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FINAL REPORT
ON
STATE-OF-THE ART
IN
IMPROVED PARTS PROGRAMMING
FOR
NUMERICALLY CONTROLLED MACHINES

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WATERTOWN, MASSACHUSETTS

FOREWORD

The research discussed in this report was accomplished by the Department of Industrial Engineering, Texas A&M University for the Texas A&M University Research Foundation under contract number DAAG47-76-C-0024. As such, the ideas, concepts and results herein presented are those of the authors and do not necessarily reflect approval or acceptance by the Department of the Army.

This report has been reviewed and is approved for release. For further information on this project contact Mr. Thomas F. Howie, Intern Training Center, Red River Army Depot, Texarkana, Texas 75501.

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(9)

FINAL REPORT,

~~ON~~

STATE-OF-THE-ART IN NUMERICAL

CONTROL MANUFACTURING TECHNOLOGY,

(6)

State-of-the-Art in Improved Parts Programming for Numerically Controlled Machines.

A Research Report

~~by~~

(10)

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ABSTRACT

This report discusses the state-of-the-art of numerical controlled manufacturing technology, as reflected by current literature and research. Standardization of machine languages and computer software are identified as areas of major importance. The incompatability of postprocessors was found to be a significant problem. The research of Bradford M. Smith in the standardization of postprocessors is identified as an important contribution to the efficient use of numerical controlled machine tools. Little research or literature on numerical controlled tooling, or its standardization; was located. Direct numerical control and computer numerical control are defined, and their impact on numerical control noted. An example of successful work exchange is cited, however, the lack of standardization of postprocessors is identified as a deterrent to effective work exchange. On line, interactive computer based information retrieval systems were used, and the results are reported.

ACKNOWLEDGEMENTS

An expression of appreciation is due to the many people who directly and indirectly contributed to this work.

Major contributions were made to this research project by Mr. Bradford L. Smith of the Naval Ship Research and Development Center, Mr. Charles L. Gilreath of the Texas A&M University Library, and Mr. Vijay Dharia, Graduate Assistant in the Department of Industrial Engineering, Texas A&M University. Mr. Smith willingly discussed, and provided copies of his research reports. Mr. Gilreath was indespensible as the terminal operator for the automated information retrieval searches, and general advisor on information science. Mr. Dharia played a major role in the acquisition of reports and publications. To each of these three men is expressed a sincere thanks.

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Chapter I

Introduction

Numerical Control (NC) Technology deals with the control of process motion or action by numerically coded instructions. Applied to manufacturing, NC commands interface a machine through electric or hydraulic drive systems. The technology, born of federally sponsored research, has spread to all sectors of manufacturing. The federal inventory is 1700 machines, valued at $350 million (1)* with 613 (2) in the Department of Defense.

This report examines the current state-of-the-art of Numerical Control Manufacturing Technology, emphasizing efforts to standardize tooling and software. The report is based on an extensive search and review of the literature, and personal conversations with two researchers in the field.

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* Numbers in parenthesis designate footnotes at the end of the paper.

Chapter II

The Current Application of Numerical Control Manufacturing

The manufacturing area best suited for Numerical Control Manufacturing Technology is metal cutting and removal; the primary reasons being twofold. First, metal removal technology is already a well engineered science with proven tools in operation. Fitting current machines and technology with numerical control has not been a difficult operation. Second, a large part of past and current research in computer applications focuses on metal removal operations. Results of this research have led to greater machine capabilities. H. R. Pinter of IBM Corporation reported that NC "eliminates the previous restriction of engineering design to the straight lines and circles required by conventional machines. The new techniques have made almost any geometric shape possible (3)."

Two other areas are receiving considerable attention in research and industry; they are the application of NC methods in engineering design and drawing. Both of these fields interface with the inclusive field of Computer Aided Manufacturing (CAM).

A brief review of several characteristics of Numerical Controlled Machine Tools (NCMT) will allow a summary of the processes they serve best. Changing a machine tool to NC does not increase its horsepower. Although reduced tool chatter is a capability of some NC machines, thus allowing higher cutting speeds, the metal removal rate is generally unchanged.

Given a simple operation, a part will be more economically produced on an automatic machine, rather than by NCMT. Specialized automatic machinery with self-contained transport systems provide the highest possible production rates. When the volume is reduced, the number of operations increased, or the complexity increased, the advantage shifts to NC. Reduced volume means the unit cost of the automatic part transfer apparatus is increased. The NC machine often has the ability to perform many operations from the same initial set up. As the geometry becomes more complex, NC may be the only feasible manufacturing method.

Most references indicated that, on an economic basis, NC is best applied to small batch production parts. NC works well on complex parts, which often have small demand and require multiple cutting operations. A single setup, as opposed to multiple assemblyline setups, is less likely to damage the expensive part, therefore, scrap cost with NC is reduced. Lower volumes do not justify expensive automatic transfer apparatus of automatic type manufacturing The flexibility of NC allows many different parts to be produced by a single machine, as the demand arises. Thus NC characteristically has a higher utilization rate than an automatic machine, which must remain idle when its' single product is not in production.

One reference indicated the trend to limit NC lot size may have gone too far. According to Richard M. Penn of Moog, Inc., "The ideal lot size is usually said to range from 20 to 500 pieces with an annual production of 100 to 5,000 pieces. Guided by this rule-of-thumb, when a manufacturing manager must produce quantities from 5,000 to 100,000 his first reaction frequently is to choose a special-purpose, high-production machine. But this rule-of-thumb is highly inaccurate and can result in lost profitability (4)."

Mr. Penn points out that proper use of break-even analysis, with proper consideration of economies of scale for additional NC machine centers, learning curve contributions, and reduced tool design and setup allow for higher than expected lot sizes for NC.

Cincinnati Milacron, Inc., has built a $1.25 million Computer Numerical Control (CNC) Manufacturing Center to "meet the needs to [sic] manufacturing concerns where production rates are too high for standard NC and too low for expensive transfer lines (5)."

The key to NC manufacturing applications is flexibility. Rather than retooling, the manufacturer is afforded the option of reprogramming.

Chapter III

Standardization of Tooling

A review of current research and literature reflected a minimal interest in the standardization of tooling in numerical controlled machinery.

The Illinois Institute of Technology Research Institute published a report of research on Computer Aided Design and Computer Aided Manufacturing in February, 1974. The report summarized the scope of 279 ongoing projects in the United States, Europe, and Japan. Only four of the projects dealt with machine tools, and of these, only one considered tool standardization (6).

A manual search of the National Technical Information Service bulletins from January, 1974 to March, 1976 revealed no reports on tool standards, and two reports on NCMT. Two separate literature searches were conducted by the Texas A&M University Automated Information Retrieval Service. A combined total of three references were generated on tool standards out of a total of 1445 on NCMT, and 3369 on Standardization.

The implication of the literature search on NCMT was that little research on tool standardization has been conducted. However, R. C. Love, a tooling specialist of Kennametal, Inc. wrote positively on the subject in July, 1972. According to Mr. Love, "A big plus now is tool standardization. As more NC machines enter a plant, tool standardization becomes a vital part of the modernization. It means finding the fewest types of tools that will do the most jobs on as many NC machines as possible. By standardizing, he can cut the cost of initial and backup tooling, reduce in-house tool inventory, and achieve interchangeability of tooling between machines (7)." Thomas R. King agrees with this argument, but says it is not happening in practice. Writing in March, 1976, Mr. King reasons that technological advancements have been so rapid and drastic, that user companies have found it more economical to purchase the latest available, rather than duplicate, machinery (8).

Group technology is a related field which promises to aid proponents of standardization in both tooling and software. Robert F. Guise, Jr. of Manufacturing Data Systems, Inc. has identified the underlying principle of Group Technology as bringing "together into families those parts that have identical or closely similar physical characteristics or features (9)." Prior to adopting the name Group Technology, David A. Price, also of MDSI, had identified its benefits under the synonymous name of Family of Parts Programming. By grouping similar parts in the same parts program, all parts from the simplist to the most complex in a Family could be produced by the same program. Using this technique in 1974, MDSI, Inc., with their proprietary machine language, Compact II, was able to produce 5,800 different motor shaft configurations from a single basic program (10).

Further investigation at the manufacturer level will be required to determine standardization efforts. A good starting point would be the tool changer and tool holder on NC Machine Centers. Substantial savings could result especially in spare tool inventories, if identical cutting tools were interchangeable between machines of different manufacturers.

Chapter IV

Standardization of Software

1. Languages

Numerical Control languages in use in 1976 numbered 60 at the minimum (12), a considerable increase from the minimum number of 33 in use in 1970 (13). A brief history of Numerical Control will identify some reasons for the large number of languages, and some difficulties in their standardization.

The Automatic Programmed Tool (APT) language, developed under Air Force sponsorship at the Servomechanism Laboratory of Massachusetts Institute of Technology in 1952, was the first NC language. The initial rudimentary version was revised by members of the Aerospace Industries Association (AIA), under sponsorship of M.I.T., in 1957. Illinois Institute of Technology Research Institute assumed full responsibility for the development of APT in 1961.

The first industrial application of NC was on complex and expensive aircraft part milling machines. As smaller users entered the field, many special purpose languages were developed to satisfy less complex machining requirements. The proliferation of specialized techniques and vocabulary words which followed complicated later efforts to standardize the industry. "When NC tools were first installed in the aerospace industries between 1958 and 1960, it was almost impossible to make tapes that ran tools (14)."

The industry had its first standard in the Electronics Industries Association (EIA) convention on one-inch paper tape to drive the machines. "Without the EIA standards on one-inch punched tape and codes used there on, NC would not be where it is today (15)." EIA and the Aerospace Industries Association followed with several more standards, and the EIA continues to monitor NC standards through committee TR-31.

"In 1963 the Business Equipment Manufacturer's Association (BEMA) sponsored the formation of an American National Standard Institute (ANSI) subcommittee for the purpose of creating a proposed standard for the APT language. This committee was designated X3J7 (16)." "The prime objective of X3J7 is to produce a standard for the APT language which will promote the interchangeability of processing APT part programs on a wide variety of computers. The secondary objective is to promote and maintain the produced standard at a level the NC community will accept as an industry standard and adhere to (17)."

