PRINCIPLES AND APPLICATION OF NUMERICALLY CONTROLLED MACHINES

THESIS

Presented to the Graduate Council of the North Texas State University in Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

By

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Denton, Texas
May, 1968
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>List</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF ILLUSTRATIONS</td>
<td>vi</td>
</tr>
</tbody>
</table>

## Chapter

1. INTRODUCTION
   - Purpose of the Study
   - Justification of Problem
   - Limitations
   - Definition of Terms
   - Procedure

2. MANAGEMENT ASPECTS OF NUMERICAL CONTROL
   - Advantages of Numerical Control
   - Engineering or Product Design
   - Process Planning
   - Economic Planning
   - Production
   - Programming
   - Point-to-Point
   - Contour
   - General Operation
   - Summary

3. NUMERICALLY CONTROLLED MACHINE TOOL INSTALLATIONS AT THE HIGH SCHOOL AND COLLEGE LEVEL IN THE DALLAS-FORT WORTH AREA
   - Programming
   - Maintenance

4. DATA CONCERNING A POSSIBLE INSTALLATION OF NUMERICALLY CONTROLLED EQUIPMENT IN THE INDUSTRIAL ARTS LABORATORIES OF NORTH TEXAS STATE UNIVERSITY
   - Retrofit
   - New Equipment
   - Maintenance
   - Proposals
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Basic Functions of Numerical Control Programming</td>
<td>37</td>
</tr>
<tr>
<td>II. A Comparison of Numerically Controlled Machine Tool Installations at Three Schools in the Dallas-Fort Worth Area</td>
<td>55</td>
</tr>
<tr>
<td>III. Basic Comparison Factors between Retrofit, Conventional, and New Numerically Controlled Machine Tools</td>
<td>66</td>
</tr>
<tr>
<td>IV. Data Concerning Strand Drill Press (Retrofit)</td>
<td>69</td>
</tr>
<tr>
<td>V. Data Concerning Southbend Milling Machine (Retrofit)</td>
<td>70</td>
</tr>
<tr>
<td>VI. Data Concerning Index Vertical Milling Machine (Retrofit of New Conventional Machine)</td>
<td>71</td>
</tr>
<tr>
<td>VII. Data Concerning Moog Hydra-Point Milling Machine (New Equipment)</td>
<td>72</td>
</tr>
</tbody>
</table>
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Examples of Zero, or Origin, Points Located on Machine Worktable and Workpiece</td>
<td>40</td>
</tr>
<tr>
<td>2.</td>
<td>Contouring Movements, Method One: Movement of Cutter in Straight Line Increments as Part of Contouring Operation</td>
<td>42</td>
</tr>
<tr>
<td>3.</td>
<td>Contouring Movements, Methods Two and Three: Straight Line Increments Drawn as Tangents and Averaged</td>
<td>43</td>
</tr>
<tr>
<td>4.</td>
<td>Tape Direction of Machine Tool: Principle of Information Flow from Punched Tape to Machine Slides or Elements</td>
<td>45</td>
</tr>
<tr>
<td>5.</td>
<td>Cartesian Coordinates: Quadrants or Coordinate Areas for Coordinate Dimensioning and Programming</td>
<td>46</td>
</tr>
<tr>
<td>6.</td>
<td>Three Axes Vertical-Spindle Machine Tool: Diagram Showing the X, Y, and Z Axes</td>
<td>47</td>
</tr>
</tbody>
</table>
Numerical control, like automation, has been described in a number of ways. One definition is

... numerical control is simply the automatic operation of machines by means of electrical devices that receive instructions from a prepared tape (usually punched tape) instead of an operator. This tape supplies dimensional information in coded form, taken from a drawing of the part to be produced (12, p. 1).

Further defined, numerical control is primarily the control of a process by numbers. Although the use of numerical control has been most prevalent to date in the machine tool industry, the concept is applicable wherever process control is needed. Numerical control is a practical philosophy of control utilizing compatible numerical values to various control elements, such as feed, speed, length, width, flow, temperature, or pressure. These values are then applied by an electrical or electronic signal to control the operation of a process or device (15, p. 1).

A typical numerically controlled machine receives information in digital form. This may appear complicated at first, but the numbers provide information symbols for only the three following functions: counting, measuring, and predicting. Coded numbers indicating these functions are punched in cards
or paper tape, or the numbers may be electronically recorded on magnetic tape. This information in turn controls the machine motions necessary to produce the desired product (17, p. 1).

Early development of numerical control actually dates back a number of years. As with many inventions, its development came into being because of a need for manufacturing a product by a less complicated method than then existed. The U. S. Air Force encountered such a problem shortly after World War II when it was faced with complex machining of aircraft components and inspection fixtures to close tolerances on a repeatable basis. During this period the Parsons Corporation of Traverse City, Michigan, developed equipment to machine flat templates for inspecting the contour of helicopter blades. The process involved the use of a number system in lieu of the usual models, templates, or cams previously used in defining the shape of helicopter blades. As numbers were not subject to deviation, improved quality and part-to-part repeatability were assured (3, p. 306). A proposal presented to the Air Force by Parsons on such a machine resulted in a development contract in 1948. In 1949 Parsons was joined by Massachusetts Institute of Technology as a major subcontractor on the project. In 1952 a three-motion milling machine was successfully demonstrated at the Servomechanisms Laboratory of Massachusetts Institute of Technology (3, p. 2).
While these developments are responsible for the present interest and use of this concept, they are not the first use of a control system. In 1807 Joseph Marie Jacquard utilized a form of punched card to weave patterns into cloth (6, p. 307).

The concept of numerical control appears to be well accepted as a valuable asset in many manufacturing organizations. Even with its acceptance, the evolution of numerical control has not necessarily been smooth. There are still misconceptions concerning the exact purpose and application of numerical control. Perhaps this is to be expected because the general application of numerical control is still relatively new, and has not been widely documented (4, p. v).

A major source of early misunderstanding developed over the initial use of numerical control. The customer was the U. S. Air Force and the requirement was for the most sophisticated types of contouring machines to produce complex aerospace parts. From this complex beginning numerical control units developed into the simpler positioning, or point-to-point, variety machine that predominates the market today. This may be one of the few cases in which an industry grew from the complex to the simple (11, pp. 7-172).

A second misunderstanding concerning numerical control has been over the term automation. Many managers with small lot production have been slow to realize that numerical control is primarily designed for limited quantities and flexibility and does not fit in the realm of mass production operations.
A third, but no less important, misunderstanding lies in the failure of management to comprehend fully the mechanics of the numerical control concept. Numerical control represents a complete departure from the conventional machine tool operation in which success depends in large upon the skill of the machinist or operator. For this reason there exists a natural adversity by many to learn about the numerical control process. To others, numerical control may bring to mind a vision of absolute computer requirement or perhaps a need for vast electronics background. There is a valid background for these misconceptions, but numerical control is a working and accepted concept and most misunderstanding is due to lack of information.

While it is important to know just what numerical control is and fully understand its functions, it is equally as important for those who have misconceptions over the process to understand just what numerical control is not. First, numerical control is not a mechanical brain, nor can it think, evaluate, judge, discern, or show any real adaptability (7, p. 8). A realistic appraisal of numerical control indicates that virtually anyone who can function in a machine tool atmosphere, or who displays the ability to understand machine operations, can grasp the fundamentals of numerical control without undue difficulty. Controls have been applied to such diverse machines as milling machines, drilling machines, lathes, precision boring machines, tube-flaring and pipe-bending
machines, drafting, plotting, wire-wrap, riveting, and flame cutting machines (16, p. 52).

In essence the numerical control process should be considered as nothing more than a further refinement of the machine tooling operation. The numerically controlled machine is really nothing more than a very obedient, non-thinking machine that will follow instructions with optimum speed, accuracy, and consistency without hesitation (7, p. 9).

Numerical control programming and operation are not the exclusive province of engineers, nor is the numerical control process suitable only for the largest plants. Application of numerical control may be found ranging from the highly complex operation to the quite simple, and in plants ranging in size from over 2,500 personnel down to twenty (13, p. 129). Furthermore, training for the operator of numerically controlled equipment can be completed in a few days if necessary, and simple programs have been completed by personnel with as little as two days training (7, p. 9).

Numerical control provides a more scientific approach to manufacturing, giving more scope to management in advance planning and in its control over actual manufacturing operations, while allowing management a direct form of communication with the machines by use of the program (4, p. 72). Acceptance of a management/machine communication concept is possibly best illustrated by the fact that various important models of new machine tools are now available with only numerical control (2, p. v).
Direct operator influence in machine operation is thus largely bypassed.

Purpose of the Study

The purpose of this study is threefold. First, numerical control will be analyzed objectively to ascertain its justification in terms of meeting the requirements of the basic manufacturing process phases. Secondly, the study will consist of an evaluation of the field of industrial arts in the Dallas-Fort Worth area to determine how numerical control has been accepted in the educational field and what preparation, if any, is being made to include the teaching of this new industrial concept. Thirdly, the study will investigate the feasibility and cost of installing numerically controlled equipment in the industrial arts laboratories of North Texas State University.

Justification of Problem

Numerical control can no longer be considered a concept of the future; it is an operational segment of industry today. Numerical control is only at the beginning of its development; yet it is already revolutionizing the way of life in many plants. Virtually the only limits on application of numerical control are human imagination and the specific economics of each situation (16, p. 52). It is considered by many to be the one overwhelming metalworking development of the century and promises to have far-reaching effects on industry in general.
The first industrial revolution possibly began when James Watt designed the steam engine. The second may have started with numerical control.

We are on the threshold of an era, perhaps a Second Industrial Revolution, in which manufacturing tools will no longer depend on man's limited dexterity, in which drudgery will be abolished by automatic controls (13, p. NCl).

These thoughts were printed over thirteen years ago in the October 25, 1954, issue of American Machinist, as part of a twenty-four-page special report entitled, "Numerical Control-What It Means to Metalworking." This was an introduction, so to speak, of a new concept to industry, for that special report was the first definitive exposition of numerical control ever published (14, p. NCl).

Three years later, in 1957, American Machinist followed up with Special Report Number 446, entitled, "The Production Man's Guide to Numerical Control," in which the numerical control study group at Boeing Aircraft Company had this to say:

... there is no doubt in the minds of the members of this group that numerical control is the touchword of a manufacturing revolution. Within the lifespan of our company, there has been no other comparably radical manufacturing improvement (15, p. 1).

