education and 2 years' experience in both numerical control programming and machine-shop tool planning; thorough knowledge of machine-shop practices, machinability of metals, and cutter speeds and feed rates.
Numerical control parts programmer, "B".	Same as parts programmer "A", except programming is limited to cutting tool movements which can be defined by straight lines, constant and/or defined radii.	Same as "A", except that 2 years' experience in numerical control programming not required.
Numerical control coordinator.	Analyzes engineering drawings to determine advisability of using tape controlled machine tools to machine specific parts, tools, loft templates, etc. Makes recommendations for changes in design to permit utilization of numerical control process. Coordinates preplanning information with programming personnel and directs them in preparation of numerical control manuscript in code form for translation to magnetic tape. Directs all data processing operations; acts as company representative to customer companies; checks all programmer manuscripts and schedules operations. Investigates and makes recommendations on improvement of numerical control systems and the acquisition of new equipment.	Two years' college training in mathematics; 2 years' experience as a machinist, tool planner, or tool designer; and 1 year's experience in numerical control programming.
Numerical control computer programmer.	Analyzes specific problems, devises programs to accomplish desired results, and prepares flow chart and machine instructions for the various computer operations required. Devises test programs and makes recommendations for improving computer techniques. Coordinates program with other personnel. Keeps informed on new developments in automatic machine-tool programming on electronic computers.	Two years' college training in accounting or mathematics and 2 years' experience in computing or tabulating.

¹Descriptions included in this table are based upon information obtained from one company and are not intended to be representative of numerical control jobs. Standard descriptions of jobs in numerical control activities may be found in the revised edition of the Dictionary of Occupational Titles to be published in Spring of 1965.

Regardless of the organizational patterns of maintenance, companies find that personnel servicing conventional machine tools can easily be shifted to service the numerically controlled machine. With additional training, those best adapted to service the control system are reported to be workers with a background of electrical or electronic experience.

Changes in Tooling Jobs

Requirements for the occupations of tool designer and tool and die maker are generally not altered although fewer and less complex jigs and fixtures are needed. New information related to general capabilities, functions, operation, and programing techniques of various numerically controlled machine tools must be learned. The use of this additional knowledge is necessary primarily to acquire new techniques to perform the usual tooling functions rather than learn actual changes in functions. As numerically controlled machines replace conventional machines in the manufacture of tools, jigs, and fixtures; many of the decisions, judgments, shop practices, and precision machinery functions presently required of these highly skilled craftsmen will also be transferred to the planning and programing operations to be coded as instructions on a control tape.

Changes in Drafting and Designer Jobs

The draftsman may have to learn changes in the engineering drawing system and how to dimension for numerical control; part designers and methods planners must acquire also a thorough knowledge of the capabilities of numerical control systems and procedures and methods of programing.

The functions and skills of the draftsman and engineer-designer may be altered considerably as a result of various new methods of automating design being developed in conjunction with numerical control. Clay model data pickup and digitizing sketches via cathode ray tube input devices are among the techniques that experts in the automobile and aerospace industries expect to be perfected over the next 5 to 10 years. These techniques produce a computer-captured model of the shape to be manufactured which can be converted readily into tape instructions for use on numerically controlled machine tools. When this occurs, it may affect the numbers of draftsmen required in the future. The principal duties of the engineer-designer will be the selection of design criteria and development of mathematical techniques for determining optimum design.

Chapter 7. Training for Numerical Control

Training or retraining of personnel is one of the key manpower adjustments associated with introducing numerically controlled machine tools. Lacking available trained personnel in their own plant or labor market, users, as a rule, fill positions for numerical control by retraining their own employees.

Assuming an expansion of numerical control--from 3,365 installations at the end of 1963 to 12,000 at the end of 1967 and a two-shift operation for each installation--it is conceivable that nearly 52,000 persons may need to be trained--one each per shift for operation, maintenance, and programing over the 4-year period. This would not include professional training for engineers, managers, and administrators.

Varying degrees of training are needed to prepare employees for the different tasks. Substantially more training is required for programing and maintenance than for machine operation. Formal classroom instruction followed by on-the-job training are generally provided for employees selected for programing and maintenance. Training for the machine-tool operator and other positions ordinarily consists of training on the job after a brief period of familiarization (usually 1 week) and practical demonstrations of the new equipment.

Company Training for Numerical Control

Formal classroom instruction is often developed and presented by representatives of the manufacturers of the machine tools and control systems at their own specially established schools. Instruction is also conducted at the user plant by equipment producers' representatives or by employees trained at the producers' schools. Only a few large user companies in the aircraft industry have found it expedient, thus far, to establish their own permanent training staff and school.