The APT standard is one of many voluntary industry standards set by consensus agreement of member parties. "There are now some 20,000 voluntary standards enforced which have been created by more than 400 organizations... (18)."

The field of numerical control is international in scope, and so are efforts to standardize its software. The International Standards Organization has nine different projects concerning NC standards (19).

There is an international move toward a universal English-like language standardized for machine tools. APT, and APT subsets, are the most popular and accepted in the United States; however, the system has its drawbacks. "APT is a very powerful programming language that is capable of handling programs for the most complex machines. It has sometimes been accused of being too powerful for handling the programs of simpler machines such as two-axis drills or two-axis milling machines (20)."

Autospot, a non-APT type language was developed expressly for the point-to-point user. Lathe and other turning operations are essentially two-axis operations, and there has been some dissatisfaction over APT's performance in this field. The U.S. Army evaluated programming languages for turning operations in Project Number 9679 (21).

Standardization is not without its critics. "...[s]tandards are the main 'non-tariff' barriers to trade that are adjudicated in Geneva by the General Agreement on Tariffs and Trade (22)."

"Corporations who have, or will achieve, successful CAM operations are understandably concerned with retention of the competitive advantages their technological development has earned them (23)." An example is Compact II, the proprietary language of Manufacturing Data Systems, Inc. which has been widely used.

According to Jack Thornton writing in American Metal Market/Metalworking News, "[M]any knowledgeable NC experts think that a single NC language is impossible, though they concede it would be nice (24)." "'A single universal NC language remains only a distant possibility,' according to Peter D. Senkiw, President of Advanced Computer Systems, Dayton, Ohio and former head of the Defense Department's attempt to unravel NC languages. That study, the Numerical Control Language Evaluation (NCLE), was published in October, 1974, and 'is quite dated already,' said Senkiw. The reason is that language proponents are constantly innovating and restructuring the languages (25)." Mr. Thornton points out that proponents of other languages who have large capital investments tied up would oppose adoption of a single NC language. Also, many dedicated languages are more efficient at their specialty than the broad-based languages (26).

Although there has been resistance to a universal language, substantial progress has occurred in several other areas of standardization. EIA Axis and Motion Nomenclature for Numerically Controlled Machines' Standard established standard coordinates for all numerically controlled machines. The Standard was developed by EIA Engineering Committee TR-31 on Numerical Control Systems and Equipment. "This standard for axis motion nomenclature for numerically controlled machines is intended to simplify programming, to simplify training of programmers, and to facilitate the interchangeability of control tapes (27)."

ANSI published the first APT Language Standard (X3.37) in October, 1974. ANSI stated its purpose in X3.37 was "...to promote interchangeability of processing of these programs on a wide variety of computers (28)." The Standard defined APT syntax, and the format of the output data (CLDATA) of the processor, but not the interpretation applied to the output data by succeeding processing or equipment. The Standard attempted to resolve contradictions of existing APT systems.

ANSI Standard X3.37 defined APT as a hierarchy of five subsets, with each higher subset including the lower and enlarging its capabilities. Some modular capabilities can be handed down to a lower set. The minimum subset (Subset 1) has motion commands limited to position coordinates or delta motions, with no geometric definition available. Subset 2, Advanced Point-to-Point System, adds geometric definition in lines. Subset 3, Minimum Contouring System, can calculate cutter offset paths, and geometric definition in planes. Subset 4, Three-Dimensional Contouring System, adds geometric definition of three-dimensional surfaces. Subset 5, Multi-Axis Contouring System, has the added capability to control cutter orientation relative to the workpiece.

Examples of a modular feature which can be added to a subset include multiple postprocessing, and trigonometric functions which can be added to the Advanced Point-to-Point System (Subset 2).

In March, 1975, ANSI Committee X3J7 released for consideration a Proposed Revision to X3.37. The 1975 revision included the addition of a machine tool type dependent postprocessor language and minor corrections to the processor language.

One major agency responding to the ANSI proposal has been the National Bureau of Standards (NBS). A Federal Information Processing Standards (FIPS) task group (TG-19) has been formed under the Institute for Computer Sciences and Technology of NBS. "TG-19 will consider the suitability of the ANSI standard for APT for use as a Federal Standard (29)."

2. Postprocessors

The majority of the software standardization effort has been directed to the basic processor, that section which geometrically describes the part to be produced. Also included in this section are the important mathematical techniques for expressing geometry in machine motions which are consistent and repeatable. The output of this processor is usually referred to as Cutter Location Data (CL Data, or CLDATA). This information is then routed through the postprocessor section of the computer program to allow the use of a specific machine to produce the part. The output of the postprocessor in conventional NC is the coded paper tape. Dr. James Childs identifies the major weakness of the postprocessing, "...since the exact tape format for different machines will be different, each type of numerical control machine must have its own unique postprocessor (30)." "The number of postprocessors that interpret word meanings differently also contributes to the difficulty of achieving the desired result (31)."

The trend in industry today is toward more uniform and standard general-purpose processors and semi-unique special-purpose postprocessors, however, several attempts have been identified that make postprocessors standardized to the degree of allowing exchange between different machines. National and international standards organizations have directed substantial efforts to solve the problem of vocabulary definition. The Unified Numerical Control Language Committee, which represents six European countries, has issued a register of postprocessor vocabulary (32). The International Standards Organization (ISO) standards, which detailed the preferred vocabulary and meaning, were in their final stages of publication in 1974 (33).

One promising concept reported by the Bendix Corporation and International Business Machines, involves automatic generation of the postprocessor by a computer. Independent subroutines for the postprocessor, which are the same for every application, are used as a base. Machine dependent routines are added or modified resulting in a new postprocessor. By 1970 Bendix had developed a system for computer-aided generation of a 3-axis postprocessor employing the IBM System/360 Computer. "The benefits of automatic software generation of post-processors will result in reduced cost and shorter lead time with increased reliability (34)."

IBM is also involved in computer generated postprocessors. "A new feature called design aid for post-processors (DAPP) is a method of reducing the cost and effort to develop new post-processors. This set of modules contains all the modules provided by the S/360 APT system (35)." Also as reported in another reference, "IBM has included in its system 370 APT package, a new post-processor writing concept called DAPP (Design Aid for Post-Processors).

This allows a programmer to generate a new post-processor by supplying the answers to a questionnaire and by writing a machine tool module (36)."

The National Engineering Laboratory (NEL), East Kilbride, Glasgow, UK, has been very active in NC research. "The Production Engineering Research Association, through a contract with NEL, has developed a generalized post-processor for point-to-point machines fitted with widely differing control systems... . It is only necessary to write a new machine tool module in order to cater for a new machine (37)."

The preceeding methods attempt to standardize similar subroutines, or modules, in postprocessors of similar machines. Such techniques omit machine dependent statements until the postprocessor is interfaced with a specific machine.

One attempt to standardize postprocessors including machine dependent functions of different machines, was identified. Such a technique would allow the same postprocessor to produce identical parts on different machines. Bradford M. Smith of the Naval Ship Research and Development Center (NSRDC) reported on his successful results in this endeavor in September, 1973. Mr. Smith identified two types of postprocessor language incompatibility. "The lack of standardization in APT post-processor vocabulary has led to each post-processor requiring slightly different APT input statements to accomplish the same function (38)." Mr. Smith proposed that a common postprocessor language be used by the Department of Defense.

The other incompatibility results from different languages used to exercise different machine tool functions. To eliminate this difference, NC machines of similar capabilities are grouped together in general categories.

Mr. Smith's goal was for every machine in a group to interpret the same CL Data correctly, i.e. each machine in the group using the same, or an identical postprocessor. The technique allowed the postprocessor to "simulate in software those machining functions called for by the part program, but not available on the selected NC machine as hardware options (39)."

"For instance, if the CL Data calls for a tool change and no automatic tool changer exists on the selected machine, the post-processor will stop the machining sequence and notify the operator that a manual tool change is required (40)." This capability was generated and proven using two different machines to make identical parts from the same CL Data. The machines used were a Sundstrand OM-3 and a Pratt and Whitney MC-1000.

Mr. Smith later developed a Part Programmers Manual which was in use at the NSRDC on a Kerney and Trecker Model 2 and a Kerney and Trecker Model EB. A draft of this manual is in Appendix A. Mr. Smith has proposed a general plan for improved use of numerically controlled machine tools in the Department of Defense (Appendix B), and a specific research project for better NC use in the Naval Air Systems Command (Appendix C).

Chapter V

Work Exchange

The standardization of postprocessors would be a major step toward the practical exchange of work between locations. A Naval Ship Research and Development Center study in 1974 surveyed Naval experience in NC parts program exchange. The study reported that "vendors are reluctant to use a numerical control parts program supplied as part of a purchase package. A vendor is not likely to use a parts program unless he has a guarantee that there are no 'minor' faults in the program which may damage his machine (41)."

Even if the exchanged parts program successfully produced the part, the recipient may find the program unacceptable for his operation. About 1972 a number of parts programs were produced by Northern Ordnance Company for use at the Naval Ordnance Station, Louisville (NOSL). Although the programs were essentially correct, "the machining techniques used by the programmers at Northern Ordnance were so different from those used at NOSL that the machinists at NOSL preferred not to use them. While much of the parts program dealing with part geometry could be used by NOSL, it was found necessary to reprogram all the cutter motion commands...because the commands were not programmed according to the commonly accepted machining practices at NOSL (42)."

Redding and Smith also cited successful examples of exchange of programs with the Navy. In a series of experiments with South Carolina Vocational School, parts were manufactured using the same control tape at two separate locations. In part, "...the results of this exercise demonstrated the ability of the school to 1) produce a part from control tape used by the Navy on a different but similar numerical control machine tool, 2) produce a part from a tape programmed remote from the machine system, and 3) produce a part on the school's numerical control machine from instructions and a control tape relayed through a commerical telephone-linked terminal and time-sharing computer (43)."