Numerical control quickly emerged from an industry research status to a production manufacturing system, its value immediately recognized by the aircraft industry. However, one thing is certain: numerical control is not limited to aircraft manufacturing nor to any other special phase of metalworking. It offers wide application and deep significance to many areas of industry and deserves serious appraisal.
Thirteen years after the first report by American Machinist, it appears that their predictions and forecasts are still true. Numerical control has done much to revolutionize the machine tool industry by such things as increasing design freedom, reducing inspection costs, reductions in lead and set up time, virtual elimination of templates and jigs, reduced floor space requirements, greater accuracy and improved product quality. A more recent appraisal of numerical control reveals the same general thoughts as recorded by American Machinist:

The development of N/C for machine tools is without a doubt the greatest boon to manufacturing since the Industrial Revolution began. For the first time the entire principle of machine control has been taken out of the hand of the operator and given to management by use of engineered data (18, p. 869).

The key word in the above statement is management. Numerical control is initially a managerial problem, and its apparent success is due largely to the careful appraisal and acceptance given it by management (10, p. 62).

There is nothing inherently advantageous in numerical control per se. Numerical control will not offer an advantage to every manufacturer, nor will it render total change to the production economy. The real advantage of numerical control lies in its effective exploitation of advances in manufacturing technology and its proper utilization as a tool (17, p. 9).

In contrast to the advantages, the real success, or popularity, of numerical control lies almost solely in its
ability to produce superior products more economically than with manual controls (3, p. 2). Numerically controlled machines are faster, consistently more accurate, far more versatile, and equally as efficient twenty-four hours a day (3, p. 2). In essence, numerical control allows the manufacturer to produce more competitively.

On the basis of present and projected use, numerical control systems will grow even more important to manufacturing in the future and will continue to enjoy increased growth and acceptance. The proper utilization of the numerical control concept will provide new dimensions for management functions and will closely correlate production with the over-all scope of management objectives.

Numerical control is established but is, in reality, still young and must yet provide a favorable atmosphere conducive to its continued growth. Various training schools are offered by different manufacturers of numerical control systems, and these are valuable and necessary to keep abreast of current technological changes. However, these schools are primarily for programmers or operators and consequently reach only a selected group of personnel concerned with manufacturing. Less defined, but considerably more important, are instruction facilities for management personnel, supervisors, or other key men who will figure in the over-all decision to invest in and to maintain the costly numerical control equipment. A background in the basic fundamentals of the numerical control
process is essential for these people, for the investment in numerical control equipment is not a casual undertaking. For example, Department of Commerce figures predict that by 1970 almost two-thirds of the dollars spent on machine tools, or nearly one billion dollars, will be spent on numerical control systems alone (9, p. 34). While the number of total numerically controlled machines in relation to the total number of conventional machine tools will remain low in the immediate future out of sheer number imbalance, the total dollar investment will not, and numerical control spending will shortly surpass that of conventional machine tool investment.

The undertaking of a numerical control installation requires careful study, not only because of the large dollar outlay but also for the effect it will have on the entire manufacturing process in a plant. While management carries the responsibility of deciding on numerical control, there are a number of other personnel who will have a direct bearing in various degrees upon its success and who should have at least a speaking knowledge of the operation. This would include such personnel as engineer, programmer, machinist, tool maker, expeditor, materials handler, stock attendant, and shipping clerk.

Clearly, a training program for the operator would be too technical for the support personnel. Yet, there exists a valid requirement for these people to be exposed to some type of information program encompassing not only the concept of numerical
control but also general machine tool operations and the manufacturing process. Their interest toward insuring success of the numerical control installation would increase from such a program as their understanding of the company operation develops. Both company and employee would benefit.

While it is possible to brief personnel on a numerical control system after installation, the approach is not altogether practical or positive in every case. Success will depend in part with employee attitude and in part with the type of education an individual has completed before starting to work. That portion dealing with former education will directly involve the field of industrial arts.

As the phase of general education which serves to familiarize students with the tools, products, processes, and occupations of industry, industrial arts is well suited to introduce the concept of numerical control before a person comes in contact with it in industry (8, p. 25).

Further defined, industrial arts involves

... instructional shopwork of a non-vocational type which provides general education experiences centered around the technical aspects of life today (1, p. 15).

Thus industrial arts is charged with providing a well-rounded, comprehensive, industrial atmosphere for learning. Since the subject is taught at both the high school and university levels, it is reasonable to assume that exposure will be made to a great majority of the individuals who may later be confronted
with numerical control, including personnel who will be in management positions as well as the programmer, operator, and supporting personnel.

The numerical control process should meet the qualifications required for a subject to be considered as an area of instruction in industrial arts. Numerically controlled equipment will soon represent a major part of new machine tool investment, and the over-all process involves working with tools, processes, material, products, and occupations in a number of industrial fields. The effects of numerical control promise to be far reaching. Because of it, manufacturing planning, personnel, and economics will all require review to some extent.

Any major industrial arts program that includes the basic drilling, turning, or milling processes is in a position to consider objectively including the numerical control process in its curriculum. Installation of new numerical control equipment would be desirable but is not necessary. Retrofitting of existing machine tools is possible in many cases, allowing installation of a good and practical numerical control system at much less cost. This approach is in keeping with industry as retro-fitting is used many times in lieu of new equipment.

**Limitations**

The study lends itself to natural limitations. The overview of the numerical control concept must be held to a general
information presentation such as might be required by management or other key personnel contemplating installation of numerically controlled equipment. The major concern is to review the advantages and disadvantages for adaptation or rejection of numerical control to existing machine tool systems. A detailed study of the numerical control functions such as programming, computer application, operator adaptation, or physical plant layout should follow in separate studies, and only after the over-all concept of numerical control has been approved for a particular need and location.

This study is limited to a review of the advantages and applications of numerical control, its effects upon the manufacturing processes, the relationship of industrial arts to numerical control, and the feasibility and cost of installing a numerical control system to existing machine tools in the Industrial Arts Department of North Texas State University.

Definition of Terms

For the purpose of this study the following abbreviations and terms common to the field of numerical control will be used:

1. Automation: automatically controlled operation of a machine, a process, or system; usually directed by electronic devices.

2. Contour positioning (continuous path positioning): numerically controlled machine tool operation in which the
cutting tool follows a predetermined path working as it tracks. The tool does not leave the workpiece.

3. EIA: Electronic Industries Association.

4. Machine tool: power-driven machine partly or wholly automatic in action; for milling, planing, turning, grinding, boring, drilling, or otherwise changing the shape of metal.

5. MCU: machine control unit; a program reader on a numerically controlled machine.

6. Metalworking industry: any of the industrial metal processes requiring use of machine tools.

7. Numerical control (NC or N/C): the process of controlling a machine by feeding it instructions in the form of numbers. Instructions are contained on punched tape, punched cards, or magnetic tape.

8. Point-to-point (discrete): numerically controlled machine operation in which the cutting tool performs an operation on the workpiece in accordance with programmed instructions and then moves to the next operation. In movement between points the tool is not in contact with the workpiece.

9. Programmer: an individual who converts the engineering drawing of a part into numerical data to be placed on the control tape or card.

10. Punched tape: one inch paper tape provided with eight channels. Holes are punched in tape for machine operation in accordance with the programmer's instructions.
11. Tape control: the same as numerical control.

12. X, Y, and Z axes: linear axis of the numerical control system. Always stated in alphabetical order. X-axis is basic reference plane (longitudinal motion), while the Y-axis is assigned horizontal cross-slide motion, and the Z-axis is perpendicular motion.

An additional glossary of numerical control terminology and definitions will be found in the appendix. This is necessitated by the numerous terms associated with numerical control that are not yet in common usage. The glossary of terms will be beneficial not only with this study but also with outside research of the subject.

Procedure

The procedure followed in this study includes research into professional literature in the numerical control and industrial arts fields. Sources of data include the library of North Texas State University, the Dallas Public Library, the library of the American Management Association, the library of Southern Methodist University, the engineering library of Collins Radio Company, letters and interviews with knowledgeable persons in fields concerning the subject, and literature and technical manuals from various numerical control manufacturers. Observation of numerical control equipment in operation, programming, tape punching, operators' training, and materials handling of raw material and finished products...
was available at Collins Radio Company. Personal trips were made to schools in the Dallas-Fort Worth areas in which installation of numerical control equipment has been accomplished or is under consideration. Previous research in this subject appears to be limited. Investigation has revealed almost nothing other than one thesis from the Industrial Arts Department of North Texas State University, entitled, "A Study of Numerically Controlled Machines," by John C. H. Chan (2).

The study is organized into five chapters. The chapters are organized as follows: Chapter I, introduction; Chapter II, management aspects of numerical control; Chapter III, numerical control and industrial arts in the Dallas-Fort Worth area; Chapter IV, proposal for the installation of numerical control at North Texas State University Industrial Arts Department; and Chapter V, a summary of findings and recommendations.
CHAPTER BIBLIOGRAPHY


CHAPTER II

MANAGEMENT ASPECTS OF NUMERICAL CONTROL

The introduction of numerically controlled equipment into a shop or factory may produce an impact throughout the organization, even calling for changes in the organizational structure and management philosophies (17, p. 27). There are possibly as many approaches to the problem of initiating a numerical control program as there are types of plants, management organizations, and management philosophies. No single blueprint can be developed that will satisfy all requirements in each case because each company and its requirements are different. Therefore, it is important that management understands not only the technological implications of numerical control but also the full range of its applications.

The most common application of numerical control has been in machine tools and related equipment. The numerical control concept is also taking over an increasingly larger share of the complete manufacturing process, including inspection and testing (4, p. 2).

Indications are that numerical control may hold some of the answers to many of management's current manufacturing problems. Those enterprises which are planning the use of numerical control have the task of analyzing and evaluating the applicability of the process to each of the manufacturing
operations within their organization and implementing it gradually in those areas deemed to be the most suitable. This must be accomplished by integrating the new numerical control methods into the existing operations (3, p. 103).

Whatever else numerical control might be, it is initially a management problem. It is important that all managers reach this understanding, because only from a management position can the total advantages of numerical control be assessed, and only by management action can the obstacles to the use of numerical control be overcome (12, p. 62).

Manufacturing management is able for the first time to plan processes and to control operations exclusively with quantitative, rather than qualitative, measurements. It is possible to numerically program manufacturing operations on the basis of direct management control of the entire manufacturing enterprise from the original idea to the finished product (5, p. 72).

Such direct management communication with machines may suggest the need for a change in the philosophy of management since the essential task of managing people must now be enlarged to include managing machines. A major purpose of numerical control is to perform what management has in mind, and it should be considered as more than just an improvement in the machine tool process. As such, numerical control must be considered not as a machine control but as a management control. There is a significant economic distinction.
Advantages of Numerical Control

The decision to invest in numerically controlled equipment is one that requires careful consideration. In most cases a large capital investment is required. Because of the size of the investment and other far reaching changes involved, management should require a justification study to be made of the advantages of numerically controlled equipment over its conventional counterpart.