Courses for part programers emphasize the techniques of programing procedures in conjunction with programing exercises of typically manufactured parts. Courses for maintenance technicians concentrate on teaching the electronics of the control system--the servosystems and special circuitry that accompany numerical control.

Formal classroom instruction for programers with a knowledge of machining and maintenance men with some knowledge of basic electronics usually lasts less than 5 weeks. But the length of on-the-job training needed for these and the other occupations varies widely. Some users indicate that it may take up to 6 months to train a programer and as long as 3 months to train a machine-tool operator. Simplification of numerical control technology, programing techniques and design of machine and electronic components reduces the length of this training. As a result of more simplified programing languages and techniques, for example, some experts assert that a tool designer can be trained to become a competent programer in 2 or 3 weeks of

working on the job and that a conventional machine-tool operator can learn to operate a numerically controlled machine tool in 2 to 5 days.

Jobs for positioning systems generally require less training than jobs for continuous path systems. Length of training, however, also depends on such factors as educational background and present skills of the person being trained. In case of a person already possessing machining skills, a relatively shorter period of retraining is required. But in the case of a young person just entering the labor market, training for any one job--with the possible exception of machine-tool operator--amounts to that normally required for the related conventional machining occupation plus the specialized training in numerical control.

Implications for Vocational Education

So far the task of training personnel for numerical control has been undertaken chiefly by the producers and users of equipment, but this type of training will probably be incorporated ultimately in the curriculum of institutions which give vocational instruction to machining workers. In the case of machinists, this would mean changes in apprenticeship training courses (reported by machinists in the labor force in 1963 as the largest single type of training program taken, and accounting for more than one-third of the machinist vocational programs they had taken); and in courses given by high schools, vocational schools, technical institutes, and the Armed Forces.

Some case examples of various types of training programs for numerical control are presented below. They include an apprenticeship program at a government metalworking installation; a machinist retraining program co-sponsored by a union and a State department of education, and a seminar series provided by a professional society.

Apprenticeship Training Program

An example of a comprehensive program for numerical control is one given at a Government metalworking installation well-known for its apprenticeship school. A unique feature is its comprehensive and long-range objective to develop highly skilled, versatile personnel for numerical control. All trainees are expected to be able to write complete and accurate program sheets for any job, to diagnose skillfully and efficiently and aid in the repair of any malfunctioning of a numerically controlled machine tool, and to understand the basic theory needed to interpret modern technical literature. Eligibility requirements for entry into training include completion of a 4-year toolmaking apprenticeship course and experience in electrical or electronics work.

The immediate goal of the course was to fill a demand for programmers and maintenance men to service the installation's newly acquired numerical controlled machine tools. Long-range objectives include qualifying senior students of Toolmaker's Apprenticeship School of this Government metalworking installation for key technical and administrative positions and to provide future instructors.

The course provides 320 hours of classroom work over an 8-week period. Students are provided with text materials and work sheets to be completed in class or at home. Table 13 describes the content of the course. Daily homework averages 2½ to 3 hours. Four hours are allotted for weekly examinations and 4 hours for a final examination.

Twenty-three employees entered training in two classes held during late 1962 and mid-1963. Between 1963-67, the new material will be incorporated into the program of the Toolmaker Apprenticeship School, although no change in the length of the present 4-year course is anticipated.

Adult Education for Retraining Machinists

A basic orientation course, sponsored by the California State Bureau of Industrial Education and the International Association of Machinists, was established in 1962 to train journeymen machinists in the fundamentals of machine-control systems. Its aim is to modify and supplement the existing knowledge and skills of journeymen machinists for competency in the installation, operation, and maintenance of numerical control. Presently being offered in two of the largest metropolitan areas of the State, the program has been completed by approximately 300 machinists as of mid 1963.

Particulars of the course were developed by the State Bureau of Education and the union's director of education. A manual was prepared especially to provide current and pertinent instructional materials for a 12-week (a total of 30 hours) course. The course includes discussion and study of feedback systems; types of sensors, servos, and monitors; and basic use and operation of amplifiers. It also includes the study of the principles of machine operation, of control systems and programing, and principles of machine maintenance.

Appropriations provided under the National Defense Education Act of 1958 aided in financing the project. All State aid, including the text, is furnished free to the schools. The only fee paid for the training by the eligible journeyman machinist is a \$1-tuition fee.

Intended only as a pilot program, indications are that the course will develop into a permanent and broader source of training. Revision of the text and course is currently being undertaken. In addition to keeping journeymen abreast of the latest developments, the course could provide an important source of training for new workers entering the work force.

Professional Seminar Sessions

A professional technical association, the American Society of Tool and Manufacturing Engineers, provides one of the principal programs for the continuing education of professional machining personnel--engineers, foreman, technicians--in the fundamentals, problems of usage, and current development of numerical control.