One attempt to make postprocessors available for exchange was a request for information by the Numerical Control Society (NCS). This information request, dated August 22, 1975, included a survey on postprocessors, and a questionnaire on part program computer tape verification. The survey and questionnaire, included in Appendix D, were the subject of a telephone conversation on May 21, 1976 with Mr. Edwin C. Hurd, Chairman of the NCS Software Committee. Mr. Hurd said that both parts of the information request had been recently completed, and that no results had been released. A decision on the information to be released was pending before the Board of Directors of the NCS.

Chapter VI

Direct Numerical Control

Progress in the field of numerical control has closely paralleled advancements in electronics. From the vacuum tube circuitry of the early 1950's, there have been quantum leaps of progress through the transistor era into the present age of integrated circuit technology. The computer industry capitalized quickly on these innovations, providing the user disciplines with large computers for all purposes, specialized lower cost minicomputers, and economical, less flexible microcomputers. Each of these systems has application to numerical control, and the applications are growing and changing with the technology.

One method which has improved the use of NC machine tools is Direct Numerical Control (DNC). DNC is defined by the National Machine Tool Builders Association (NMTBA) as "[A] system connecting a set of numerically controlled machines to a common memory for part program or machine program storage, with provision for on-demand distribution of data to the machines. Direct Numerical Control Systems generally have additional provisions for collection, display or editing of part programs, operator instructions, or data related to the numerical control process (44)." Such a system would typically include a central plant located multipurpose computer, also capable of other diversified plant tasks, such as payroll and inventory. Each NC machine on the shop floor may have an operator's panel where the part program can be monitored on a cathode ray tube, errors edited, or operations halted.

There are at least two benefits of such systems. A central computer station can reduce maintenance costs, and simplify control and supervision. The DNC system allows for expansion by changing software. A hierarchy approach allows Adaptive Control or Management Information Systems to be integrated. Adaptive Control optimizes metal cutting by automatically selecting the most efficient speed and feed based upon feedback from a transducer that senses force, torque or temperature. Management Information Systems (MIS) integrate data on production, inventory, and demand into an ordered array to aid management in planning.

A number of more specific advantages have been summarized by Childs. "Instead of the computers preparing instructions and then punching these on tape, the instructions are transmitted from the computer directly to the drive motors of the machine (45)." Elimination of the tape reader and faster tape verification with editing capability are major advantages. "Despite many improvements, the tape reader is still the single most unreliable part of an NC system, vulnerable as it is to abuse from the operator and the environment (46)."

Despite the advantages of DNC on the large scale, its implementation in industry has been slow. "The American Machinist 11th Inventory of Machine Tools shows that...the total population of DNC systems in the United States is less than 40 (47)."

Chapter VII

Computer Numerical Control

Computer Numerical Control (CNC) is defined by NMTBA as "[A] numerical control system wherein a dedicated, stored program computer is used to perform some or all of the basic numerical control functions (48)." CNC makes use of minicomputers and microcomputers, two terms which have occasionally been used interchangeably. Both are solid state computers which vary in their flexibility and the degree of dedication, the microcomputer being less flexible and more highly dedicated. The literature indicated some overlap in the range of application of the two systems.

"Many of the recent product developments...feature control systems whose basic building block is a general purpose minicomputer. The introduction of a microprocessor represents the next step in the evolutionary process of applying computer technology to NC. Since computers and computer-like systems utilize storage devices or memories, it is a natural extension to utilize this hardware to store not only the data required to configure the NC system, but also to store part programs (49)."

Future application decisions will need to consider the cost of software programming and its development, storage, and peripheral equipment required. The flexibility of software provides the control features at the cost of memory to store them, and adapts a general purpose controller to a particular machine (50)." "Software is the key to CNC, the costs of which are easily overlooked. The cost of software development is growing in relation to decreasing hardware costs (51)."

Many of the leading NC electronic suppliers have cut back or curtailed production of conventional hard wired controls in favor of CNC. Westinghouse Electric Company and Vega no longer produce hardwire NC, and Bendix will be 80 percent CNC in 1977 (52).

Chapter VIII

Automated Literature Search

1. Overview

A substantial portion of the literature review for this project was conducted through the Texas A&M University Automated Information Retrieval Service, the University Library's computerized literature searching service. Two commercial online, interactive, computer-based retrieval services are accessable by means of a remote, time sharing terminal at the University Library. The two services available are DIALOG, the information retrieval service of Lockheed Missiles and Space Company, and ORBIT, the information retrieval service of System Development Corporation.

Searches of the DIALOG and ORBIT systems are conducted in a similar manner. Words, and word groups which identify the subject material (key words), are placed into the computer by the customer in the form of a query. The computer responds with the number of references in an individual data base which include the subject of interest. The search area may be expanded or restricted after each response by alteration of combinations of key words. Important information on a reference, such as the author, title, and source, can then be printed at the users request.

The services contain specific data bases which vary in their area of emphasis. DIALOG contains 35 data bases, 18 of which are classified in Science, Technology or Engineering. ORBIT contains 16 data bases. ORBIT has been operational since 1965, DIALOG since 1967. The data bases used are summarized in Table 8-1.

Table 8-1

SUMMARY OF DATA BASES USED

DATA BASE	COVERAGE	TOTAL CITATIONS	FREQUENCY OF UPDATING	NUMBER UPDATED PER PERIOD	SERVICE
NTIS[1]	Jan 1964	481,900	Biweekly	2,300	ORBIT/ DIALOG
COMPENDEX[1]	Jan 1970	412,000	Monthly	6,000	ORBIT/ DIALOG
INSPEC[1]	Jan 1969	355,000	Monthly	5,000	DIALOG
ISMEC[1]	Jan 1973	34,200	Monthly	1,400	DIALOG
SCISEARCH[1]	Jan 1974	800,000	Monthly	40,000	DIALOG
SSIE[2]	Jan 1974	130,000	Monthly	9,000	ORBIT
CDI[3]	1861	417,000	Annual	39,375	DIALOG
F&S INDEXES[1]	Jan 1972	524,900	Monthly	8,300	DIALOG

1. DIALOG DATA BASES FACT SHEET, DIALOG Information Retrieval Service, Oct, 1975.

2. SDC Search Service Data Bases, Systems Development Corporation, Nov, 1975.

3. Comprehensive Dissertation Index, 1974 Supplement, Vol. 5, 1975.

Three seperate online literature searches were conducted, the results of which are presented in Table 8-2, Table 8-3, and Table 8-4.

The first search of three data bases was conducted on March 15, 1976. The objectives of the first search were to gain an estimate of the magnitude of the literature written on numerical control, and to obtain specific references. A simplified logic flow chart is presented in Figure 8-1.

After the results of the first search were analyzed, a second search of seven data bases was conducted on April 15, 1976. Focus was directed to tools, postprocessors, and standardization.

A third search of four data bases was conducted on July 27, 1976. This search acted as a control, to determine if any area of interest had been excluded inadvertently. The effects of using different word forms of the key words "tool" and "postprocessor" were measured. An attempt was made to locate additional work by the two primary researchers (previously identified by the first two searches). A business oriented data base was included to broaden the extent of the search.

Table 8-2

Information Retrieval Search of March 15, 1976

Summary of Results

Data Base

1. NTIS
2. COMPENDEX
3. INSPEC

Key Words used in Search	Number of References Generated 1	2	3	Code Used in Flow Chart
Numerical Control	176	123	1450	NC
Machine Tools	523	2234	2519	MT
Numerical Control and Machine Tools	72	92	920	NCMT
Programming Languages	2282	861	905	PL
Punched Tape	142	84	319	PT
Machine Oriented Languages	112	3	114	ML
Standards	14181	5876	3171	ST
Standardization	926	979	1272	SZ
Numerical Control and Machine Tools and Programming Languages or Punched Tape or Machine Oriented Languages or Standards or Standardization	20	6	45	
Review	14917	-	6190	R
State of the Art	1155	-	250	SA
Numerical Control and Machine Tools and Review or State of the Art	1	-	2	

Table 8-3

Information Retrieval Search of April 8, 1976

Summary of Results

Data Base

1. NTIS
2. COMPENDEX
3. INSPEC
4. ISMEC
5. CDI
6. SCI SEARCH
7. SSIE

Key Words Used in Search	Number of References Generated						
	1	2	3	4	5	6	7
Numerical Control	180	438	1450	-	1	0	-
Machine Tools	524	2255	2519	-	-	-	-
Numerical Control and Machine Tools	-	265	926	152*	-	-	-
Computer Software	134	119	851	-	-	-	-
Numerical Control and Machine Tools and Computer Software	-	1	6	-	-	-	-
Tool	611	6136	1148	-	-	-	-
Numerical Control and Machine Tools and Tool	-	86	216	-	-	-	-
Standardization	-	964	1317	162	-	-	-
Numerical Control and Machine Tools and Tool and Standardization	-	0	1	2*	-	-	-
Group Technology	-	55	6	-	-	-	-
Numerical Control and Machine Tools and Tool and Group Technology	-	1	-	-	-	-	-
Post Processors	8	14	13	2	0	1	3

*Numerical Control and Tool

Table 8-4

INFORMATION RETRIEVAL SEARCH OF

JULY 27, 1976

Summary of Results

DATA BASE

1. NTIS
2. INSPEC
3. COMPENDEX
4. F&S INDEX

	1	2	3	4
Numerical Control	185	1,497	452	353
Technology	28,274	6,775	12,436	3,535
Manufacturing	5,101	3,363	4,629	1,588
Numerical Control and Technology	19	20	24	8
Numerical Control and Manufacturing	37	162	66	11
Standardi(zation)	1,057	1,379	1,839	97
Generali(zation)	15,965	1,841	5,864	25
Numerical Control and Standardi-(zation)	4	22	9	1
Numerical Control and Generali-(zation)	5	3	4	0
Machine tool	87	576	973	-
Machine tools	540	2,578	2,345	-
Numerical Control and Machine Tool	8	156	67	-
Numerical Control and Machine Tools	73	943	262	-
Tool	632	1,177	6,492	2,351
Tooling	62	52	726	145