The advantages of numerical control seem to be worth study, especially when compared with conventional units. Lead and setup time is reduced, accuracy is improved, machining time is usually reduced, and virtual elimination of templets, jigs, and fixtures is accomplished. Over-all cost per unit produced is reduced and more important, management control is improved.

To best understand the relationship of management control to numerical control and how the advantages of numerical control affect the relationship requires a review of the basic process phases in manufacturing. There are four basic areas, or process phases, common to most manufacturing functions. They may be identified as (1) the engineering or product design phase, (2) the process planning phase, (3) the economic planning phase, and (4) the production phase.

Engineering or Product Design

The first process phase in manufacturing is that of engineering or product design. Determination of product lot
size, material, and tolerances is made in the first phase. The flexibility characteristic of numerical control is especially suited to original product design. When engineering modifications are needed, numerical control facilitates changes in design because engineering data are now processed in a way not formerly possible. A design change, either experimental or for actual production, can be retooled by simple tape revision or by changing the instructions contained on one or more punched cards (3, p. 166).

In the past, designers or engineers have been guided by a standard requiring economically producible shapes to be a prime consideration. Difficult shapes were to be avoided whenever possible to insure reproduction at reasonable costs. The advent of numerical control permits freedom for designs that have been considered to be economically unproducible in the past (1, p. 65).

Experimental design has taken on an entirely new dimension with numerically controlled machine tools. In some cases the step from working drawing to working model is never taken because of production expenses. The numerical control process permits translating the design into coordinate measurements and transferring these into a continuous path program for a contouring machine. The end result is a prototype part or die that is sculptured out of a raw block of metal, or other suitable test material such as plastic. The model produced by numerical control can be tested, experimented with, modified,
used, or rejected at a fraction of the cost and lead time of the conventional model (7, p. 48). Thus the skill of the designer is translated directly to the part and is not effected by human interference during the machining operation. The increased lead time available to designers permits sound designs in close liaison with tooling (3, p. 166).

The inherent flexibility of numerical control permits design changes to be made with minimum expense. An example is tolerance. As a general design rule, costs increase as tolerances become tighter. Thus a major concern of the engineer is to design tolerances as loosely as possible and still maintain a workable part, or to design units of such a character that tolerances are not critical. Many times large amounts of engineering and design time are spent creating parts around the capable tolerance limits of a machine tool rather than meeting the requirement of the part itself (1, p. 66). This situation may be greatly overcome by the use of numerical control. If a given numerical control machine has an accuracy of plus or minus 0.001 inch, there is no way to obtain any other figure—either greater or smaller. As a result, it costs no more to specify the tightest producible tolerance than to specify one of a lesser degree (1, p. 67).

Process Planning

The second phase of the manufacturing process is process planning. This phase includes the choice of the manufacturing
device, machine routing, order of operations, tool designs, feeds and speeds, jigs, fixtures, and time study of the operation. Also included would be operational analysis, quality control, and inspection.

The effect of numerical control upon machine routing, or order of operations, is minor. Even though numerically controlled units may be different than conventional machines, the fundamental order of operations remains basically the same. However, many additional advantages from the use of numerical control equipment result from operations not directly associated with the machine operation. These include the reduction of lead time and the elimination of costly tooling (12, p. 66).

Tool design, in particular, presents a very noticeable departure from conventional methods by the introduction of numerical control. Because numerical control allows such devices as complicated fixtures and drill jigs to be essentially deleted, tooling is greatly reduced in costs. The numerical control function to the machine provides position and repeatability without the need for an aid such as a drill jig or a milling fixture of complicated nature. The real purpose of a fixture on numerically controlled machine tools is reduced to one of providing an easy way to hold a part in position for machining. Usually, the simplest form of clamping fixture is adequate (1, p. 67). Considerable money is thus saved in the production of jigs and fixtures as their need is
diminished. Additional money is saved in reduction of storage space for these items.

In many cases the tape program actually replaces the jig or fixture. For example, the time required for programming and tape preparation may be considerably shorter than the time needed for the special tooling required of conventional machining operations. Time saved in this manner is directly proportional to the complexity and accuracy of the part under consideration. In most cases, the more complex a part, the greater will be the saving in time and money over conventional methods (12, p. 66).

An added advantage of the programmed tape is that a program does not wear out like a jig or fixture. If a working tape should become damaged, it may be replaced by a new one duplicated from the master in a matter of minutes on a tele typewriter. To replace a worn jig or fixture requires costly retooing and machine operation. Storage space for the master tape can be a file cabinet.

Speeds and feeds on the numerically controlled machine can be programmed for optimum performance at maximum machine capability. No time is lost to operator decisions or fatigue. The maximum chip production per unit may be forecast (12, p. 64).

In a rapidly developing industry, design changes are frequent and competition for the market is severe. Numerical control offers a great deal of flexibility in a relatively short time for such changes to be made. Management can plan
and control practically the entire operation change by placing the revisions on tape (4, p. 16).

Economic Planning

A third consideration in the manufacturing process is that of economic planning. Determination of lot size and finished goods inventory is the primary concern of this phase.

Making short runs profitable is always a major concern with any manufacturing operation. Costs persist regardless of lot size. With conventional machines a one part requirement results in practically a handmade product. The machinist or operator must position and reposition his cutting tool or work table and go through a seemingly endless task of dimensions, measurements, corrections, trial cuts, and further corrections until the desired result is obtained.

In the event a larger number of parts are to be made, the procedure is still largely the same. Special tooling to speed up the work, even if limited, may not be economical because cost per piece will still be relatively high due to the time involved in setup and operation. Costs multiply even more when precision machining is required (4, p. 17).

Numerical control offers reductions in machining costs in short to medium range production because of reductions in tooling and setup expenses. Small lot production is best suited to display the advantage of using a programmed tape to function as operator and fixture. The numerical control
process is as accurate as its program and may be repeated over and over again. The numerical control process is easily confused with automation, and for this reason many companies with small-lot production have been slow to realize that numerical control is primarily for limited quantities and flexibility (13, p. 7-174).

Reduction of lot size costs by use of numerical control results in a corresponding reduction in the finished goods inventory. Usually the average stock level of finished goods will depend upon a combination of lot size costs, usage or sales, and availability of storage facilities (2, p. 113). Conventional machining setups and tooling are costly when compared with numerical control, resulting in larger lot sizes and larger finished goods inventory to cover expenses.

Because numerically controlled tooling, setups, and machining times are reduced, the over-all costs of producing smaller economic lot sizes are smaller than the cost of maintaining inventory. Raw material inventories can be revised to keep pace with the increased flexibility and speed of numerically controlled production. Decreases of in-process and finished-product inventories can be expected to be significant (16, p. 22). Of particular importance will be the reduction in spare part obsolescence, because slow moving parts may almost be manufactured as needed (17, p. 420). Once a part manufacturing description has been programmed and reduced to numerical data, the program may be kept in storage. In
effect, the program then becomes the part inventory as the numerical data can be transferred into physical parts on short notice (1, p. 68).

A common procedure is to develop programs for parts that are needed only on an infrequent basis and to inventory only the basic casting or raw stock. When an order is received, the program is taken from its file, the machine tool is set up, the program is loaded, and the part is produced. This is a simple example but the basic functions are sound, economical, and proven. Not only is part and tooling warehousing released, but taxes on an inventory of expensive finished parts are eliminated (7, p. 51).

Production

The final phase in the manufacturing process is that of production. While this phase is essentially one of time reduction and increased production, it could also be considered an economic phase. In the production phase the sum total of all four phases is brought together, and their success means increased competitiveness for the user.

Success of the production phase is dependent upon proper application of numerical control principles to the first three manufacturing process phases. Improved design, accuracy, machine routing, operation order, lot sizes, and setup all contribute to a successful fourth phase of production.

Within the production phase itself, numerical control has directly influenced two principle areas of the manufacturing
operation: the operator's function and responsibility and
the role of the supervisor.

On conventional machine tools the initial responsibility
confronting an operator is drawing interpretation, closely
followed by his skill in machine operation, measurement, and
judgment. He is responsible for total production on his
machine from start to finish, regardless of quantity. Operator
decision constitutes a major part of the production process.
Consequently, a large amount of the operator's time involves
no metal cutting. Actual machine production of only 20 per-
cent of a working shift is not an unusual circumstance (2,
p. 84). Unproductive time may be attributed to

1. Handling and setup of the work-piece, cutting tools,
   and fixtures.

2. Constant review and checking of blueprints and/or
   operation sheets.

3. Checking part tolerances between operations.

4. Operator fatigue.

5. Intermittent visits to the methods or engineering
departments by the operator or supervisor.

6. Trips to the tool crib (2, p. 84).

Layout is another time consuming function for the opera-
tor, requiring a combination of calculation, measurement, and
precise scribing. The routine sequencing of the controls
governing coolant flow, drive motors, and gear changes all
involve significant amounts of mental activity, and a careful
operator may spend more time on these functions than on cutting metal (8, p. 494).

Operator variables affect production in other ways as well. Typical examples include (1) operator speed decreases on parts as continued machining constantly increases their value; (2) different operators have different ideas about machining speeds and feeds; and (3) operators vary widely in the time it takes to make calculations and setups (16, p. 18). The value of eliminating operator decision becomes apparent.

In a numerically controlled operation the job of interpretation by the operator is essentially eliminated, having been completed at the programming stage. The same holds true of operator manipulation of the machine and the operator's judgment concerning dimensions, feeds, speeds, and coolant control (1, p. 69). Operator variance and decision may be replaced by a highly efficient, non-fluctuating, control process in the form of numerical control.

The operator on a numerically controlled machine could be considered primarily a monitor. He will be called on to make minor machine adjustments during operations, load and unload piece parts, and place the program medium in the machine control unit (12, p. 73). Contrary to early belief, the operator has not been removed from the machining operation. His role and function have been considerably altered, but the operator is still very much a part of the manufacturing process. On some of the less sophisticated numerically
controlled machines, there may be functions which cannot be programmed, requiring the operator to perform them manually (7, p. 10). While it is true that the operator of a numerically controlled machine will no longer be responsible for direct control of the machining process, he will have responsibility for monitoring the process against malfunctions. In addition, the operator will also have the important role of feeding back information to the programmer and will assist him in simplifying and improving the programming techniques (7, p. 10).