Table 13. Content of Training Courses on Numerical Control Open At a U.S. Government Metalworking Installation

Title of course	Length of course in hours	Content
Primary number system -----	28	General binary number system and binary coded decimal system. Number systems based on 8 and 16 also covered.
Algebra -----	32	Concepts of vectors and direction cosines. Algebraic and graphical methods for solving simultaneous equations. Comprehensive discussion of cartesian, polar, spherical, and cylindrical coordinate systems and their relation to machine axis movements.
Analytic geometry -----	32	Methods of linear, parabolic, and circular interpolation. Curve fitting methods based on calculus using the simplified and practical heuristic approach.
Switching circuits -----	24	Mathematical theory applied to electric or electronic devices. Explanation of complex switching networks using modern algebra.
Electronics -----	44	Basic electronic components, including transistors and servomechanisms. Practical experience with electronic testing devices. Techniques for reading and analyzing electronic schematic diagrams such as those associated with control and operation of numerically controlled machines.
Electricity -----	32	Basic electrical components. Techniques for reading and analyzing electrical schematic diagrams.
Hydraulics and pneumatics -----	44	Basic units of hydraulic and pneumatic circuitry. Techniques for locating defective parts. Knowledge of J.I.C. symbols and the ability to read and analyze hydraulic and pneumatic diagrams, such as those for numerically controlled machines.
Programing (machine and computer).	84	Training in two phases. Phase one involves techniques for writing programs for a variety of numerically controlled machine tools. General discussion of programming rules for specific machines followed by demonstrations of programs written by students. Phase two involves short discussion of the role of computers in programing machine tools, including demonstrations of typical programs for numerical control with an evaluation relative to manual programing.

Source: Training Manuals. U.S. Government Metalworking Installation.

Essentially, the program is an orientation, 3-day workshop seminar covering varied types of numerically controlled machine tools. The program is designed to give engineers an introduction to programming languages and methods, machine capabilities, and management aspects of numerical control. The program is also intended to help train employees of companies just adopting numerical control and employees designated by their company to study the feasibility of using numerical control in their plant.

The seminars are open to nonmembers of the Technical Society and participants have included college professors and presidents of firms as well as machine-tool design, application, electrical design, and project engineers.

Chapter 8. Implications for Employment

In assessing the employment implications of numerical control of machine tools, as in the case of any laborsaving machinery, it is important to recognize the difficulty of isolating the expanding and displacing effects of this specific technological change from those resulting from changes in market demand, location, foreign competition, mergers, and consumer taste. Numerical control, moreover, affects a wide diversity of metalworking industries, having different trends of growth and is only one of many technological changes affecting processes, materials used, and products of metalworking industries. Although direct measurement of the manpower impact is not possible, some factors affecting employment can be described.

Labor Displacement and Expansion

The extent of labor displacement or expansion in metalworking industries depends greatly on the economic circumstances of the change and speed with which numerical control is introduced. When production is relatively constant or increasing slowly, the increased output per man-hour as a result of numerical control could result in a reduction in employment. The extent of this reduction might be less than otherwise because of the plant's improved competitive position in the world market with foreign producers.

Under highly competitive domestic conditions, it is possible that plants with lower costs because of numerical control may increase their employment, but at the expense of competing plants or subcontracting (such as independent tool and die and machine shops). They may thereby gain a larger share of the market with the impact falling on the smaller and presumably less financially capable plants.

Since the introduction of numerical control is usually gradual—one machine tool at a time phased over a period of time—the small number of workers whose jobs are eliminated could probably be transferred within the plant or company to avoid layoff. However, if a large number of numerical control machine tools are introduced in a short period of time, without a substantial increase in production, the ability to transfer displaced workers would become more difficult and possibly result in layoffs.

During periods of expanding demand, new production peaks might be met through use of numerical control without adding as many workers as might be required with conventional equipment and, therefore, would reduce employment opportunities. Where numerical control is introduced to manufacture new items in demand which could not be produced economically with conventional machining methods, numerical employment would increase.

Implications for Equipment Producers

Numerical control also affects the demand for labor on the part of those who produce the equipment--machine-tool builders and manufacturers of control systems and computers.

Machine-Tool Builders. Numerical control could stimulate new machine-tool builders and their sales and employment could, therefore, increase. Employment in the machine-tool industry (metal-cutting segment) in 1963 averaged 64,400, about 1 percent higher than in 1962. By August 1964, the number of employees had risen to 71,100. A relatively high and unchanged proportion of employees--31 percent--are administrative, clerical, and professional.

As demand for numerical control equipment rises, however, demand for some types of conventional tools may be displaced. Since one numerical machine can often do the job of two or more conventional tools, total unit sales of machine tools may be reduced as numerical control becomes more important. In addition, some machine-tool builders are using this new equipment in their own production. The net result of contracting and expansive factors on employment is therefore difficult to determine.