Table 8-4 (continued)

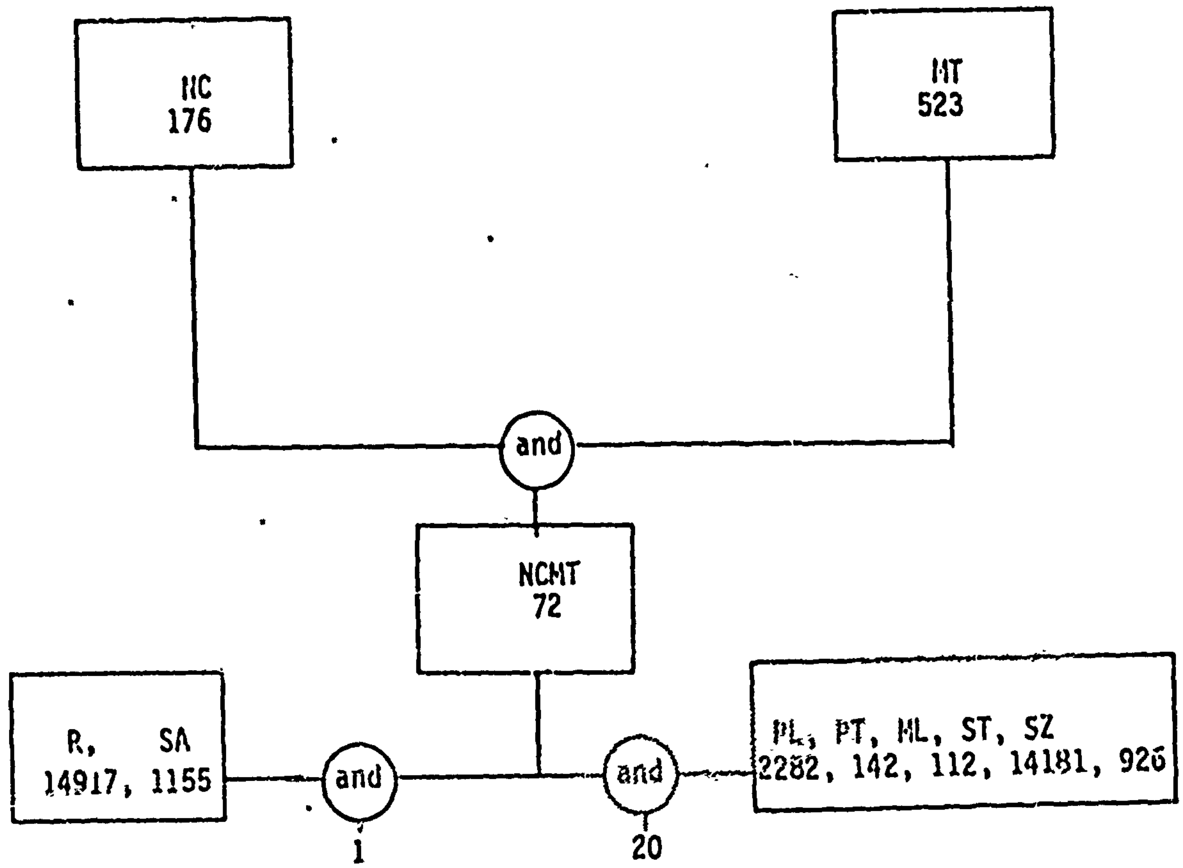
	1	2	3	4
Numerical Control and Tool	12	227	103	225
Numerical Control and Tooling	0	17	14	3
Tool and Standardi(zation)	-	1	52	-
Tooling and Standardi(zation)	0	2	21	-
Numerical Control and Tooling and Standardi(zation)	-	-	2	-
Postprocessor	8	11	13	0
Post processor	8	15	15	0
Numerical Control and Postprocessor	1	2	1	0
Numerical Control and Post processor	3	9	5	0
Numerical Control and R. M. Sim	0	2	1	-
Numerical Control and B. M. Smith	2	0	0	-
Numerical Control and J. L. Redding	0	1	0	-

Figure 8-1

Information Retrieval Search Of March 15, 1976

Simplified Logic Flow Chart

(Numbers Reflect NTIS Results Only)



2. Data Bases Used

NTIS: The National Technical Information Service is a Federal Agency, under the Department of Commerce. It is "the central point in the United States for public sale of research, development, and other Government-funded reports prepared by Federal agencies, their contractors, or grantees. In addition to the data produced by the Department of Commerce's 20 operating units, more than 225 other Government organizations use NTIS to announce and distribute their publications and data (53)."

COMPENDEX: COMPENDEX, produced by the Engineering Index, Inc. is a data base corresponding to The Engineering Index Monthly. The data base offers a world-wide coverage of engineering from professional and technical journals, proceedings, transactions, reports, and special publications. 2299 publications were included in 1975 (54).

INSPEC: INSPEC is an abstracting service provided by the Institution of Electrical Engineers (IEE), located in Great Britain. The service is subdivided into Computer and Control Abstracts, Physics Abstracts, and Electrical and Electronic Abstracts; all are a part of the overall service, Science Abstracts. The data base draws mainly from professional and technical journals and conferences. In 1975, virtually all articles in approximately 223 journals were included. The articles of approximately 2240 additional journals considered significant by the editors were also included in 1975 (55).

ISMEC: Information Service in Mechanical Engineering (ISMEC) is a data base parallel to INSPEC produced by the Institution of Electrical Engineers and the Institution of Mechanical Engineers. Information relevant to mechanical engineering and engineering management is selected from periodical literature, books, reports, and conference proceedings. In 1974 the references were drawn from a collection of approximately 243 periodicals, and an additional 2000 publications submitted to INSPEC (56).

SCISEARCH: SCISEARCH is an index to the literature of science and technology from the Institute for Scientific Information. 1100 Life Science Journals are included (57).

SSIE: SSIE is a service of the Science Information Exchange (SIE) of the Smithsonian Institution. The SIE "facilitates effective management and coordination of scientific research and development by providing for exchange of information about current research projects supported by the U.S. Government and other participating agencies (58)." The data base allows users to monitor the progress of incomplete research, and proposals on planned projects. Over 1300 funding organizations voluntarily submit project information (59).

COMPREHENSIVE DISSERTATION ABSTRACTS: Comprehensive Dissertation Abstracts include "virtually all of the dissertations accepted for academic doctoral degrees..........granted by United States educational institutions. Some dissertations accepted by foreign universities are also included (60)." The data base corresponds to Comprehensive Dissertation Index (CDI), a service of Xerox University Microfilms.

F & S INDEXES: Funk and Scott Indexes is a business and economics data base from Predicasts, Inc. Articles relevant to business research are drawn from over 250 financial publications, business oriented newspapers, trade magazines and special reports (61).

Footnotes

1. "Standard for APT Programming Language," Dimensions, Vol. 59, No. 7 (July, 1975), 165.

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3. H. R. Pinter, "IMB's Relation to NC Development," Proceedings of the Eleventh Annual Meeting and Technical Conference of the Numerical Control Society, ed. M. A. DeVries, (Spring Lake, New Jersey: Numerical Control Society, Inc., 1974), 148-160.

4. Richard M. Penn, "To NC or Not to NC," Proceedings of the Eleventh Annual Meeting and Technical Conference of the Numerical Control Society. ed. M. A. DeVries, (Spring Lake, New Jersey: Numerical Control Society, Inc., 1974), 10-21.

5. Beth K. Granat, "Machine Tool Builders Give N/C Market Edge to CNC over Hand-Wired," American Metal Market/Metalworking News, March 29, 1976, p. 22.

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7. R. C. Love, "NC Spurs Standardization," Tooling and Production, Vol. 38, No. 4 (July, 1972), 40-41.

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11. Douglas A. Ackley, "Post-Processors for the Seventies," Proceedings of the Seventh Annual Meeting and Technical Conference of the Numerical Control Society, ed. H. A. DeVries (Princeton: Numerical Control Society, 1970), 424-430.

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13. W. E. Mangold, Numerical Control Programming Languages (North-Holland Publishing Company, 1970), 102.

14. John M. Evans, Jr., "The Role of Standards in Integrated Manufacturing Systems," Proceedings of the Twelfth Annual Meeting and Technical Conference of the Numerical Control Society, ed. M. S. Melman and E. W. Zimkus, Jr., (Spring Lake, New Jersey: Numerical Control Society, Inc., 1975), 211-217.

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16. Louis E. Sanchez, "ANSI Subcommittee X3J7 for APT Languages," Proceedings of the Eleventh Annual Meeting and Technical Conference of the Numerical Control Society, ed. M. A. DeVries, (Spring Lake, New Jersey: Numerical Control Society, Inc., 1974), 143-147.

17. Sanchez, loc. cit.

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19. Sanchez, loc. cit.

20. James S. Childs, Numerical Control Part Programming (New York: McGraw-Hill, 1970), 178.

21. Bradford M. Smith, "Final Subcommittee Report of 22 October, 1975," (unpublished report of the Chairman, CAD/CAM Subcommittee, Manufacturing Technology Advisory Group, Naval Ship Research and Development Center, Bethesda, Maryland, 1975) A2-1.

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APPENDICES

APPENDIX A

Draft Part Programmer's Manual

AIR/ ON OFF

NORMAL IMPLEMENTATION

This statement controls the operation of air jets used for chip removal. Control is normally effected through the use of miscellaneous function M Codes on the postprocessor N.C output.

PROPOSED IMPLEMENTATION

. Where the N C machine is not equipped with air jets under program control, this function must be implemented manually by the machine tool operator. The postprocessor brings the machine tool to a halt by placing an OPSTOP code on the N C output. The operator is then advised through a message on the text output to control the function of the air jets manually.

BREAK

This statement is normally used where the N C output of the postprocessor is punched paper tape. The statement is used to segment the paper tape into convienent and manageable lengths. BREAK causes the postprocessor to terminate the paper tape in an orderly fashion as with an END statement. A new length of paper tape is then started with all functions such as the spindle and coolant restored to the condition they were in before the break.