There is some diversity of opinion as to the skill required for an operator of a numerically controlled machine (12, p. 73). In theory the machine does all of the work that formerly required skill and experience. As such, it should be possible to train anyone to clamp parts in the appropriate fixture and run the machine. In practice this has not always been found to be true. Well trained machinists or tool makers have been found to be more expedient in the operation of numerically controlled machines, especially during the shake-down period when the equipment is new to the shop. A trained operator can be of great help in evaluating programs and designing simple holding fixtures for new programs (12, p. 73). However, steps should be taken to provide semi-skilled operators as soon as possible. Highly skilled operators are not always available, and they will ultimately find the work of operating a numerically controlled machine not challenging.
enough. A semi-skilled, properly trained operator can run a proven program on a numerically controlled machine and produce well made, accurate parts (9, p. 153).

Generally, production has been found to increase when numerically controlled equipment is manned by good operators. Numerical control operators should be given sufficient training to reach a basic understanding of the system and of the tape format. The program should be considered as much a tool as a scale or caliper. As an operator is expected to be knowledgeable of his measuring tools, he should also be able to read a tape and understand its function and recognize the conditions under which erroneous information can enter a system and cause a malfunction (10, p. 94).

With high operator confidence in numerically controlled equipment and good programming, individual machine "up time" can run as high as 90 per cent (12, p. 64). Average production times of 70 to 80 per cent are not uncommon for numerical control equipment (2, p. 84). These figures are very good when compared with conventional machines whose "up time" would be considered exceptional at 70 per cent but would be considered normal at 30 to 35 per cent (12, p. 64).

The new role of the supervisor in a numerically controlled operation is of major importance to success to the over-all operation. A conventional machine tool operation requires that a supervisor constantly check machine practices, general operation, and drawing interpretation of each of the workmen
under his direction. He could be considered the number one craftsman (1, p. 70).

Once numerically controlled equipment is in operation, there is very little a supervisor can do to alter the manner in which a machine is receiving its instruction from a piece of programmed tape.

... the supervisor's principle job then becomes one of work-flow expediting. The supervisor must be sure that he has the tapes, the raw material inventory, and the right type of setup in order to produce the work with his machines. Thus, he is more a manager of machines than a manager of men (1, p. 70).

The predictable accuracy, repeatability, and ability of a machine to follow a program without making mistakes afford the supervisor a feeling of substantial contribution to the over-all quality and efficiency of a program. Even a machine or control unit malfunction may not result in scrap. Safety and checking devices built into the machine control unit will normally bring operations to a halt with any malfunction in the operation (7, p. 51).

By use of numerical control a supervisor can usually over-see more production. Because his primary job becomes one of accountability and control in the over-all work flow, it may become possible to double the number of men and numerically controlled machines under an individual supervisor's direction (1, p. 70).
Acceptance of the numerical control concept has required acceptance of change in established processes and thinking. A significant change has centered around the term programming as it applies to numerical control.

A thorough engineering background for the programmer and computer direction for the numerically controlled machine was one of the early assumptions connected with the numerical control concept. Such assumptions, although not accurate, were understandable because a computer was used with the first numerically controlled machine at the Massachusetts Institute of Technology, and computer programming for numerical control normally requires a solid mathematics background (2, p. 2).

Development and application of the point-to-point numerical control system have demonstrated that a variety of occupational background experiences may be successfully utilized for programming. In many cases setup men, toolmakers, machinists, or skilled operators having a sound knowledge of machine tool operations, cutting tools, and basic mathematics have been trained as numerical control programmers (4, p. 10).

Opinions on the desired technical or mathematics background levels for numerical control programmers appear to be divided. One thought suggests a usable knowledge of shop mathematics including basic trigonometry as a minimum (2, p. 153); a second belief advocates some background in analytic geometry with a minimum requirement based on a working knowledge of
algebra and trigonometry (16, p. 342); while a third consideration recommends that a good shop background and an ability to read engineering drawings are sufficient (7, pp. 53-54). These opinions may seem somewhat nebulous, yet all could be considered desirable. Numerical control operations differ from company to company, and the qualifications for a programmer are based on the requirements of a particular numerical control operation.

The general scope of programming may touch on all steps of a numerical control operation. A potential programmer should have a sound shop background and be familiar with manufacturing operations. For this reason the most promising programmer may come directly from within the existing manufacturing organization.

... the best machinist in the shop was picked to operate the first tape controlled machine. Further training in programming school qualified the machinist to provide the most efficient operation and maintenance of the machine. ... the programmer not only prepares the tape manuscript, but also designs the tooling for each job. ... the programmer gets in on the engineering design so a part can be conceived in a way to make it adaptable for production on tape equipment (15, p. 72).

The programmer's degree of training will depend on
1. His education and experience background
2. Whether point-to-point or computer programming is involved
3. The complexity of parts to be machined
4. The amount of computer assistance available (2, p. 153).
The basic requirements of a candidate for any type of numerical control programming should consist of

1. A usable knowledge of shop mathematics including basic trigonometry

2. Thorough working familiarity with blueprints


These prerequisites appear to be the most desirable for successful point-to-point programming on numerical control equipment. Contour machine programmers would possess the same basic background and training but probably will require in addition aptitude for higher mathematics.

Table I outlines the basic functions required of a numerical control programmer (16, pp. 5-63). No distinction is made between point-to-point or contour programming as the basic steps are common to both.
TABLE I
BASIC FUNCTIONS OF NUMERICAL
CONTROL PROGRAMMING

<table>
<thead>
<tr>
<th>Programming Steps</th>
<th>Effects</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepare setup sheet</td>
<td>Contains information for tool and operations planners; tool design and machine operator</td>
<td>Details of operation; fixtures required; cutter required; and allowable tolerances</td>
</tr>
<tr>
<td>Select machine tool</td>
<td>Required by machine operator; tool crib</td>
<td>Sequence of cuts; coolant control; speeds and feeds; and machine stops</td>
</tr>
<tr>
<td>Prepare rough sketch of fixture</td>
<td>Required by machine operator</td>
<td>Indicates suggested clamping method, clamp location, workpiece orientation and location points</td>
</tr>
<tr>
<td>Calculate numerical data describing part</td>
<td>Information placed on program medium; punched tape, cards, magnetic tape</td>
<td>Describes part in X, Y, and Z coordinate equation of lines and curves; start and finish of curves</td>
</tr>
</tbody>
</table>

If properly programmed, a numerically controlled machine is seldom subjected to delay or downtime. Almost continuous production may be attained if desired, providing the program is free from errors. Much of the job cost is determined at the programming stage, and if a job is programmed poorly, the machining will be performed in a similar manner as long as the program is used. Conversely, if sound programming principles are followed, the production operation will be efficient and economical (1, p. 67).
Point-to-Point

There are essentially two different types of numerical control systems: point-to-point (discrete) positioning and contour (continuous path) (14, p. 2).

Point-to-point positioning is the newer and simpler of the two systems and is

. . . characterized by the fact that the cutting tool and the workpiece are positioned with respect to one another before machining occurs (16, p. 132).

Accomplishment of the above function may be attained in one of the two following ways:

. . . the machine table which carries the work is moved from one point to the next so as to position the work accurately for the various machining operations that are to be performed at those points. The table and the workpiece on it then remain stationary while the work, such as drilling, boring, reaming, tapping or other operation, is carried out. In some cases it may be the cutting tool that is moved from one position to the next, but the principle is the same (4, p. 5).

During movement from one point to the next, the cutting tool is not in contact with the workpiece. This is the major difference between point-to-point positioning and contour operations (7, p. 13).

In point-to-point positioning, the precise path of the workpiece or cutting tool from one point to the next cannot be defined, nor can it be predicted (16, p. 118). This is due to electrical control circuits, or circuitry, in the numerical control system. The control circuitry of a positioning tape machine is designed to receive information in the form
of coordinate values of a point and to initiate electrical signals which actuate the prime movers of the machine to go to the specified points (16, p. 118).

If it becomes necessary to control precisely the movements on a point-to-point machine, a contour type numerical control system may be required. However, in some cases a point-to-point machine may have limited continuous path capability. Normally this will be limited to a milling type operation of straight lines along either the X or Y axis, or at a 45-degree angle between the two axes with no movement on the Z, or depth, axis (7, p. 29).

Both absolute and incremental dimensionings are used to locate coordinate positions on point-to-point systems. There are advantages and disadvantages to each, but most point-to-point systems employ the absolute dimensioning system (2, p. 194).

In absolute dimensioning, all measurements on the workpiece are made from single fixed zero, or origin, point. The zero point may be a specified point on the machine worktable or it may be established at some specific point on the workpiece (7, p. 27). Either location may be used, depending on individual machine configuration. An example of point locations may be seen in Figure 1.
Fig. 1—Examples of zero, or origin, points located on machine worktable and workpiece (7, p. 26).

In most cases the workpiece is mounted toward the center of the machine worktable. As shown in Figure 1, zero points may be located on either the worktable or the workpiece depending on the machine limits; however, all dimensions must originate from the selected zero point (7, p. 26). In the above illustration, the hole to be drilled would be programmed three inches from the zero point located on the worktable, and if the zero point on the workpiece is used, the hole would be programmed one inch from the point.
The most common applications of the point-to-point system have been in the drilling machine areas. Other applications include boring, turning, welding, and other similar operations requiring a positioning sequence only.

Contour

Contour, or continuous path, control is more complex and sophisticated in operation than point-to-point. The basic difference between the two is the path taken by the cutting tool in a contouring operation (16, p. 155). In contouring control a predetermined path is programmed into the operation, and the workpiece is affected by the cutting tool throughout the operation. The path of the cutting tool is directed by continuous, precisely coordinated, movement of machine axis (2, p. 63). As a result, the cutting tool shapes or contours the workpiece by continuous movement in small, overlapping straight lines (14, p. 3). The straight line increments are also referred to as linear interpolation (2, p. 63).

In order to implement a contouring movement, it is first necessary that circular or other curved cuts be broken into short, straight line increments or segments (2, p. 63). Figures 1 and 2 illustrate, in exaggerated form, examples of the straight line increments or linear interpolation as applied to a contouring operation.
Fig. 2—Contouring movements, method one: movement of cutter in straight line increments as part of contouring operation.

The straight line cuts, as shown in Figure 2, are calculated to be sufficiently short so that the maximum distance between the straight line and its related arc does not exceed the tolerance requirement (2, p. 64).

Figure 3 relates two additional methods of straight line approximations of curves. In example (a), the straight line increments are drawn as tangents to the curve; the finished part will be slightly oversize although within tolerance. Averaging the straight lines through the arc as shown in (b) is the preferred practice (2, p. 64).
Fig. 3—Contouring movements, methods two and three: straight line increments drawn as tangents and averaged.