Control System Producers. Numerical control also opens new product and service opportunities for producers of electronic industrial controls and therefore may create new employment opportunities. These firms are part of the electronics industry and separate employment statistics are not available. Control producers find an expanding market for such elements as transducers, relays, comparators, and servomechanisms. Some of the leading control producers have established special departments devoted solely to the research, design, and fabrication of numerical control systems, not only for machining, but also for applications in drafting, inspection, and assembly. In addition, integrating the hardware produced into a complete system creates demand for systems engineering personnel, including all types of control engineers and technicians.

Computer Manufacturers. Since it is not generally considered economical to have a computer solely for the needs of programing numerical control, the effect on employment at computer manufacturers may be negligible. Computers are required only for programing the more complex but for less numerous continuous path system. Users of numerically controlled machines who already have computers have capacity to handle this added task. Users who do not have computers may use the services of outside companies owning computers or of the data-processing centers of computer manufacturers.

Employment in the Metalworking Industry Group

Employment in the metalworking industries as a group averaged 6.6 million in 1964, about 38 percent of total manufacturing employment.

The industry groups covered included ordnance, fabricated-metal products, machinery, electrical equipment, transportation equipment, and instruments and related products—industries that use and produce numerically controlled tools. Employment increased by 33 percent between 1947 and 1964 compared to an increase of 11 percent for manufacturing as a whole. The gain was limited very largely to the first 10 years of the period. Between 1957 and 1964, the total number of employees increased by about 117,000 or 2 percent; employment of production workers declined by about 168,000 or 4 percent. Of the six industry groups, only the transportation, industry group did not record an employment gain in this period.

Administrative, professional, technical, and clerical employment increased by 111 percent between 1947 and 1964, while production worker employment in the metalworking industries rose by only 14 percent. Accordingly, the proportion of production workers to total metalworking employment had declined from about 80 percent to 69 percent in 1964. In that year, the administrative, professional, technical, and clerical employees comprised 31 percent of the total, ranging from 23 percent in fabricated-metal products to 59 percent in ordnance and accessories.

Production workers in metalworking industries averaged in 1964 a slightly longer workweek than factory workers generally (table 14). Average weekly overtime hours varied, from 1.8 hours in ordnance to 3.9 hours in the transportation equipment and machinery industry groups.

Table 14. Average Weekly Hours and Overtime Hours of Production Workers in Metalworking Industries, 1964

Industry	Average weekly hours	Average weekly overtime hours
Manufacturing -----	40.5	3.1
Fabricated-metal products-----	41.4	3.4
Machinery -----	41.8	3.9
Electrical equipment -----	40.3	2.3
Transportation equipment -----	42.1	3.9
Instruments and related products _	40.8	2.5
Ordnance and accessories-----	41.0	1.8

Estimated rates of output growth over the 1957-76 period prepared by the National Planning Association for 18 metalworking industries (3-digit SIC) project a fairly high rate of expansion for many industries. (The NPA projections are based on the assumption of a 4.2-percent growth rate in the gross national product.) Introduction of numerical control in metalworking industries over the next few years may, therefore, take place under favorable economic conditions. Of the 18 industries, the projected rate for 4 would increase from 2 to 4 percent; 8, from 4 to 6 percent; and 6, 6 percent and over.

Employment, as analyzed by the Bureau of Labor Statistics, is also expected to increase in many of these industries but not as rapidly as output because of productivity advances resulting from technical innovations, including numerical control. The extent of employment change which will vary from industry to industry is difficult to estimate. Employment in electronics, for example, is expected to increase, but at a slower rate than in the recent past. In the aerospace industry, employment may continue to decline. Future employment trends in the motor vehicles and parts industry are uncertain. With more than 20 percent of total metalworking employment on defense work in 1963, the outlook for metalworking jobs depends to a considerable extent on Government policies.

Employment Changes in Specific Machining Occupations

Workers most directly affected by the introduction of numerical control are those who set up and operate machine tools. In early 1963, about 1.1 million workers were employed as all-round machinists, machine-tool operators, tool and die makers, instrument makers, and setup and layout men. (This Bureau of Labor Statistics estimate includes workers employed in all sectors—manufacturing and nonmanufacturing.)

Although growth in employment in each machining occupation could be slowed by extended use of numerical control, some occupations may be affected more than others. Since one numerically controlled machine tool displaces several conventional machines, employment of machine-tool operators is particularly sensitive to change. In early 1963, machine-tool operator employment (skilled and semiskilled) was estimated at about 570,000. The probable decline of this level of employment will be partially offset by the demand for skilled machine-tool operators as part programmers.