CLAMP/ ON
OFF

Initiates or terminates a holding operation.

CLAMP/ n, (ON
OFF)

Controls a holding operation on clamp number "n". "ON" is assumed if the option is not specified.

```
        XAXIS
        YAXIS
CLAMP/  ZAXIS   ,  (ON
        AAXIS       OFF)
        BAXIS
        CAXIS
```

Controls a clamping operation on one axis of the machine tool. "ON" is assumed if the option is not specified.

```
CLAMP/  ALL     ,  (ON
        CHUCK       OFF)
        COLLET
        HEAD
        PALLET
        RAIL
        SADDLE
        TABLE
```

Initiates a clamping operation on the device selected. "ON" is assumed if the option is not specified.

NORMAL IMPLEMENTATION

Control is normally effected through the use of miscellaneous function M Codes on the postprocessor N C output.

PROPOSED IMPLEMENTATION

Where the N C machine is not equipped with clamping devices under program control, this function must be implemented manually by the machine tool operator. The post-processor brings the machine tool to a halt by placing an OPSTOP code on the N C output. The operator is then advised through a message on the text output to control the function of the clamps manually.

$$\text{CLRSRF/}\begin{pmatrix}\text{XYPLAN}\\ \text{YZPLAN}\\ \text{ZXPLAN}\end{pmatrix},\ n$$

Defines the normal distance from the part reference system origin to the clearance plane parallel to the selected coordinate plane.

CLRSRF/ n

Defines the normal distance from the part reference system origin to the clearance plane parallel to the XY coordinate plane.

CLRSRF/ (definition of a plane)

Defines the clearance plane explicitly.

IMPLEMENTATION

The CLRSRF statement is used by the postprocessor to define a clearance plane to be used in conjunction with subsequent RETRCT statements. When a RETRCT is encountered, the postprocessor will automatically retract the tool to the clearance plane.

COOLNT/ (n), FLOOD / MIST / AIR , (ON / OFF)

Controls the selection of coolant desired.

COOLNT/ (n), ON / OFF

The optional scalar value "n" selects which coolant is desired to be controlled.

NORMAL IMPLEMENTATION

This statement is used to control the flow and the type of coolant used. Use of the minor words FLOOD, MIST, and AIR alone constitute a request for that type of coolant to be turned ON. The statement COOLNT/ON is used to reinstate the coolant that was last used by the programmer. Where none has been previously specified, the default option FLOOD is used. Control is normally effected through the use of miscellaneous function M Codes on the postprocessor N C output.

PROPOSED IMPLEMENTATION

Where the N C machine is not equipped with coolant under program control, this function must be implemented manually by the machine tool operator. The postprocessor brings the machine tool to a halt by placing an OPSTOP code on the N C output. The operator is then advised through a message on the text output to control the function of the coolant manually.

CYCLE/BORE, z, f, $\begin{matrix}\text{IPM}\\\text{IPR}\end{matrix}$, (C)

This statement specifies a boring operation starting with a rapid positioning motion to a height C above the programmed point. This is followed by a plunge motion at feedrate f to a depth z. The spindle will then stop and dwell for two seconds. Finally the tool will retract at rapid feedrate to the clearance height C. If C is omitted, .050 inches is assumed. C is assumed to be positive and z negative with all programmed points defined on the part surface.

CYCLE/CSINK, d, a, f, $\begin{matrix}\text{IPM}\\\text{IPR}\end{matrix}$, (C)

This statement specifies a counter-sinking operation where the tool positions at rapid feedrate to a height C above the programmed point. A plunge motion is made at feedrate f to a depth calculated to leave a countersink diameter d with included tool angle a. A rapid retraction is then made to the clearance height C. If C is omitted, .050 inches is assumed.

CYCLE/DEEP, z1, z2, - - , z20, f, $\begin{matrix}\text{IPM}\\\text{IPR}\end{matrix}$, (C)

This statement defines a deep drilling sequence where the tool positions at rapid feedrate to a height C above the programmed point and the following sequence occurs:

1. Plunge at feedrate f to the depth z1.
2. Retract at rapid feedrate to clearance height C.
3. Plunge at rapid feedrate to within .050 inches of the previous z depth.
4. Repeat steps 1 - 3 for all z parameters.
5. Retract at rapid feedrate to the clearance height C. Where the C parameter is omitted, .050 inches is assumed:

CYCLE/DRILL, z, f, $\begin{matrix}\text{IPM}\\\text{IPR}\end{matrix}$, (C)

This statement functions the same way as a CYCLE/DEEP with only one z parameter given.

CYCLE/FACE, z, f, $\begin{matrix} IPM \\ IPR \end{matrix}$, (C)

This statement specifies a facing operation sequence consisting of a rapid positioning motion to a clearance height C above the programmed point, a plunge motion at feedrate f to the depth z, a two second dwell, and a rapid retraction to the clearance height C. Where the C parameter is omitted, .050 inches is assumed.

CYCLE/MILL, z, f, $\begin{matrix} IPM \\ IPR \end{matrix}$, C

This statement sets up a milling sequence for all subsequent programmed points until another CYCLE statement is encountered. The milling sequence consists of a rapid positioning motion to a clearance height C above the first programmed point followed by a plunge motion at feedrate ½f to the depth z. The motion to each successive programmed point is at feedrate f. No retraction is made to the clearance height C. Where the C parameter is omitted, .050 inches is assumed.

CYCLE/REAM, z, f, $\begin{matrix} IPM \\ IPR \end{matrix}$, (C)

This statement specifies a reaming sequence consisting of a rapid positioning motion to a height C above the programmed point, a plunge at feedrate f to the depth z, and a retraction at feedrate f to the clearance height C. If C is omitted, .050 inches is assumed.

CYCLE/TAP, z, f, $\begin{matrix} IPM \\ IPR \end{matrix}$, (C) .

This statement specifies a tapping sequence starting with a rapid positioning motion to a height C above the programmed point. With the spindle in the clockwise direction a plunge motion follows at a feedrate f to the depth z. The spindle is reversed and a retraction is made at a feedrate f to the clearance height C. A rapid positioning motion is made to the next programmed point and the spindle is reset to the clockwise direction. If C is omitted, a height of .050 inches is assumed.

CYCLE/THRU, z1, z2, z3, - - -, z20, f, IPM/IPR, (C)

This statement defines a series of feed motions interspersed with rapid plunge motions. The tool is first positioned at rapid feedrate to a height C above the programmed point. The following sequence is initiated:

1. Plunge at feedrate f to the depth z1.
2. Plunge at rapid feedrate to depth z2 minus the clearance dimension C.
3. Plunge at feedrate f to the depth z3.
4. Repeat 1 - 3 for all z values given.
5. Retract at rapid feedrate to clearance height C.

Where the C parameter is omitted, .050 inches is assumed.

CUTCOM/ n

Specifies the cutter compensation register to be used in the N C controller.

CUTCOM/ ON
OFF .

Turns cutter compensation ON or OFF.

CUTCOM/ RIGHT
LEFT

Specifies the direction of cutter compensation to be used.

CUTCOM/ RIGHT / LEFT , (n), (XY PLAN / YZ PLAN / ZX PLAN) , (LENGTH, m)

Determines if compensation is applied to right or left side of cutter path. The following options can be used in the order shown.

1. A scalar "n" can be used to specify the cutter compensation register to be used in the N C controller. The default register is governed by the postprocessor.

2. The coordinate plane to be used for the cutter compensation can be selected. Default value is the XY plane.

3. Cutter length compensation can be specified as a scalar value "m". Default length compensation is zero.

IMPLEMENTATION

Cutter compensation is a feature of an N C controller which enables an operator to adjust the programmed center path to compensate for minor variations in cutter diameter and length from the nominal values used in the part program. These variations are usually the result of regrinding, wear, or inaccuracies of tool length adjustment. Where the N C machine controller is not equipped with the cutter compensation feature, this statement cannot be correctly processed. The postprocessor must then flag the use of this statement as an error.

CYCLE/BORE, THRU, - OPTIONS -

This statement specifies a boring operation consisting of a rapid plunge, a feed motion and a rapid retraction. The depths for these motions are specified by the couplets RAPTO, FEEDTO, and RTRCTO. When several successive rapid and feed motions are desired at the same X - Y point, they can be specified by scalar lists after the RAPTO and FEEDTO modifiers.

CYCLE/BORE, DEEP, (STEP, m,n,p,etc.) - OPTIONS -

This statement specifies a boring operation consisting of a rapid plunge, a series of feed motions, and a rapid retraction. The initial plunge depth is controlled by the RAPTO couplet. The feed motions are in "woodpecker" fashion; feed to depth, retract to initial plunge depth, plunge back to the previous feed depth, feed down again, etc. The ultimate feed depth is under control of the FEEDTO modifier. Depths for the intermediate positions are under control of the STEP modifier.

CYCLE/BORE, DRAG, - OPTIONS -

This statement specifies a boring operation where the spindle is brought to a halt at the end of the cut and then withdrawn. Otherwise the parameters and operation are the same as for CYCLE/BORE, THRU.

CYCLE/BORE, NODRAG, (ORIENT, n)

This statement is similar to the DRAG option except at the end of the feed motion the spindle is stopped in a known orientation and a move is made in X or Y to back the cutter away from the work before the cutter is retracted.

CYCLE/BORE, MANUAL, - OPTIONS -

This statement allows for a manual retraction of the tool once the feed motion has terminated. The machine tool spindle is turned off automatically.

For all BORE operations the following couplets can be used as options:

RAPTO, m	The tool will plunge at rapid feedrate to the position defined by the delta distance "m". A positive value is measured from the point back along the spindle center line. A negative value is measured from the point in the opposite direction.
FEEDTO, n	The tool will plunge under feedrate control to the position defined by the delta distance "n". Positive and negative values are measured as for RAPTO.
RTRCTO, p	The tool will retract at rapid feedrate to the position defined by the delta distance "p". Positive and negative values are measured as for RAPTO.
(IPM / IPR / MMPM / MMPR), f	The tool will move at a feedrate "f" in units of inches or millimeters per minute or per revolution.
DWELL, s	Commands a dwell of "s" seconds.
DWELL, REV, r	Commands a dwell of "r" revolutions of the cutter.