Essentially, any contour or continuous path machining operation is one of continuous short, straight line cutting movements. Accuracy can be quite close, as intervals of as little as 0.0001 inch are possible, making it feasible to generate in physical form any true mathematical shape (11, p. 3).

General Operation

By one definition, numerical control is explained as

... the operation and control of a machine tool by numbers which are given to the tool through a control system and which direct some or all of the functions of any given machine (7, p. 58).

The numbers and control system referred to in the above definition might be best classified as the controlling medium. During the life span of numerical control several methods of
control medium have been adopted. Included are motion picture type film, punched cards, and various types and sizes of tape (2, p. 17). Of these, the perforated, or punched, paper tape seems to be the most predominate type of input media now in use and might be considered as the numerical control standard (7, p. 7). Electronics Industries Association (EIA) standards specify that numerical control storage input medium shall be

... a punched tape, one inch wide and having eight rows of holes in an ordered fashion running along the length of the tape. ... requirements for the size and spacing of the holes as well as tolerances for the thickness and width of the tape have also been established (2, p. 18).

Tape is normally handled on reels which are placed into the machine control unit (MCU). Tapes for exceptionally short operations requiring repeated runs may be made into a closed loop insuring continuous operations until the job is completed.

Information to be placed on the tape is first compiled by the numerical control programmer. After the programmer has compiled the various calculations required for a specific operation, the information is recorded on a process, or manuscript, sheet in order of their operation. The process sheet may be one of several different formats and may contain blanks for the sequence of operations, directions, speeds, and all other auxiliary functions (14, p. 13). Information from the process sheet is then encoded into the tape on a teletypewriter or other similar tape preparation machine.
Finished tapes are first checked by the programmer for errors and then sent to the designated machine. The machine operator places the tape into the machine control unit, completes all other setup functions, and begins the numerically controlled operation.

During operation of the machine tool, numerical data from the punched tape direct machine movement via the machine control unit and tape reader. An illustration of tape direction may be seen in Figure 4.

![Diagram of tape commands]

**Fig. 4--Tape direction of machine tool: principle of information flow from punched tape to machine slides or elements.**

The principles displayed in Figure 4 are the same for all machines using numerical control (4, p. 120).
Whether the programmed operation is point-to-point or contour, certain conditions concerning machines movements will remain the same. As most machine tool movements are at angles to each other, they are required to be calculated from some fixed reference (2, p. 44). To simplify measurements, the Cartesian coordinate system is used. Figure 5 illustrates the Cartesian system of measurement which provides a convenient means of locating points from two or three fixed lines, or planes through these lines, which are positioned at right angles to each other (2, p. 45).

Fig. 5—Cartesian coordinates: quadrants or coordinate areas for coordinate dimensioning and programming.

At left in the above figure may be seen the four quadrants or coordinate areas for coordinate dimensioning and
programming (4, p. 121). At the right of Figure 5 may be seen the three axes, X, Y, and Z, and coordinates of three planes, or Cartesian coordinates (4, p. 121). Distance is measured in units to the right or left of an axis and may be either positive or negative. The location of any point or series of points may be conveniently described by use of this system (2, p. 45).

Depending on limitation, a machine tool may be numerically controlled on two, three, four, five, or more axes. A three axes machine is normally controlled on its X, Y, and Z axes (7, p. 16). An example of a three axes machine is shown in Figure 6.

Fig. 6—Three axes vertical-spindle machine tool: diagram showing the X, Y, and Z axes.
The above diagram illustrates a typical three axes vertical-spindle machine tool and its X (longitudinal), Y (transverse), and Z (vertical) movements (4, p. 35).

The more complex four, five, or six axes machines will have controlled movement in the tilt and swivel of the heads, tilt of the table, and varying degrees of indexing of the table (7, p. 17). Examples of miscellaneous machines employing secondary or tertiary movements of machine components may be found in the Appendix.

Summary

A numerically controlled machine tool offers certain advantages over its conventional counterpart. Ultimately the advantages may be summed up as higher profits. Perhaps the real economic justification of a numerical control system is due to the depth in which it assists management to attain its goals.

The advantages of numerical control cannot be accurately listed in order of their importance, due to the various circumstances under which a system might be installed. Applications of numerical control systems are not the same in every case. A summary of the over-all basic advantages of numerical control and the factors which have made it popular is as follows:

1. There is virtual elimination of templet, jigs, and fixtures.
2. Inherent mathematical accuracy is attained.
3. Less setup time, shorter lead times, lower over-all costs are realized.
4. Human error in machining procedures is minimized.
5. Rapid interchangeability of control equipment from one job to another is accomplished by inserting new instructions.
6. Machining time is usually reduced; speeds and feeds are planned.
7. Optimum production runs are possible, cutting inventories.
8. One numerically controlled machine can frequently do the work of two or more conventional machines.
9. Part duplication is constant and accurate.
10. Programs do not deteriorate with use; are readily modified, and conveniently stored.
11. Difficult or impossible parts are practical with numerical control.
12. Over-all planning is simplified and management control is improved.

The applications and economic advantages of the numerical control process are quite varied and flexible. In addition to the individual advantages of numerical control, there are three supplementary explanations of why the concept continues to find wide acceptance. They are

1. Equipment is available to meet a wide variety of manufacturing jobs at a price that the average company can afford to pay.
2. The transformation of an engineering drawing into punched tape via the programming function is within the reach of numerous companies, and programmer training can be accomplished in a relatively short time with existing personnel.

3. Outside numerical control services are available throughout the country. New data communications equipment makes it possible to send information over telephone wires to distant centers and receive back tape-punching electronic signals within minutes. This is especially important to the smaller operation that cannot afford a computer (11, p. 34).

The broadest implications of numerical control are found in its use by management. Companies which recognize the advantages and opportunities offered by numerical control will be able to react in better fashion in changing markets.
CHAPTER BIBLIOGRAPHY


CHAPTER III

NUMERICALLY CONTROLLED MACHINE TOOL INSTALLATIONS
AT THE HIGH SCHOOL AND COLLEGE LEVEL
IN THE DALLAS-FORT WORTH AREA

Installation of numerically controlled machine tools in the Dallas-Fort Worth area has not been limited to industry alone. At least three Dallas-Fort Worth area schools consider the numerical control concept to be a significant industrial process and have initiated comprehensive programs of study involving numerical control theory and application.

In the Dallas-Fort Worth area, numerically controlled machine tools have been installed at the high school level. Mesquite High School in Mesquite, Texas, and Trimble Technical High School in Fort Worth, Texas, have successfully completed installations of numerically controlled machine tools. Both schools are instructing numerical control principles, numerical control programming, and numerically controlled machine operation.

Tarleton State College in Stephenville, Texas, has initiated a program of instruction involving numerical control APT programming. Currently, there are no numerically controlled machine tools in the industrial arts laboratories at Tarleton State College, but equipment installation is planned for the near future.
The types of equipment, dates of installation, levels of instruction, maintenance procedures, and various other information concerning the numerically controlled machine installations at each of the three schools will be found in Table II.

In Table II, a majority of the numerical control installations at the schools are of recent date. The most popular type of machine tool has been the Index Model "745", 2-axis milling machine. One Index machine is installed at Mesquite High School, and two of the machines are currently installed at Trimble Technical High School. The Index machine in both installations is a new machine tool retrofitted with a SLO-SYN numerical control system. The original machine installed at Trimble Technical High School in 1963 incorporated a Pratt & Whitney drill with a Cincinnati numerical control system.

Both high school programs include programming, tape preparation, and machine tool application. Both high schools maintain tape punching machines in addition to their numerically controlled machine tools.

The level of instruction at Mesquite High School (1) and Trimble Technical High School (3) is basically the same. Normally, only senior students are allowed to take part in the numerical control instruction, and then only after successfully completing a regular machine shop course.
<table>
<thead>
<tr>
<th>Installation Factors</th>
<th>Tarleton St. College</th>
<th>Trimble Tech High School</th>
<th>Mesquite High School</th>
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</thead>
<tbody>
<tr>
<td>Date N/C machines first installed</td>
<td>None</td>
<td>1st. - 1963</td>
<td>Fall, 1967</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd. - 1967</td>
<td></td>
</tr>
<tr>
<td>Date N/C instruction first started</td>
<td>Fall, 1967</td>
<td>1st. - 1963</td>
<td>Spring, 1968</td>
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<td></td>
<td></td>
<td>2nd. - 1967</td>
<td></td>
</tr>
<tr>
<td>Type N/C instruction given</td>
<td>APT Programming only</td>
<td>Principles,</td>
<td>Principles,</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td>operation of</td>
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<td>N/C equipment</td>
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<tr>
<td>Level at which N/C instruction is</td>
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<td>regular machine course</td>
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<tr>
<td></td>
<td></td>
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<td>Type of N/C machine tool installed</td>
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<td>Model &quot;745&quot;</td>
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<td></td>
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<td>axis drill</td>
<td>Index, 2-axis</td>
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<tr>
<td></td>
<td></td>
<td>2nd: Model &quot;745&quot; Index, 2-</td>
<td>vertical mill</td>
</tr>
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<td></td>
<td></td>
<td>axis vertical mill</td>
<td></td>
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<tr>
<td>Type of N/C system used on machine</td>
<td>None</td>
<td>1st: Cincinnati</td>
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<tr>
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The numerical control program at Tarleton State College (2) consists of two courses in APT part programming. There is currently no numerically controlled equipment available for practical application at Tarleton. Access to the computer at Texas A. and M. University in College State, Texas, is made available on an unscheduled basis for assistance in computing contour programs.

Programming

Instruction in the programming principles is considered to be important at all three institutions. Students at both high schools are involved in part programming and are able to apply the results of their work to the numerically controlled machine tools in their shops. Fredin flexowriter tape punching machines are in use at both high schools as part of the overall programming process.

The instruction of programming makes up most of the total numerical control program at Tarleton State College.

Maintenance

Maintenance of the numerically controlled equipment at the subject schools has not proven to be a real problem to date. Normal, conventional type, machine tool maintenance is usually all that is required of the machine tool itself. Maintenance is largely performed by the students according to a regular maintenance schedule.
Maintenance of the numerical control system is greatly simplified by the use of solid-state circuitry. Both high schools have chosen control units which do not require any special cooling or air conditioning systems. Periodic inspections and maintenance of the control systems are performed by the control system dealer in accordance with a maintenance contract. By using the maintenance contract with the dealer, the schools need not keep expensive test equipment on hand nor are they required to keep a special, trained electronic maintenance man in the shop.