The impact of numerical control on employment of machinists and instrument makers (experimental machinists) is likely to be more limited. In early 1963, machinist and instrument maker employment was about 350,000. Since many machinists and instrument makers are employed in metalworking repair shops and research and development laboratories where numerical control is not likely to be used extensively, the impact of this technology on their employment may be limited.

Tool and die makers may be affected by widespread use of numerical control. More than 150,000 tool and die makers were employed in early 1963. According to Department of Labor estimates, about 35,000 workers will be needed during the 1960's to replace experienced tool and die makers who retire or die. Additional thousands may be needed as a result of industrial expansion. An adequate supply of workers, however, are not expected to qualify through apprenticeship during the 10-year period, 1960-70. An important source for overcoming such shortages is through the upgrading of machine-tool operators and machinists. One of the results of the wider use of numerical control may be to reduce this prospective shortage.

Chapter 9. Labor-Management Adjustments

Problems of job adjustment and displacement at plants introducing numerically controlled machine tools are largely matters of collective bargaining in the metalworking industries where about 75 percent of employment is covered by union contracts. The principal unions in these industries are the United Automobile, Aerospace and Agricultural Implement Workers of America; the International Union of Electrical, Radio and Machine Workers; the International Association of Machinists and Aerospace Workers; and the United Steelworkers of America.

This chapter briefly reviews some collective bargaining adjustments to technological change generally, not specifically for numerical control. Only illustrative examples are given since data on the prevalence of such provisions are not available. The introduction of numerical control reportedly has had little impact as yet on labor-management relations. Nevertheless, some brief discussion of methods of determining skill ratings and wage payments, of determining jurisdiction over new jobs, and of aiding in the adjustment of displaced workers is pertinent to this analysis of possible implications of numerical control.

Method of Determining Skill Level and Wage Rates

One important labor-management problem that arises in introducing numerical control pertains to the determination of levels of skill and wage rates for the jobs associated with the new technique.

Collective bargaining contracts generally specify the wage setting and job classification procedures governing affected jobs within the bargaining unit. Under formal job evaluation systems, new jobs would be processed according to the criteria set forth in the plan. Where incentive plans are in force, the introduction of numerical control may entail efforts to revise rates. (According to a BLS study, about 21 percent of production workers in metalworking were paid on an incentive basis as of 1958.)

Questions may arise under the recognition clause of the contract. While experience is still limited, it is reported that operators and maintenance workers on numerically controlled machine tools are usually regarded as part of the production worker group covered by union contracts. The status of the programmer, on the other hand, has been under dispute. For example, in a grievance case in an automobile plant that was settled by an impartial arbitrator, management argued that work of programming for numerical control belonged to a production engineer of the methods department, a management unit, and therefore was outside the bargaining unit. The union countered that many of the functions of programming had always been part of the toolmaker's activities and belong to production workers in the bargaining unit. The arbitrator decided that, under the recognition clause, toolmakers could not be totally excluded from performing the programming function since this would deprive them of work that they had performed previously by virtue of their classification.

As numerical control is extended, grievances over the operation of provisions in collective bargaining agreements for job classification, seniority, and wage rate setting for new jobs, may arise more frequently.

Methods of Adjusting to Displacement

In some metalworking firms, labor-management agreements attempt to cushion the impact of worker displacement by various techniques. None of these techniques were specifically adopted to cope with the effects of numerical control but are generally applicable in case of displacement because of technological or related changes. They would be applicable, for example, in the case of worker displacement resulting from a plant shut-down because of inability to compete with more highly automated plants. The introduction of numerical control is part of the general background of technological change that is stimulating labor and management to consider measures for job security, etc. These measures are described below under four broad types:

Measures for Advance Notice. In some metalworking firms, labor-management agreements provide that employees and unions be given notice of anticipated layoffs, plant closing, and major changes, a fixed period of time in advance of the effective date of the change. Such advance notice provides opportunity for planning programs of adjustment. The period of time given may be from 1 month to a year. In a few metalworking plants, joint union-management committees have been set up to study the effects of automation and recommend methods of adjustment.

Methods of Avoiding Layoff. A variety of methods are used in achieving technological change without layoff of individual workers. The exact extent of these practices in metalworking industries is not known.

Some employers make use of attrition to reduce the work force to the level needed by the new equipment. No one is hired to fill vacancies left by death, retirements, and quits. Since numerical control is usually introduced gradually, one tool at a time, and thus affects only a few employees at a time, the use of attrition may be a particularly effective method of avoiding layoffs.

Early retirement provides a way of avoiding layoffs where technological change is reducing job opportunities, by encouraging older workers to leave the work force. Younger workers who might otherwise be laid off because of technological change can then be retained. A large proportion of private retirement plans contain provisions for payment of benefits on retirement before 65. Recent agreements in the auto and farm equipments industries liberalized provisions for early retirement benefits.