CYCLE/DRILL, THRU, - OPTIONS -

This statement specifies a drilling operation consisting of a rapid plunge, a feed motion, and a rapid retraction. Depths for these motions are contained in the modifier couplets RAPTO, FEEDTO and RTRCTO. Where several successive rapid and feed motions are desired at the same X - Y point, they can be specified by scalar lists after the RAPTO and FEEDTO modifiers.

CYCLE/DRILL, DEEP, (STEP, m_1, m_2 - - m_n), - OPTIONS -

This statement specifies a drilling operation consisting of a rapid plunge, a series of feed motions, and a rapid retraction. The initial plunge depth is controlled by the RAPTO couplet. The feed motions are in "woodpecker" fashion; feed to depth, retract to initial plunge depth, plunge back to the previous feed depth, feed down again, etc. The final feed depth is controlled by the FEEDTO couplet. Depths for the intermediate positions are under the control of the STEP couplet.

CYCLE/DRILL, BRKCHP, (STEP, m_1, m_2 - - m_n), - OPTIONS -

This statement is identical with the above DEEP statement except that the drill is not retracted to the initial plunge depth after each step of the sequence. The small retraction that is made after each step is sufficient only to break up the chip. The amount of retraction is determined by the postprocessor.

CYCLE/DRILL, CSINK, CSKDIA, m, TLANGL, n, - OPTIONS -

This statement specifies a countersinking operation consisting of a rapid plunge, a feed motion, and a rapid retraction. The plunge depth and retraction position are controlled by the RAPTO and RTRCTO modifier options. The feed depth is computed by the postprocessor from the scalar values of "m" and "n". These are the desired countersink diameter and the tool angle. If the HOLDIA option is included, an additional amount of plunge depth is calculated before the feed motion starts.

CYCLE OPTIONS

The following optional couplets can be included with CYCLE/DRILL commands.

HOLDIA,	The scalar "d" specifies the diameter of the hole being drilled. Different diameters for successive holes such as would be produced by a stepped drill can be specified in a scalar list after the HOLDIA modifier. The data is used to calculate an additional amount of rapid feedrate plunge before the cutting feedrate is started.

RAPTO, m
FEEDTO, n
RTRCTO, p
(IPM / IPR / MMPM / MMPR), f
DWELL, s
DWELL, REV, r

Same as for CYCLE/BORE options

CYCLE/TAP, - OPTIONS -

This statement specifies a fixed cycle of tapping operations consisting of a rapid plunge, forward spindle, feed to depth, reverse spindle, feedout to the feed start position, and a rapid retraction. The following modifiers are used to specify the cycle. All modifier couplets are optional.

(RIGHT / LEFT)	The forward direction of the spindle is right for clockwise and left for counterclockwise.
RAPTO, m FEEDTO, n RTRCTO, p (IPM / IPR / MMPM / MMPR), n	Same as for CYCLE/BORE options
TPI, m	Can be used in lieu of IPM above to specify the threads per inch "m" for feedrate control.
DWELL, s DWELL, REV, r	Same as for CYCLE/BORE options

CYCLE/MILL, - OPTIONS -

This statement specifies a series of milling operations consisting of a rapid plunge, a feed motion, a milling sequence and a rapid retraction after the last point of the milling sequence. The following modifiers are used to specify the cycle. All modifier couplets are optional.

RAPTO, m

FEEDTO, n

RTRCTO, p

(IPM / IPR / MMPM / MMPR), f

DWELL, s

DWELL, REV, r

CYCLE/MANUAL

A manually controlled operation is to be performed at each X - Y point. The machine operator will restart the machine after the operation is completed.

CYCLE/OFF

This statement terminates a previously defined cycle operation sequence.

CYCLE/ON, - OPTIONS -

This statement reinstates the last defined cycle operation sequence. Options may be appended to modify any aspect of the sequence desired.

DELAY/n

Causes a suspension of all machine operations for "n" seconds. Used to halt the machine for a given length of time.

DELAY/REV, n

Causes a suspension of all machine operations for "n" revolutions of the spindle.

IMPLEMENTATION

Dwell times are usually initiated by an appropriate miscellaneous function, M code or by a preparatory function G code. The length of dwell is governed either by an associated motion register (X,Y,Z,etc.) or by activating a preset timer in the NC controller. In the case of a dwell for a specified number of revolutions, the postprocessor first calculates the time in seconds from the known spindle speed and the given number or revolutions. The appropriate output block is then generated.

For N C controls with no control of delay time, the postprocessor should generate a warning message indicating a delay was called for but not executed.

END

This statement indicates the logical completion of a section of programming. An orderly completion of all postprocessor output follows. A Stop code and End of Tape code followed by trailing leader codes are placed on the postprocessor N C output. Final messages are printed on the text output concerning tape length produced, machining time, and number of processing errors. Following the END statement a postprocessor expects either a FROM statement or a FINI statement.

FEDRAT/ n , (RANGE, m / LOW / MEDIUM / HIGH)

Specifies the feedrate in inches per minute. Range selection is optional.

FEDRAT/ IPM / IPR / MMPM / MMPR , n , (RANGE, m / LOW / MEDIUM / HIGH)

Specifies the feedrate "n" in units of inches or millimeters per minute or per revolution. Range selection is optional.

IMPLEMENTATION

The postprocessor will ordinarily calculate the proper F code feedrate number to be placed on the N C output based upon data such as the commanded feedrate, the length of tool motion being executed, and the spindle speed if IPR has been specified. The feedrate may have to be reduced as a result of acceleration - deceleration requirements of the machine, surface feet per minute claculations, or tape reader speed limitations. All feedrates are tested by the postprocessor to lie within maximum and minimum bounds. The optional range selection will normally result in a miscellaneous M code being generated to shift gears of the servo transmission along with a delay preparatory function G code to cause a dwell for the required length of time for gear changing.

For those N C machines without gear changing ability, the RANGE option is ignored. If by chance the commanded feedrate exceeds the capability of the machine tool, a warning message is placed on the output text listing and the maximum feedrate is assigned. If a feedrate command is encountered which cannot be executed within given range, an automatic range change is made and a warning message is generated.

For those N C machines with manual control of feedrate only, an OPSTOP code is generated and a message is placed on the output listing instructing the machine operator to manually adjust the feedrate to the required value.

GOHOME

Commands all axes of the machine tool to a position which is defined within each individual postprocessor. The statement is often used for changing tools or at the end of a part program. Rapid feedrate is used for this move.

INSERT/ ' - - - - - - - - - '

Characters specified between the apostrophe delimiters are inserted directly into the output control information. Imbedded blank characters are inserted in the same manner.

LEADER/ n

Specifies the amount of leader to be produced in units set by the postprocessor. (Commonly inches)

LINTOL/ n

Controls the linearization function. The value "n" specifies the acceptable deviation of the tool tip from the desired cutter path.

LINTOL/ ON
OFF

Commands that the linearization function in the postprocessor be on or off. The postprocessor linearization function forces the machine tool to stay within a specified tolerance of a straight line connecting two successive cutter location points. Intermediate points are calculated to fulfill this purpose. Linearization is performed only for non-rapid movements when started by a LINTOL statement.

LOAD/TOOL, (n), (LENGTH, m), (HOLDER, LARGER / SMALL / MEDIUM / P)

Controls the loading of a tool specified by the optional parameters or by a previous SELECT/TOOL statement. "n" is the tool identification. Cutter length compensation can be optionally specified by the couplet [LENGTH; m], and a tool holder is described by the last optional couplet.

NORMAL IMPLEMENTATION

The tool to be loaded by this command is specified by the value "n". This is either the tool number or its location in the automatic tool changer. If "n" is omitted the next tool available will be loaded. Use of just the basic statement LOAD/TOOL with no other data implies that the tool was previously specified by a SELECT/TOOL statement. Control of the tool loading operation is normally effected through the use of miscellaneous function, M Codes, preparatory function, G Codes, and tool function, T Codes, on the postprocessor N C output.

PROPOSED IMPLEMENTATION

Where the N C machine is not equipped with tool changing capability under program control, this function must be implemented manually by the machine tool operator. The postprocessor brings the machine tool to a halt by placing an OPSTOP code on the N C output. The operator is then advised through a message on the text output to load the specified tool manually.

MCHTOL/n

This feature of a postprocessor checks the amount of overshoot or undershoot that will occur when a change in direction has been programmed. If the deviation from the desired cutter path exceeds the value "n", the postprocessor will compensate by inserting commands on the N C output. Dwell commands are used to correct for excessive undershoot. The commanded feedrate is reduced to correct for overshoot.

OPSKIP/ ON OFF

This statement allows the machine tool operator to skip over optional sections of N C control information. All blocks of postprocessor N C output occurring after an OPSKIP/ON statement are flagged in such a way to allow the N C controller to ignore them whenever the machine operator uses the block delete function of the controller.

IMPLEMENTATION

Where this command is used for controllers not equipped with the block delete option, it is ignored.

OPSTOP

Optionally halts all machines motions under tape control and turns off the coolant, spindle, and tape reader. This command is similar to the STOP command but is under the option of the machine operator. Through a switch on the control panel he can enable or disable this feature. If the switch is off, the command is ignored.

IMPLEMENTATION

For a machine not equipped to recognize the OPSTOP miscellaneous function M Code, the postprocessor should cause the machine to stop unconditionally.

ORIGIN/ X,Y, (Z)

This statement defines the machine origin in terms of the part programming reference system. X, Y, and Z give the location of the machine tool origin in the coordinate system used for the part program. The value Z is optional. Its default value is zero.

PIVOTZ/n

This statement is used only by multiaxis postprocessors to define the relationship of the part programming origin to the pivot plane of the machine tool. The pivot plane is the basic reference plane of the machine tool. It is generally a Z plane. All machine slide dimensions are measured from the pivot plane. "n" specifies the distance from the part origin to the pivot plane.