While the total number of numerical control installations at schools in the Dallas-Fort Worth area is small to date, the scope and level of existing installations seem to be significant. The installation of a numerically controlled machine tool is a large undertaking, even in industry, and certainly a major decision for a high school to make. The completeness of the high school programs, their choice of equipment, and their objectives indicate a careful study of industry and an awareness of the problems of industry.
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CHAPTER IV

DATA CONCERNING A POSSIBLE INSTALLATION OF NUMERICALLY CONTROLLED EQUIPMENT IN THE INDUSTRIAL ARTS LABORATORIES OF NORTH TEXAS STATE UNIVERSITY

Once the decision to install a numerical control system has been made, considerations must be directed toward obtaining a suitable combination of machine tool and control system that will prove compatible with existing laboratory facilities.

Because numerical control of machine tools is an advanced manufacturing process, a more extensive planning and program analysis will be required than that normally given to the procurement of conventional machine tools (1, p. 136).

Planning for the installation of numerically controlled equipment should begin as soon as possible, even before the equipment is actually ordered. The following considerations should be given some thought at the earliest opportunity:

1. Select the personnel who will be responsible for instructing machine operation, programming, and maintenance of the new equipment and arrange for their training.

2. Give careful thought to accessories that are available with the new equipment. Order desired accessories with the machine if possible to avoid additional installation cost at a later date.
3. Check the power requirements for the new equipment to insure that the proper voltage, or voltages, is available and that there is no abnormal voltage fluctuation in the lines. Avoid connecting numerically controlled machines to lines already carrying heavy machine loads.

4. Insure that the compressed air service is adequate.

5. Check the building foundation to insure that the floor will support the weight of the new equipment.

6. Avoid locating the numerically controlled equipment in the proximity of any heavy magnetic field. The more sensitive portions of the control system could be affected by outside electrical interference.

7. Steps should be taken to provide for special forced air cooling or air conditioning for the control system, should it be required.

8. A proper environment should be provided for the numerically controlled equipment. Care should be taken not to locate the equipment in areas of heavy dust accumulation, high moisture, temperature extremes, heavy shocks, or any other condition which might have an adverse effect on the control cirquit.

As noted in Chapter III, the successful installation and operation of numerically controlled machine tools have been accomplished at the high school level. It is therefore reasonable to assume that a similar installation could be undertaken in the industrial arts laboratories at North Texas State University.
For planning purposes, two options for the acquisition of numerically controlled equipment will be considered. The feasibility of retrofitting an existing machine tool in the industrial arts laboratories with numerical control will be explored as well as investigation into the purchase of new numerically controlled equipment.

Retrofitting offers two possibilities: the retrofitting of new conventional machine tools with numerical controls or the retrofitting of a used machine tool with numerical controls. Both options are cheaper than the purchase of new numerically controlled equipment.

Retrofit

The term "retrofit" relates to the application of a numerical control system to a conventional machine tool (1, p. 179). Retrofitting is applicable to either new conventional machine tools or to older machine tools already in service.

Each potential retrofit application will require special study as over-all objectives and limitations differ with each installation. Retrofit involves more than a simple rehabilitation or modification of a machine tool. New types of work will become possible through retrofitting, and there may even be a change in the type of classification of the machine (4, p. 252).

Usually, retrofitting will be evaluated against conventional replacement or new numerically controlled equipment.
Situations which do not require the precise accuracies that numerical control is capable of are ideal for the retrofit concept. In addition, the capital costs for retrofitting often are appreciably lower than those involving new numerically controlled machines (4, p. 253).

Whether to retrofit an existing machine tool with numerical controls or not requires careful consideration, and

... the machine tool builder making comparable equipment should be consulted, especially if he supplies systems as well. ... machine tools must be in good condition for retrofitting and any necessary rebuilding estimated. Retrofitting should not be rejected out of hand; successful installations of this type have been made and continue in production (2, p. 109).

The age of the equipment considered for retrofitting often has little bearing on suitability of the modification, although conversion costs are likely to be higher on older equipment (1, p. 179). Machine tools originally built as early as 1942 have been successfully retrofitted with numerical controls, and the first numerically controlled machine demonstrated at the Massachusetts Institute of Technology was actually a retrofitted tracer profiler machine (1, p. 179).

The retrofitting of conventional machine tools with numerical control may be accomplished in several different ways. Included are (1) the addition of accessory tables, (2) retrofitting of new conventional machine tools with numerical controls, (3) acquiring new machines designed for later addition of numerical controls, (4) installation of field conversion kits to existing machines, and (5) rebuilding and modification
of used machines (4, pp. 249-251). Of these considerations, only two are practical for a proposed installation of numerically controlled equipment in the North Texas State University industrial arts laboratories. They are retrofitting of new conventional machines with numerical controls and the installation of field conversion kits.

Several types of the numerically controlled machine tools on the market today are actually conventional design machines that have been retrofitted with numerical controls. Some degree of modification in basic machine design is necessary for incorporation of a numerical control system. A direct result is a partial loss in machine performance as compared with machines originally designed and constructed for numerical control. The basic technical problems of retrofitting conventional equipment with numerical controls are about the same as those of retrofitting used machines, except that machine condition would not be a factor.

Findings in Table II of Chapter III disclose that the types of machines chosen by the referenced schools have all been new conventional machines retrofitted to numerical control. Such an arrangement of machine tool and control system offers certain advantages. First, the equipment is available through Dallas dealers who are capable of providing proper installation, operational support, and contract maintenance. Secondly, the initial cost of a retrofitted new machine is somewhat lower than the cost of new fully numerically controlled
equipment. Third, the machine specifications are more in line with a desired level for use in a teaching situation, whereas machines fully designed for numerical control are constructed for industry and normally will be over-designed for school shops.

Field conversion kits for retrofitting numerical controls to used machines are available but not in wide use. A more common, and more expensive, approach is the redesigning and modification of used machines (4, p. 250). This approach is not practical for consideration in the proposal for North Texas State University. Only the field conversion kit will be considered.

The field conversion kit method involves the use of a packaged modification kit containing such items as drive motors and couplings for each axis, spindle controls, and various other installation hardware. The kits are normally designed for interface between specific numerical control systems and machine tools and must be ordered accordingly.

The following advantages of considering the field conversion kit are essentially the same as those in considering the retrofit of new conventional equipment: Dallas area dealers with their maintenance support, more reasonable costs, simplified installation, and the availability of a student level machine tool.
New Equipment

Improved specifications are the primary advantage of new full numerically controlled equipment. Generally new equipment that has been designed specifically as a numerically controlled machine tool will be capable of improved tolerance, accuracy, repeatability, and productivity over that of the retrofitted machine.

Machine tools designed specifically for numerical control, while superior to their conventional predecessors

... need not be entirely different in design concept. Indeed most numerically controlled machines successfully operating in the field today adhere to basic conventional machine design principles. As new designs are developed and more is learned of rigidity and response requirements for numerical control machining, more radical designs will appear which will offer more power in addition to superior part accuracy and surface finish (1, pp. 178-179).

Two essential requirements of numerical control operation are low friction and accurate response to commands. Machine tools designed specifically for numerical control satisfy such requirements through the use of advanced design in the slides and ways and by anti-backlash recirculating ball nut leadscrews (1, p. 179).

Data found in Table III (4, p. 258) further summarize comparison between conventional, retrofit, and new numerically controlled machine tools.
TABLE III
BASIC COMPARISON FACTORS BETWEEN RETROFIT, CONVENTIONAL, AND NEW NUMERICALLY CONTROLLED MACHINE TOOLS

<table>
<thead>
<tr>
<th>Comparison Factors</th>
<th>Retrofit Compared to Existing Conventional Machine</th>
<th>New N/C Machine Compared to Existing Conventional Machine</th>
<th>Retrofit Compared to New N/C Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>Greatly increased</td>
<td>Greatly increased</td>
<td>Nearly same</td>
</tr>
<tr>
<td>Flexibility &amp; versatility</td>
<td>Much greater</td>
<td>Much greater</td>
<td>Same</td>
</tr>
<tr>
<td>Planning and scheduling</td>
<td>More realistic</td>
<td>More realistic</td>
<td>Same</td>
</tr>
<tr>
<td>Lead time</td>
<td>Much greater</td>
<td>Much greater</td>
<td>About same</td>
</tr>
<tr>
<td>Labor</td>
<td>Reduced</td>
<td>Reduced</td>
<td>Same</td>
</tr>
<tr>
<td>Product quality</td>
<td>Tolerances are improved</td>
<td>Tolerances are greatly improved</td>
<td>Somewhat poorer</td>
</tr>
<tr>
<td>Tooling</td>
<td>Greatly reduced</td>
<td>Greatly reduced</td>
<td>Same</td>
</tr>
<tr>
<td>Materials inventory</td>
<td>Greatly reduced</td>
<td>Greatly reduced</td>
<td>Same</td>
</tr>
<tr>
<td>Number of setups</td>
<td>Greatly improved</td>
<td>Greatly improved</td>
<td>Same</td>
</tr>
<tr>
<td>Scrap loss</td>
<td>Reduced</td>
<td>Reduced</td>
<td>Slightly poorer</td>
</tr>
<tr>
<td>Amount of paper work</td>
<td>Reduced</td>
<td>Reduced</td>
<td>Same</td>
</tr>
<tr>
<td>Floor space required</td>
<td>More</td>
<td>More</td>
<td>Same</td>
</tr>
<tr>
<td>Capital costs</td>
<td>Higher</td>
<td>Much higher</td>
<td>Lower</td>
</tr>
</tbody>
</table>
Maintenance

The maintenance considerations for retrofit or new numerically controlled machines are about the same. Neither could cause any undue problems for the suggested numerical control installation at North Texas State University.

Numerical control systems have advanced to the degree that most models now employ fully transistorized units for the control circuits. Modular construction allows quick, simple inspection and easy removal of modules or individual units of the control unit for testing or service (2, p. 35).

With the advent of fully transistorized solid state circuitry and increased reliability, the excuse of not having trained maintenance personnel has become less valid (3, p. 68). Many suppliers of numerically controlled equipment offer training courses in the maintenance of their control unit. Advantage should be taken of any manuals, training aids, or preventive maintenance recommendations that may be available from the dealer.