Labor-management agreements in some metalworking firms (notably in the automobile and farm equipment industries) provide for transfer of workers whose jobs have been eliminated to other jobs within the plant or to other plants within the same company. In a few cases, relocation allowances covering the cost of moving are provided.

Methods of Easing the Burden of Unemployment. A substantial number of workers in automobile, farm equipment, aerospace, and electrical machinery industries are covered by severance pay plans, which provide a lump-sum benefit to workers who are permanently laid off, usually varying with length of service. Also, in these industries, a substantial number of employees are covered by plans providing supplementary unemployment benefits. These payments, made out of a fund financed by employers, are intended primarily to supplement benefits paid out by the State unemployment insurance system.

Methods of Facilitating New Employment. Employers and unions in metalworking industries have sometimes tried to find jobs for laid-off employees in other companies through newspaper ads, private and public employment offices, etc. The International Association of Machinists, for example, located jobs in different parts of the country for several thousand workers laid off in New York. Some metalworking unions have initiated retraining programs for displaced workers. As numerical control is more widely adopted, retraining programs, along the lines described earlier, will probably be considered more intensively.

Appendix. Selected Bibliography on Outlook for Numerical Control of Machine Tools

Introduction

Ashburn, Anderson. "Automation--Its Development in Metalworking," Mechanical Engineering, November 1955, pp. 958-962.

Perkins, Roy B. Evolution of Numerical Control, Paper presented at Thirty-First Annual Meeting of American Society of Tool and Manufacturing Engineers, Chicago, April 29-May 3, 1963, 14 pages.

Proceedings of the Michigan Machine Tool Conference, March 28-29, 1962. Edited by Clark E. Chastam. Industrial Development Research Programs, Institute of Science and Technology, The University of Michigan, June 1962, Ann Arbor, Michigan.

"The Eight American Machinist Inventory of Metalworking Equipment, 1958," American Machinist, November 17, 1958, pp. 1-4.

National Machine Tool Builders' Association, Machine Tools Today, Washington, National Machine Tool Builders' Association, 1964, pp. 1-48.

Numerical Control in Machine Tool Technology

Aerospace Industries Association of America, Inc., Numerical Control, Washington, Aerospace Industries of America, Inc., 1957, pp. 8-25, 47-57.

"Apt-Manufacturing by the Numbers," Aerospace, March 1964, pp. 17-20.

Carlberg, Edward F. Trends and Future Directions of Numerical Control, Paper presented at Thirty-First Annual Meeting of American Society of Tool and Manufacturing Engineers, Chicago, April 29-May 3, 1963, 8 pages.

Childs, J. J. "How Air Force Requirements Blazed the Path to Numerical Control," Machine and Tool Blue Book, May 1961, pp. 90-93. (Also issues of June 1961, pp. 132-134; July 1961, pp. 133-136; January 1962, pp. 118-120; February 1962, pp. 134-135.)

Clark, Jr., Stephen C. "Numerical Positioning," Automation, April 1958, pp. 60-67.

McCleary, E. L. A Look at the Bright Future of Numerical Control, Paper presented at Creative Manufacturing Seminars of American Society of Tool and Manufacturing Engineers, Detroit, 1963-64, 13 pp.

Shallenberger, Frank K. "Economics of Plant Automation," Automation in Business and Industry, New York, John Wiley and Sons, Inc., 1957, pp. 547-575.

Stocker, Jr., William M. "The ABC's of Numerical Control," American Machinist, August 8, 1960, pp. 93-108.

Taft, Charles K. What is Numerical Control?, Paper presented at Thirty-First Annual Meeting of American Society of Tool and Manufacturing Engineers, Chicago, April 29-May 3, 1963, 14 pages.

"What is N/C's Place in Manufacturing?" American Machinist, March 19, 1962, p. 106.

Status of Numerical Control Applications

Aerospace Industries Association of America, Inc., Aerospace Technical Forecast 1962-1972, Washington, Aerospace Industries of America, Inc., 1962, pp. 125-126.

"Numerical Control Shows Record Growth," American Machinist, July 22, 1963, pp. 71-76.

Taylor, Frederick. "Autos in a Flurry," Wall Street Journal, July 17, 1964, p. 1.

U.S. Department of Commerce, Bureau of the Census and Business and Defense Services Administration, Machine Tools with Numerical and Prerecorded Motion Program Controls: 1954 - June 30, 1962, Washington, Bureau of the Census, 1963, pp. 1-4.

U.S. Department of Commerce, Bureau of the Census and Business and Defense Services Administration, Machine Tools with Numerical and Prerecorded Motion Program Controls; 1963, Washington, Bureau of the Census, 1964, pp. 1-3.