PPRINT/ '- - - - - - -'-'

The statement is used to place comments in the postprocessor text output. These are used to give messages to the part programmer or machine tool operator concerning part setup, tool changes, or reasons for a programmed STOP or OPSTOP. The specified string of characters are inserted into the printed output of the postprocessor.

RAPID

This statement specifies that the next programmed movement is to be executed at the maximum possible feedrate. The RAPID command applies only to the next movement. All successive moves are at the previously defined feedrate.

RETRCT

Commands a rapid traverse movement of the tool to the clearance surface which has been previously defined by a CLRSRF statement. Motion is along the tool axis (Z axis). The command is used on positioning and milling machines.

REWIND

This command repositions the control medium to its starting point. The machine is brought to an orderly halt with spindle, coolant, etc. turned off.

REWIND/n

Repositions the control medium to the reference mark number "n".

ROTATE/ HEAD / TABLE , n

Commands the rotation of a head or table in the positioning mode only. Motion is not under feedrate control. The scalar "n" specifies the absolute value of the angle or rotation and is given in degrees.

ROTATE/ HEAD / TABLE , INCR, m, (CLW / CCLW) , (ROTREF)

The angular rotation from the present position is specified by the couplet (INCR,m). It is an incremental movement of "m" degrees. Where the optional direction selector is not specified, the rotation is governed by the sign of "m". Rotation is clockwise for positive "m" and counterclockwise for negative "m". Use of ROTREF insures that after rotation the part coordinate system and the machine coordinate system remain in alignment.

ROTATE/ HEAD / TABLE , ATANGL, n, (CLW / CCLW) , (ROTREF)

The couplet (ATANGL, n) commands a rotation to the angle "n" degrees. Direction of rotation is governed by the optional selector. Default direction is clockwise. As above the option ROTREF will cause rotation of the part programming coordinate system.

PROPOSED IMPLEMENTATION

The ROTATE command normally results in A or B axis movements on the postprocessor N C output. For machine tools not equipped for these movements there can be no simple manual remedy. The postprocessor should flag this condition as being beyond the capability of the selected machine tool.

SELECT/HEAD, n Selects head by number.

ALL
BOTH
HIGH
LEFT
LOW
MAIN
RAIL
RIGHT
SADDLE
SIDE
RAM
QUILL

NORMAL IMPLEMENTATION

This statement identifies a particular head on the N C machine which will be referenced by future statements.

PROPOSED IMPLEMENTATION

This statement will be ignored by all machines with a single head.

SELECT/TOOL, (n), (LENGTH, m), (HOLDER, P / LARGE / MEDIUM / SMALL)

NORMAL IMPLEMENTATION

This statement controls the selection from the tool changer of the tool specified by the identification number "n". If "n" is omitted, the next tool available will be selected. Cutter length compensation can be optionally specified by the couplet (Length, m). The tool holder can be described by the last optional couplet. The tool will not be loaded into the active spindle until a LOAD/TOOL statement is encountered at a later time. Control is normally effected through the use of miscellaneous function, M Codes, preparatory function, G Codes, and tool function, T Codes on the postprocessor, NC output.

PROPOSED IMPLEMENTATION

Where the N C machine is not equipped with automatic tool changing capability under program control, this function must be implemented manually by the machine tool operator when the LOAD/TOOL statement is encountered. The postprocessor must simply store the data given in the SELECT/TOOL statement for future use when issuing a message to the operator for loading the tool.

SEQNO/ n

Specifies that the next output block will be assigned the sequence number "n" only the ~~next block will~~ be effected. Normal sequencing will then resume.

SEQNO/ ON
OFF

Starts and stops the sequence numbering function.

SEQNO/AUTO

Specifies that each block sequence number will correspond to the number of the cutter location record being processed.

SEQNO/INCR, m, (r)

Specifies that the next output block will be assigned a sequence number equal to the previous number (or zero if no previous number was assigned) plus the scalar value "m". Subsequent sequence numbers will be incremented by the value "m". If the scalar value "r" is present, a sequence number will only be assigned once every "r" output blocks.

SEQNO/ n, INCR, m

Specifies that the next output block will be assigned sequence number "n" and that each following block will be incremented by "m".

SEQNO/ n, INCR, m, (r)

Specifies that the next output block will be assigned sequence number "n" and that each following block will be incremented by "m" and "r" as above.

$$\text{SET/MODE, } \begin{array}{l} \text{CIRCUL} \\ \text{LINEAR} \\ \text{PARAB} \end{array}$$

Specifies the particular mode of interpolation to be used, (whenever possible) for all non-linear motions.

$$\text{SPINDL/ } n, \left(\begin{array}{l} \text{CLW} \\ \text{CCLW} \end{array}\right), \left(\text{RANGE, } \begin{array}{l} m \\ \text{LOW} \\ \text{MEDIUM} \\ \text{HIGH} \end{array}\right)$$

Commands the spindle to be turned on at the specified angular velocity "n" revolutions per minute. The default of the optional angular direction is clockwise. The default of the optional range is determined by the postprocessor. "m" specifies a range by number.

$$\text{SPINDL/ON, } \left(\begin{array}{l} \text{CLW} \\ \text{CCLW} \end{array}\right), \left(\text{RANGE, } \begin{array}{l} m \\ \text{LOW} \\ \text{MEDIUM} \\ \text{HIGH} \end{array}\right)$$

Commands the spindle to be turned on. Previous spindle speed direction, and range are reinstated unless direction or range is specified. If SPINDL/ON appears as the first specification, a default spindle speed is assigned by the postprocessor.

SPINDL/OFF   Turns off the spindle motor and coolant.

SPINDL/NEUTRL   Places the spindle motor transmission in the neutral position.

SPINDL/LOCK   Fixes the spindle shaft so that it cannot be turned.

SPINDL/ORIENT, (n) .

Causes the spindle to be oriented into an absolute angular position specified by the optional scalar "n" or in the absence of "n" in a position determined by the machine hardware or the postprocessor.

$$\text{SPINDL/}\begin{matrix}\text{SFM}\\\text{SMM}\end{matrix},\ n,\begin{pmatrix}\text{CLW}\\\text{CCLW}\end{pmatrix},\left(\text{RANGE},\begin{matrix}m\\\text{LOW}\\\text{MEDIUM}\\\text{HIGH}\end{matrix}\right)\left(\text{RADIUS},\begin{matrix}r\\\text{TOOL}\\\text{XCOORD}\\\text{YCOORD}\\\text{ZCOORD}\end{matrix}\right),\left(\text{MAXRPM},\ x\right)\ .$$

Commands the spindle to be turned on so as to produce a cutting speed of the specified distance per unit time. "n" specifies the surface velocity in feet per minute or meters per minute. The default of angular rotation is clockwise. Other optional couplets as shown can be added to specify the spindle range, tool radius and maximum spindle speed.

NORMAL IMPLEMENTATION

Control of spindle speed is accomplished by varying the speed of the drive motor and by changing the gear ratio between the motor and the spindle. The desired gear range can be specified by the words HIGH, MEDIUM, and LOW or can be selected by number. m = 1 specifies the lowest range; m = 2 is the next higher range; m = 3 next, etc. For transmissions with three ranges, LOW, MEDIUM and HIGH correspond to m = 1,2,3. But for transmissions with only two ranges, MEDIUM and HIGH both select the m = 2 range. Control is accomplished through the use of appropriate miscellaneous function, M Codes, and preparatory function, G Codes.

PROPOSED IMPLEMENTATION

Where the N C machine is not equipped with spindle functions under program control, this function must be implemented manually by the machine tool operator. The postprocessor brings the machine tool to a halt by placing an OPSTOP code on the N C output. The operator is then advised through a message on the text output to manually set the speed direction, and range of the spindle drive system to the proper values.

STOP

Halts all machine motions under tape control and turns off the coolant, spindle, and tape reader.

TMARK

This command causes a rewind stop code to be placed on the postprocessor N C output. It is used by the N C controller to terminate the rewind sequence of the control tape and restart machining from a known point in the program.

TMARK/n

Commands that a reference mark with the value "n" be placed on the output control medium. Rewinding to this position is accomplished with a REWIND/n command.

TRANS/X, Y, (Z)

Defines the translation parameters used to modify tool position coordinates. Z is optional. Default value is zero.

UNLOAD

NORMAL IMPLEMENTATION

This statement causes the removal of the current tool from the active spindle. Control is normally effected through the use of miscellaneous function M Codes on the postprocessor N C output.

PROPOSED IMPLEMENTATION

Where the N C machine is not equipped with an automatic tool changing mechanism under program control, this function must be implemented manually by the machine tool operator. The postprocessor brings the machine tool to a halt by placing an OPSTOP code on the N C output. The operator is then advised through a message on the text output to remove the current tool from the spindle.

APPENDIX B

Proposal for Improving DOD's Use of Numerically Controlled Machine Tools

DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
HEADQUARTERS
BETHESDA, MARYLAND 20034

ANNAPOLIS LABORATORY
ANNAPOLIS, MD 21402
CARDEROCK LABORATORY
BETHESDA, MD 20034

IN REPLY REFER TO:
1858:BMS:lfs

From: Chairman, CAD CAM Subcommittee of the DOD Manufacturing Technology Advisory Group
To: Distribution List

Subj: Proposal for Improving DoD's Use of Numerically Controlled Machine Tools

1. As the result of talks with many people in the course of our committee's work for the MTAG meeting in Corpus Christi, Texas I feel there is an urgent need for a cooperative effort among the three services to improve DoD's use of numerically controlled machine tools, specifically the problem of workload exchange between different NC machines. This problem was highlighted in the recent report from the General Accounting Office "NC Industrial Equipment: Progress and Problems."

2. I, therefore, propose to you the idea of a Tri-Service project to develop a flexible, integrated manufacturing base within the Department of Defense capable of quick response to varying needs while making efficient use of available manpower and equipment. This concept is founded upon the proven characteristics of over 600 numerically controlled (NC) machine tools now installed at 48 DoD activities. The manufacturing methods and computer software to be developed by this project will allow component part workload to be rapidly and easily shifted among these NC machine tools. At present, because of inconsistencies in data formats, machining techniques, and NC computer languages, the time and expense of shifting workload to different machines is often prohibitive.