Maintenance of the machine tool itself is basically the same as any conventional machine tool and should present no real problems. Service contracts can normally be set up with the dealer for support maintenance of the numerical control system. A similar approach has been taken by the schools discussed in Chapter III for the maintenance of their control systems.
Material found in Table III suggests that the greatest differences are to be found between conventional machines and retrofitted or new numerically controlled machines while a lesser difference exists between retrofit and new machines. Tolerances, productivity, and product quality will be measurably increased with new numerically controlled machines, but capital costs are also increased. Retrofitted machines offer about the same advantages over conventional machines as do new numerically controlled machines; however, retrofitting costs are not as high as the investment in new equipment. Table III serves as a general overview and should be used only as a guide in comparing conventional machine tools with retrofitted numerically controlled machines or new numerically controlled machines.

Proposals

Tables IV, V, VI, and VII contain findings from a study of four possible approaches to finding the best suitable combination of machine tool and numerical control system available for the industrial arts laboratories of North Texas State University. Retrofitting of existing machine tools in the industrial arts laboratories are considered, as well as the cost of a new conventional machine tool retrofitted with numerical control and the cost of a new numerical control machine tool. General machine tool and numerical control system specifications are outlined along with approximate machine costs.
## TABLE IV
### DATA CONCERNING STRAND DRILL PRESS (RETROFIT)

<table>
<thead>
<tr>
<th>General Specifications:</th>
<th>Costs:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Machine Tool:</strong> EXISTING: Aktiebolaget Strand Drill Press, Model CS30/S.</td>
<td><strong>N/A</strong></td>
</tr>
<tr>
<td>*Numerical positioning table: SLO-SYN NCR1012TP</td>
<td></td>
</tr>
<tr>
<td>table size... 10&quot; x 12&quot;</td>
<td><strong>$5,810.00</strong></td>
</tr>
<tr>
<td>longitudinal travel... 9&quot;</td>
<td></td>
</tr>
<tr>
<td>cross travel... 9&quot;</td>
<td></td>
</tr>
<tr>
<td>capacity... 300 lbs.</td>
<td></td>
</tr>
<tr>
<td>positioning speed... up to 60&quot; per min.</td>
<td></td>
</tr>
<tr>
<td>positioning accuracy... ±.001&quot;</td>
<td></td>
</tr>
<tr>
<td>mill feed rates... 3/4&quot; to 18&quot; per min.</td>
<td></td>
</tr>
</tbody>
</table>

### N/C System: SLO-SYN Model NC1R24

Control medium, tape: EIA standard, 1" 8-track
Controlled operations: straight line milling point-to-point
Number of controlled axis: two
Data input: automatic/manual
Accuracy: see above
Mill feed rates: see above
Special cooling required: no
Automatic coolant flow: optional
Power requirements:
- electric: 105 to 130 V., 60 cycle, 5 amp.
- air: yes
Spindle control: SLO-SYN Model EM144099G-1
Model features:
- Modular construction, solid-state circuitry with plug-in circuit cards.

Approximate cost of retro-fitting existing Strand Drill Press with numerical positioning table and SLO-SYN Numerical Control: **$11,885.00**

*Note: The existing drill press must be fitted with a numerical positioning table in order to perform numerically controlled functions.*
# TABLE V
DATA CONCERNING SOUTHBEND MILLING MACHINE (RETROFIT)

<table>
<thead>
<tr>
<th>General Specifications:</th>
<th>Costs:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Machine Tool:</strong> EXISTING: Southbend Milling Machine, Model ML-5593, purchased August 18, 1959.</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Proposed Numerical Control System for Southbend Mill:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>N/C System:</strong> SLO-SYN Model NC1R24</td>
<td>$5,500.00</td>
</tr>
<tr>
<td>Control medium: tape: EIA standard, 1&quot; 8-track</td>
<td></td>
</tr>
<tr>
<td>Controlled operations: straight line milling point-to-point</td>
<td></td>
</tr>
<tr>
<td>Number of controlled axes: two</td>
<td></td>
</tr>
<tr>
<td>Accuracy: ±.001&quot; with 5 pitch lead screw</td>
<td></td>
</tr>
<tr>
<td>±.0005&quot; with 10 pitch lead screw</td>
<td></td>
</tr>
<tr>
<td>Mill feed rates: 30&quot; to 60&quot; per min.</td>
<td></td>
</tr>
<tr>
<td>Data input: automatic/manual</td>
<td></td>
</tr>
<tr>
<td>Special cooling required: no</td>
<td></td>
</tr>
<tr>
<td>Automatic coolant flow: optional</td>
<td></td>
</tr>
<tr>
<td>Power requirements:</td>
<td></td>
</tr>
<tr>
<td>electric: 105 to 130 V., 60 cycle, 5 amp.</td>
<td></td>
</tr>
<tr>
<td>air: yes</td>
<td></td>
</tr>
<tr>
<td>Motor coupling kits:</td>
<td></td>
</tr>
<tr>
<td>X and Y axes: SLO-SYN Model GM101584-G1</td>
<td>200.00</td>
</tr>
<tr>
<td>Spindle control: SLO-SYN Model EM144099-1</td>
<td>575.00</td>
</tr>
<tr>
<td>Mounting kit: SLO-SYN Model BH101607G-5</td>
<td>40.00</td>
</tr>
<tr>
<td>Model features: Modular construction, solid-state circuity with plug-in circuit cards.</td>
<td></td>
</tr>
<tr>
<td>Approximate total cost of retrofitting existing Southbend Mill with LS0-SYN Numerical Control.</td>
<td>$6,315.00</td>
</tr>
</tbody>
</table>
# TABLE VI

**DATA CONCERNING INDEX VERTICAL MILLING MACHINE**  
(RETROFIT OF NEW CONVENTIONAL MACHINE)

<table>
<thead>
<tr>
<th>General Specifications:</th>
<th>Costs:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Machine Tool:</strong></td>
<td></td>
</tr>
<tr>
<td>Table size:</td>
<td>.9&quot; x 40&quot;</td>
</tr>
<tr>
<td>Table travel:</td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>26&quot;</td>
</tr>
<tr>
<td>Cross</td>
<td>10&quot;</td>
</tr>
<tr>
<td>Vertical</td>
<td>17&quot;</td>
</tr>
<tr>
<td>Throat:</td>
<td></td>
</tr>
<tr>
<td>Spindle to table</td>
<td>17&quot;</td>
</tr>
<tr>
<td>Spindle speeds:</td>
<td>8 total</td>
</tr>
<tr>
<td>Space requirements:</td>
<td>37&quot; x 24&quot; x 80&quot;</td>
</tr>
<tr>
<td>Approximate shipping weight</td>
<td>2,100 lbs.</td>
</tr>
</tbody>
</table>

| **N/C System:**         |        |
| Control medium:         | SL0-SYN Model NC1R24 |
| Tape:                   | EIA standard, 1" 8-track |
| Controlled operations:  | straight line milling point-to-point |
| Number of controlled axis | two |
| Accuracy:               | ±.001" with 5 pitch lead screw  |
|                         | ±.0005" with 10 pitch lead screw |
| Mill feed rates:        | 30" to 60" per min. |
| Special cooling required | no |
| Automatic coolant flow: | Optional |
| Data input:             | Automatic/manual |
| Power requirements:     |        |
| Electric:               | 105 to 130 V., 60 cycle, 5 amp. |
| Air:                    | Yes |
| Motor coupling kits:    |        |
| X and Y axes:           | SL0-SYN Model GM101584-G1 |
| Spindle control:        | SL0-SYN Model EM144099G-1 |

**Model features:**
- Modular construction, solid-state circuity with plug-in circuit cards.

**Approximate total cost of new Index Mill retrofitted with SL0-SYN Numerical Control system:** $8,870.00
TABLE VII
DATA CONCERNING MOOG HYDRA-POINT MILLING MACHINE
(NEW EQUIPMENT)

<table>
<thead>
<tr>
<th>General Specifications:</th>
<th>Costs:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Machine Tool:</strong> Model HP Bridgeport Mill</td>
<td>$11,945.00</td>
</tr>
<tr>
<td>Table size: 9&quot; x 30&quot;</td>
<td></td>
</tr>
<tr>
<td>Table travel:</td>
<td></td>
</tr>
<tr>
<td>longitudinal: 20&quot;</td>
<td></td>
</tr>
<tr>
<td>cross: 10&quot;</td>
<td></td>
</tr>
<tr>
<td>vertical: 11½&quot;</td>
<td></td>
</tr>
<tr>
<td>Throat:</td>
<td></td>
</tr>
<tr>
<td>spindle to table: 1.5½&quot;</td>
<td></td>
</tr>
<tr>
<td>Spindle speeds: 8 total</td>
<td></td>
</tr>
<tr>
<td>Chrome plated ways: standard</td>
<td></td>
</tr>
<tr>
<td>Motor option: 1 hp., or 1½ hp.</td>
<td></td>
</tr>
<tr>
<td>Machine capabilities: milling or drilling</td>
<td></td>
</tr>
<tr>
<td>Space requirements: 64&quot; x 60&quot; x 80&quot;</td>
<td></td>
</tr>
<tr>
<td>Hydraulic oil (required): 10 gallons</td>
<td>40.00</td>
</tr>
<tr>
<td>Approximate shipping weight: 4,800 lbs.</td>
<td></td>
</tr>
<tr>
<td><strong>N/C System:</strong> Model 83-500 Hydra-Point Control</td>
<td></td>
</tr>
<tr>
<td>Control medium: tape: EIA standard, 1&quot; 8-track</td>
<td></td>
</tr>
<tr>
<td>Controlled operations: straight line milling point-to-point</td>
<td></td>
</tr>
<tr>
<td>Number of controlled axis: two</td>
<td></td>
</tr>
<tr>
<td>Accuracy: ±0.001&quot;</td>
<td></td>
</tr>
<tr>
<td>Mill feed rates: 1&quot; to 40&quot; per min.</td>
<td></td>
</tr>
<tr>
<td>Data input: automatic/semi-automatic/manual</td>
<td></td>
</tr>
<tr>
<td>Power requirements:</td>
<td></td>
</tr>
<tr>
<td>electric: 208, 220, or 440 V.; 3 phase 60 cycle</td>
<td>1,995.00</td>
</tr>
<tr>
<td>air: 85 psi/min.</td>
<td></td>
</tr>
<tr>
<td>Basic automatic programming function-optional</td>
<td></td>
</tr>
<tr>
<td>Approximate total cost of Bridgeport Mill and Hydra-Point numerical control system: $12,980.00</td>
<td></td>
</tr>
</tbody>
</table>
Tables IV, V, VI, and VII are suggestive of the options that are open to a possible installation of numerically controlled equipment at North Texas State University. The cost figures are budgetary and should not be considered as quotes. Such items as possible trade-in allowances, shipping costs, installation expenses, or possible school discounts are not figured.