Outlook for Numerical Control

"A Survey of Current Equipment and Systems," Metalworking, December 1962, pp. 25-26.

Hitchcock's Machine and Tool Directory, 1962, Hitchcock Publications, Wheaton, Ill., 1962 edition, 442 pages.

Jones, H. F. "Automation Holds Key to Fast Style Changes," The Iron Age, July 9, 1964, p. 37.

Melman, Seymour. "Machine Tools: A Backward Industry," Challenge, June 1962, pp. 27-31.

Metaxas, Ted. "You Can't Afford to Overlook Numerical Control," Mill and Factory, August 1960, pp. 79-80.

"Numerical Control: The Second Decade," American Machinist, October 26, 1964, pp. nc 1-48.

Stocker, Jr., William M. "How to Prove the Profit in Numerical Control," American Machinist, October 30, 1961, pp. 77-120.

17th Annual Survey of Business Plans for New Plants and Equipment, 1964-1967, McGraw-Hill Company, Department of Economics, New York, April 1964, 29 pp.

"The Ninth American Machinist Inventory of Metalworking Equipment," American Machinist, June 10, 1963, pp. env 1-72.

U.S. Department of Commerce, Business and Defense Services Administration. The U.S. Industrial Outlook for 1963, Washington, U.S. Government Printing Office, 1963, p. 52.

U.S. Treasury Department, Internal Revenue Service. Depreciation Guidelines and Rules, Pub. No. 6156 (7-62), Washington, U.S. Government Printing Office, 1962, pp. 14-16.

"What's Holding Back Numerical Control?" Factory, April 1961, pp. 67-69.

Impact on Unit Labor Requirements

Childs, J. J. "Will Numerical Control Save You Money?" Machine and Tool Blue Book, October 1961, pp. 132-134.

Friden Flexowriter for Numerical Control, Rochester, N. Y., Friden Inc., 1961, pp. 21-25.

Hale, Frank W. Economic Aspects of Positioning Numerical Control Systems, West Hartford, Conn., Pratt and Whitney Co., Inc., April 1962, pp. 20-33.

Jollis, C. S. "The Advantages of Numerically Controlled Machine Tools," Computers and Automation, March 1961, pp. 15-18.

"Justifying N. C. - Design Flexibility," Metalworking, January 1962, pp. 21-23.

- "Justifying N. C. - Layout Eliminated," Metalworking, September 1962, pp. 81-82.
- "Justifying N. C. - Lower Manufacturing Costs," Metalworking, March 1962, pp. 43-44.
- Knaus, Jr., Walter P. and Edgar, Charles T. "Figuring Where N/C Pays Off," American Machinist, June 8, 1964, pp. 76-77.
- McAvay, William. Numerical Control for Short Run Production, Paper presented at Thirty-First Annual Meeting of American Society of Tool and Manufacturing Engineers, Chicago, April 29-May 3, 1963, 15 pages.
- "N. C. Can Cut Machinery Costs On Short Run Production," Metalworking, March 1962, pp. 45-46.
- "N/C: How and When to Buy It," Steel, May 4, 1964, pp. 3-16.
- Randall, Jr., H. B. "Numerical Control Cuts Production Costs," Automation, July 1964, pp. 55-57.
- Stanford Research Institute, Management Decisions to Automate, Report prepared for Office of Manpower, Automation and Training, U.S. Department of Labor, Washington, D.C., 1964, pp. 20-23.
- Tilton, Peter D. Retrofit Applications of Numerical Controls for Machine Tools, Pasadena, California, Stanford Research Institute, December 1957, pp. 51-76.
- "To Evaluate N. C. Economies, Check All Its Benefits," Metalworking, December 1962, pp. 21-24.
- U.S. Army, Ordnance Weapons Command, Ordnance Corps Study of Numerically Controlled Machine Tools, Joliet, Ill., Headquarters Ordnance Weapons Command, 1960, pp. 14-43.
- Vlahos, C. J. "N/C Makes Giants of Small Manufacturers," Mill and Factory, February 1964, pp. 59-62.

Occupations and Training

- Bloomberg, Ray. "At Boeing Nearly Everybody Studies Numerical Control," Control Engineering, August 1959, pp. 38-40.
- "California Classes Boost Journeyman Training," Machinist, May 31, 1962, p. 11.
- Childs, J. J. "Numerical Control and Personnel Requirements," Machine and Tool Blue Book, December 1961, pp. 123-126.

- Clarke, Robert E. Methods of Training Plant Personnel for Numerical Control, Paper presented at Thirty-First Annual Meeting of American Society of Tool and Manufacturing Engineers, Chicago, April 29-May 3, 1963, 7 pages.
- Friden Flexowriter for Numerical Control, op. cit., pp. 8-11, and 21-23.
- Hale, Frank W. The Place of Numerical Control in Vocational Education, Presented at American Vocational Association Seminar, Milwaukee, Wisconsin, December 5, 1962, 8 pages.
- Heeb, Harry B. "Programming Is Easy for Point to Point Numerical Control," Machinery, June 1962, pp. 92-97.
- Hyman, I. Harry. "A Toolroom Foreman Talks Training," American Machinist, February 6, 1961, pp. 80-82.
- "Job Switch for T and D Makers?" American Machinist, November 13, 1961, p. 119.
- Keebler, James C. "Planning and Programing N/C," Automation, September 1964, pp. 58-144.
- McRainey, J. H. and Miller, L. D. "Project 60 - Numerical Control," Automation, August 1960, pp. 70-100.
- Monroe, Harry. "Training for Maintenance," Automation, March 1962, pp. 142-145.
- "National Education Act Helps Two Ways," Control Engineering, August 1960, pp. 77-79.
- Olesten, Nils O. "Steppingstones to Numerical Control," Automation, June 1961, pp. 60-66.
- "Organization of a Numerical Control Operation," Mechanical Engineering, May 1959, p. 61.
- "School for Maintenance," Mill and Factory, April 1963, pp. 82-86.
- Severson, Thomas V. A User's View of Tape Machines, Paper presented at Thirty-First Annual Meeting of American Society of Tool and Manufacturing Engineers, Chicago, April 29-May 3, 1963, 7 pages.
- Smith, H. A. "Organizing Maintenance for Numerically Controlled Machines," Plant Engineering, June 1960, pp. 111-113.
- "Tool with Skill of a Machinist," Business Week, June 17, 1961, pp. 80-87.

"Train Students Early for N/C," Iron Age, January 24, 1963, p. 43.

"Traveling Seminar Advises Metalworking Management," American Machinist, February 19, 1962, p. 93.

U. S. Army, Ordnance Weapons Command. Ordnance Corps Study of Numerically Controlled Machine Tools, Joliet, Ill., Headquarters Ordnance Weapons Command, 1960, pp. 32-54.

"Zeroing In on Zero Downtime," Factory, September 1961, pp. 112-116.

Implications for Employment

Corplan Associates of Illinois Institute of Technology Research Institute. Technological Change - Metalworking Industries, Chicago, Ill., Illinois Institute of Technology, 1964, pp. 43-49, 53-59.

Fulton, Joseph F. "Employment Impact of Changing Defense Programs," Monthly Labor Review, May 1964, pp. 508-516.

"Job Switch for T and D Makers?" American Machinist, November 13, 1961, p. 119.

Lynn, Frank. "Metalworking in 1980," American Machinist, December 9, 1963, pp. 81-85.

"Machining Occupations," Occupational Outlook Handbook, 1963-64 Edition, Bureau of Labor Statistics (Bulletin 1375) Washington, U. S. Government Printing Office, 1963, pp. 433-447.

Manpower Report of the President and a Report on Manpower Requirements, Resources, Utilization and Training by the U. S. Department of Labor, March 1963, pp. 17-20, 108-109, 163-167.

Labor-Management Adjustments

Bok, Derek and Kossoris, Max D. Methods of Adjusting to Automation and Technological Change. Report prepared for the President's Committee on Labor-Management Policy, U. S. Department of Labor, Washington, D. C. , 33 pp.

Killingsworth, Charles C. "Industrial Relations and Automation," The Annals of the American Academy of Political and Social Science, March 1962, pp. 71-75.

Killingsworth, Charles C. "Studies Relating to Collective Bargaining Agreements and Practices Outside the Railroad Industry," Report of the Presidential Railroad Commission, Appendix Vol. IV, Washington, D. C. , 1962.

Labor Arbitration and Dispute Settlements: Labor Relations Reporter,
Vol. 48, No. 44, The Bureau of National Affairs, September 27, 1961,
pp. 37 LA 192-195.

Markhem, Charles (Ed). Jobs, Men and Machines Problems of Automation,
New York, F. A. Praeger, 1964, 166 pp.

U. S. Department of Labor, Bureau of Employment Security, Work Force
Adjustments to Technological Change, Selected Employer Procedures,
January 1963.

Bureau of Labor Statistics, Labor Mobility and Private Pension
Plans, A Study of Vesting, Early Retirement, and Portability Provisions
(Bulletin 1407), Washington, U. S. Government Printing Office, June 1964.

Recent Collective Bargaining and Technological
Change (Report 266), Washington, U. S. Government Printing Office,
March 1964, 14 pp.

Wecksler, A. N. "N/C and People," Mill and Factory, February 1964,
pp. 63-66.

"Worker Security in a Changing Economy," Monthly Labor Review, June 1963.
Entire issue.