Additional studies should be made into both the machine tool and numerical control system costs as well as installation costs before any combination of machine and control system can be determined.
CHAPTER BIBLIOGRAPHY


CHAPTER V

SUMMARY, FINDINGS, AND RECOMMENDATIONS

The purpose of this study was to investigate the numerical control concept and its effect upon industry, to determine to what extent numerical control exists in the industrial arts programs of schools in the Dallas-Fort Worth area, and to explore the feasibility and probable costs of installing numerically controlled equipment in the industrial arts laboratories of North Texas State University.

During the course of the investigation, major concentrations of effort were applied to the following areas:

1. What are the managerial aspects of the numerical control process; what new philosophies will management be required to consider because of numerical control?

2. What will be the effect of numerically controlled equipment upon existing manufacturing processes?

3. From where will the operators, programmers, and supervisors required for numerically controlled equipment come, and of what must their background and training consist?

4. What is the relationship, if any, between the numerical control concept and the philosophy of industrial arts?

5. How have other schools in the Dallas-Fort Worth area responded to numerical control as an industrial process?
6. Are there any existing installations of numerically controlled equipment in schools in the Dallas-Fort Worth area, and if so, where?

7. How successful have installations of numerically controlled equipment been at other schools in the Dallas-Fort Worth area; what has been their approach to teaching numerical control; and what type maintenance problems have they experienced?

8. Are the industrial arts laboratories at North Texas State University suited for installation of numerically controlled equipment, and if so, what would be the estimated costs involved to install such equipment?

Sources of data included the library of North Texas State University, the Dallas Public Library, the library of the American Management Association, the engineering library of Collins Radio Company, the library of Southern Methodist University, letters and interviews with knowledgeable persons in the fields of numerical control sales, teaching, and operation. In addition, material was obtained from literature, specifications, prices, and technical manuals from various manufacturers of numerically controlled equipment and numerical control systems. Observation was made of numerically controlled equipment in operation, of numerical control programming, and of the machine operator's functions. Personal trips were made to schools in the Dallas-Fort Worth area in which installation of numerically controlled equipment has been accomplished.
Summary

The numerical control process is an operational concept that is finding wide acceptance and application in industry today. Even though the numerical control process is relatively new in terms of age, its growth and acceptance have been widespread. Virtually the only limits on the application of the numerical control process are human imagination and the specific economics of a given situation. The numerical control process is considered by many to be the one overwhelming metalworking development of the century.

Numerical control is primarily the control of a machine process by numbers. A typical numerically controlled machine tool receives information in digital form from punched cards, punched paper tape, or magnetic tape. The numbers provide information symbols to the machine tool for only three functions: counting, measuring, and predicting. The numerical information directs, or controls, the machine motion necessary to produce the desired product.

Because numbers are not subject to deviation, the entire principle of machine control has been removed from the hand of the operator and given to management by the use of engineering data.

Other advantages of the numerical control process include greater machine accuracy, virtual elimination of templettes, jigs, and fixtures, reduced inventories, less setup time required, shorter lead time, increased floor space, and reduced
Examples of numerically controlled machines range from the $200,000.00 complex contour skin milling machine to the point-to-point drill in the $10,000.00 range.

At least three schools in the Dallas-Fort Worth area consider the numerical control concept to be a significant industrial process and have initiated comprehensive programs of study involving numerical control theory and application.

The industrial arts laboratories at North Texas State University appear to be well suited for installation of numerically controlled equipment; however, a more detailed, formal cost study should be made before any real movement in such a direction should be taken.

Findings

During the process of this study, certain findings revealed the following:

1. Numerical control is the automatic control of machines by means of electrical devices that receive instructions from a prepared tape.

2. To date, the use of numerical control has been most prevalent in the machine tool industry.

3. The numerical control concept is applicable wherever process control is needed.

4. Numerical control is a practical philosophy of control utilizing compatible numerical values to various control elements such as feed, speed, length, width, flow, temperature, or pressure.
5. The numerical control process is primarily designed for limited quantities and flexibility; it does not fit into the realm of mass production and should not be compared with, nor defined as, automation.

6. Numerically controlled machines include such diverse equipment as milling machines, drilling machines, lathes, precision boring machines, tube-flaring machines, drafting, plotting, wire-wrap, riveting, and flame cutting machines.

7. Numerical control provides a more scientific approach to manufacturing by allowing management more scope in advance planning and control over actual manufacturing operations.

8. Direct management communication with machines through use of the program will require a review in the philosophy of management as the essential task of managing men must be enlarged to include that of managing machines.

9. Advantages of the numerical control process include reductions in lead and setup times, improved accuracy, a virtual elimination of templates, jigs and fixtures, reductions in product unit cost, and improvement in management control.

10. The use of numerically controlled machines will allow increased flexibility of engineering design.

11. Operators of numerically controlled equipment may be obtained from existing shop personnel.

12. Numerical control programmers need not have an engineering background; however, they should have good shop experience and a capability for higher mathematics.
13. The two major types of numerically controlled operations are point-to-point and contour.

14. Numerically controlled machine tools have been successfully installed at the high school level in the Dallas-Fort Worth area.

15. The numerical control installations at the high schools include new machine tools retrofitted with numerical controls.

16. Conditions in the industrial arts laboratories at North Texas State University are favorable for the installation of numerically controlled equipment.

17. Options open to a possible installation of numerically controlled equipment at North Texas State University include the retrofitting of existing machine tools with numerical controls, the purchase of a new machine tool retrofitted with numerical controls, or the purchase of a new machine tool that has been fully designed as a numerically controlled machine.

18. The approximate purchase cost of a numerically controlled machine tool for North Texas State University ranges from $6,315.00 to $12,980.00.

Recommendations

In view of the findings of this study, the following recommendations are offered:

1. That management understands not only the technological implications of numerical control but also the full range of
2. That those planning an installation of numerically controlled equipment analyze and evaluate fully the applicability of the process to existing and proposed manufacturing processes in their area.

3. That additional studies be made into the existing high school numerical control installations in the Dallas-Fort Worth area to investigate further the possibility of a similar type installation in the industrial arts laboratories at North Texas State University.

4. That a major cost study be initiated by the Industrial Arts Department of North Texas State University to define problem areas and formally arrive at a decision on the feasibility of installing a numerically controlled machine tool in the industrial arts laboratories.

5. That the Industrial Arts Department of North Texas State University seriously considers initiating a program of instruction in numerical control principles at the earliest possible date, even before any installation of numerically controlled equipment takes place.
APPENDIX
GLOSSARY OF NUMERICAL CONTROL TERMS

1. ABSOLUTE DIMENSION: A dimension expressed with respect to the initial zero point of a coordinate axis.

2. ACCURACY: Conformity of an indicated value to the true value. The accuracy of a control system is expressed as the system deviation, or the difference between the ultimately controlled variable and its ideal value.


4. AUXILIARY FUNCTION: Any function or operation of a machine other than positioning or contouring. Includes such operations as coolant flow, tool selection, etc.

5. BACKLASH: A relative movement between interacting mechanical parts, resulting from looseness.

6. BINARY: A system for describing numbers using only two digits.


8. BLOCK: A word or group of words considered as a unit, and separated from other such units by an end of block character on the tape.

9. CARTESIAN COORDINATES: Values representing the location of a point in relation to two straight lines called axes. One axis is horizontal, the other is vertical. The point is located by measuring its distance from each line along a parallel to the other line. The system can be extended into three-dimensional by using a third axis. The third axis is perpendicular to the plane containing the other two axis.

10. CHARACTER: A number, letter, or symbol read on one line across the control tape.

11. CODE: A system of characters with arbitrary rules for their association in representing information.

12. COMMAND: A signal of group of signals initiating one step in the execution of a program.
13. COORDINATES: The positions of points in space with respect to X, Y, and Z axes.

14. ENCODE: To translate from an easily recognizable language into a coded language.

15. FLOATING ZERO: Also zero offset. A characteristic of a numerical control system that permits the zero reference point on an axis to be established readily at any point in travel. The control unit retains no information on the location of any previously established zero points.

16. INCREMENTAL COORDINATES: Coordinates measured from the preceding value in a sequence of values.

17. MISCELLANEOUS FUNCTION: The same as auxiliary function.

18. NUMERICAL DATA: Also engineered data. Data in which information is expressed by a set of numbers of symbols that can only assume discrete values or configurations.

19. PRECISION: Closeness of agreement among repeated measurements of the same characteristic by the same method under the same conditions. See accuracy and reproducibility.

20. PROCESS PHASES: Also manufacturing process phases. Four phases in a manufacturing process. Often defined as the engineering or product design phase, the process planning phase, the economic planning phase, and the production phase.

21. PROGRAM: A set of instructions that define a desired sequence of conditions for a process or function. Transferred by numerical data to the control tape.

22. REPEATABILITY: Closeness of agreement of repeated position movements to the same indicated location and under the same conditions.

23. REPRODUCIBILITY: The ability of a system to maintain its output or input precision over a long period of time.

24. RETROFIT: The modification or adaptation of a conventional machine tool into a numerically controlled machine tool by the addition or retrofitting of a numerical control system.

25. ZERO OFFSET: A characteristic of a numerical machine control permitting the zero point on an axis to be shifted readily over a specified range. The control unit retains information on the location of the "permanent" zero.
MILLING MACHINE, PROFILING AND CONTOURING

VERTICAL TURRET LATHE VERTICAL BORING MILL

UNIVERSAL GRINDER

OPENSIDE PLANER
*IF Z IS UNDER TAPE CONTROL
LEAVE AS IS; IF NOT, +W BECOMES +Z

MILLING MACHINE, PROFILING
AND CONTOURING

MACHINING CENTER MILLING,
DRILLING, BORING

*IF Z IS UNDER TAPE CONTROL
LEAVE AS IS; IF NOT, +R BECOMES +W

SKIN MILL
PROFILE AND CONTOUR MILL
TILTING HEAD AND 5 AXIS

PROFILE AND CONTOUR MILL
HORIZONTAL SPINDLE AND 5 AXIS

PROFILE AND CONTOUR MILLING,
MOVING TABLE AND 5 AXIS

TURRET LATHE

*IF Z IS UNDER TAPE CONTROL LEAVE AS IS, IF NOT, +W BECOMES +Z.

MILLING MACHINE, PROFILING AND CONTOURING

ENGINE LATHE

SKIN MILL

SHAPER

MILLING MACHINE, PROFILING AND CONTOURING

Profile and Contour Mill, Tilting Table and 5 Axis

SINGLE SPINDLE DRILLING MACHINE

HORIZONTAL BORING MILL

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