3. The ability to program a part data package for manufacture on any one of a variety of NC machines will have a significant impact throughout the entire Department of Defense. Individual machine shops will be able to maximize utilization by easily shifting NC workload to available resources rather than having to wait until the pre-chosen machine becomes free. The DoD Logistics System will benefit from this approach since digital data packages for required parts can be quickly sent to activities with available NC machine capacity for subsequent manufacture without the need for reprogramming.

4. While there are several problem areas that remain to be solved before workload can be easily shifted among different NC machines, one of the more complex is that of programming the control tapes. A common language set is needed so that parts do not have to be reprogrammed for each new machine.

Parts could be initially programmed for a general category of machines such as lathes, drills or 3-axis mills. A part programmer would develop a generalized program without regard for the specific machine to be selected. Computer software would process this generalized program in the same way for all machines within the same category. The software would simulate where necessary for hardware features called for by the part programmer but unavailable on the particular machine chosen. This methodology allows a part program to be easily shifted among functionally equivalent NC machines.

5. To guide and stimulate the development of such a flexible manufacturing base within DoD, I suggest the formation of a Working Group under the CAD CAM Subcommittee. Such a Working Group would be made up of representatives from all three services who are actively participating in projects related to the above goal. The Working Group could be organized with a minimum of time and red tape. Funding for new developments could be arranged on a shared basis through Military Interdepartmental Purchase Requests (MIPR) from already funded projects that would themselves benefit from the development of the capabilities.

6. I realize that some of the ideas I have presented here may seem unorthodox yet I feel that this goal of a flexible integrated manufacturing base is timely and realistic. It is a goal that can be used to focus all of our individual efforts. However, it requires our mutual cooperation. Recent years have seen several projects in the Army, Navy and Air Force which have addressed portions of this problem in workload exchange. There has been limited success, but there has also been some duplication of effort. We can no longer tolerate this fragmented approach. Funding is scarce enough and the pressures are already upon us to produce parts that are more complex in shorter time spans and with fewer people. The time is now to start a Tri-Service project for the development of a flexible integrated manufacturing base which can adequately and economically support the operating forces of the future.

7. I earnestly solicit your comments and suggestions on this idea.

BRADFORD M. SMITH

APPENDIX C

Proposal for Manufacturing Technology Project

DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
HEADQUARTERS
BETHESDA, MARYLAND 20034

ANNAPOLIS LABORATORY
ANNAPOLIS, MD 21402
CARDEROCK LABORATORY
BETHESDA, MD 20034

IN REPLY REFER TO:
1858:BMS
3900 (4)

From: Commander, David W. Taylor Naval Ship R&D Center
To: Commander, Naval Air Systems Command (AIR 52022)

Subj: Proposal for Manufacturing Technology Project

Ref: (a) "NC Industrial Equipment: Progress and Problems", U. S. General Accounting Office, 24 Sep 1974
(b) "Use of NC Equipment Can Increase Productivity in DOD", U.S. General Accounting Office, 29 June 1975
(c) Draft DOD Directive "Management of NC Plan Equipment", 1975
(d) Manufacturing Technology Guidelines for Proposal Submissions NAVAIR 52022

Encl: (1) Exchangeable Part Data Packages for Numerical Control Manufacturing

1. Recent studies of DOD industrial facilities by the U.S. General Accounting Office in references (a) and (b) have pointed out the large increases in productivity that are being realized through the judicious use of numerical control (NC) industrial equipment. However, the studies highlight several technical problems which must be solved before users can achieve maximum benefits from this equipment. These problems stem from inadequacies in the computer support that is used for preparation of NC control tapes.

2. Inconsistencies in the NC language required to control different NC machines make it necessary to choose which machine to use before a program can be written. If this machine is unavailable at the time a part is needed, the job is needlessly delayed unless it can be reprogrammed for a similar machine that is free. Often the time and expense of the reprogramming is prohibitive.

3. The development of improved software to support over 120 NC machines now installed in the Naval Air Systems Command will result in a flexible, integrated manufacturing system where a part data package can be used on any available NC machine. The system will be capable of quickly responding to NAVAIR needs while making efficient use of available

manpower and equipment. This capability is cited as a specific objective of DOD in reference (c).

4. The enclosed manufacturing technology project, enclosure (1), proposes the demonstration and implementation of this flexible manufacturing concept. The proposal is prepared along guidelines set up by reference (d). The project is based on prior work done at the David W. Taylor Naval Ship Research and Development Center on programming languages for NC. Close liaison will be maintained with other interested DOD activities, the appropriate American National Standards Institute committees, and with the Federal Information Processing Standards Task Group 19. Expected benefits of this project include:

Decreased Part Programming Time

Rapid Shifting of NC Workload

Simplified Part Programmer Training

Efficient Scheduling of Workload

Quick Response to Repair Part Needs

5. NAVAIR currently employs approximately 50 NC part programmers at a labor cost of around $1 million annually. This project could conservatively expect to save 24% of this figure annually.

MANUFACTURING TECHNOLOGY PROPOSAL

1. TITLE — Exchangable Part Data Packages for Numerical Control Manufacturing

2. TECHNOLOGY AREA — Computer-Aided Design/Computer-Aided Manufacture

3. PROBLEM

A. Inconsistancies in current Numerical Control (NC) language used for the control of different NC machines make it necessary to choose which machine will be used before a program can be written. Thus part programs cannot be re used without modification for any machine other than the one orginally chosen. Software techniques can be developed to enable a part to be manufactured on different, although functionally equivalent, NC machines without any changes required to the input data package.

B. This improved software will support over 120 NC machines already installed in the Naval Air Systems Command. Each one of these machines is presently operating as an independent, productive link in NAVAIR's system. This manufatturing technology project will integrate these autonomous links into a flexible and versatile manufacturing system where a part data package can be used on any available NC machine. The resulting system will be capable of quickly responding to NAVAIR needs while making efficient use of available manpower and equipment.

C. There are significant benefits to be gained from the ability to program a part for NC manufacture without regard for the specific machine tool to be used.

Rapid Exchange of Workload

The choice of the exact machine tool to be used can be deferred until machine tool availability is known. Then the part program can be easily processed by computer for the selected machine tool. This feature will compensate for unexpected bottlenecks, machine downtime, and costly reprogramming of workload. Currently 15-18% of a part programmer's time is spent reprogramming workload for different machines. Shifting part data packages between different NARF's will be made much easier. Such versatility and flexibility will be a great assistance to production planners.

Decreased Part Programming Time

The part programmer's task is simplified because he need not remember the idiosyncracies of each machine tool's APT language set. Consequently, he will make fewer errors in coding, leading to fewer computer runs. It is also expected that he would spend less time referring to part programming manuals. An 8-10% increase in efficiency is expected.

Simplified Part Programmer Training

Since the APT language would be the same for all functionally equivalent machines, the techniques of NC programming can be taught more fully in the classroom and not by trial and error out on the job.

4. RELATED DEVELOPMENTS

The American National Standards Institute will shortly be adopting a standard on the APT language that will directly impact this project. Close liasion will be maintained with ANSI and with the Federal Information Processing Standards Task Group 19 on APT.

5. SOLUTION

A. not applicable

B. Prior work done at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) on programming languages for NC has shown how a common language set can be developed around the existing APT system to allow easy exchange of part data packages. Special attention has to be given to the machine tool dependent language capabilities and to development of software routines to process this language in the same manner for all functionally equivalent machine tools. Simulation will be done in software wherever necessary to compensate for differences in the hardware of a selected machine tool. The project will identify problem areas other than NC language commonality that prohibit easy shifting of workload among different NC machines and will propose NC language features to help solve these problems. A network of industrial shops will be created to test the common NC language set under actual shop conditions. Actual parts will be processed through the system. The methodology will be documented with an APT part programmer's manual and a post-processor implementation guide.

6. IMPLEMENTATION

Fiscal Year 1977 - $91K

- Firm up initial vocabulary ....
- Methodology analysis and review...........
  using NAVAIR part programmers
- Develop computer program specifications....
- Contract for demonstration of approach.....
  Contractor is required because NAVAIR
  lacks capability to modify their own APT
  computer system.
- Revise and test vocabulary.................

Fiscal Year 1978 - $129K

- Firm up contract specifications...........
- Develop a user's guide....................
- Contract for postprocessor modifications............................
- Document project results..................
- End of project demonstration..............

7. COST SAVINGS

More Efficient Part Programming

The part programmer's task is simplifi[illegible] need to remember the idiocyncracies of eac[illegible] language. He will [illegible] fewer errors in co[illegible] computer runs [illegible] each part. He will spen[illegible] to [illegible] ...als. Estimated la[illegible]

NOTE: This information was deleted in the original copy obtained from Mr. Smith.

of annual workload.

NAVAIR has 50 part programmers

Average labor cost is $21K

∴ Annual savings are $84-105K

Less Reprogramming of Workload

Since a part program can be processed quickly and easily for any available machine tool, costly reprogramming of parts is eliminated. Presently 15-18% of a part programmer's time is spent in reprogramming parts because the machine for which the program was originally written is at another facility or is not available to do the job.

Annual savings are $157-189K

Total Annual Cost Savings $241-292K

Based upon a $220K MT development cost and an 8 year useful life of the software developed, the MT payback ratio is:

$$\frac{\text{Cost Savings}}{\text{MT Investment}} = \frac{8 \times 241}{220} = 8.67$$

8. TECHNOLOGY TRANSFER

The proposed project includes an "End of project demonstration" at which NAVAIR and DTNSRDC will publicize and explain the details of system operation and effectiveness. Additionally, the liasion with various standards committees mentioned plus presentation at related technical conferences will assist in translating the results of this project to other interested government and industtrial facilities.

APPENDIX D

NCS Software Committee

Request for Information

NUMERICAL CONTROL SOCIETY

524 ST. CLAIR AVENUE • P.O. BOX 138 • SPRING LAKE, NEW JERSEY 07762

August 22, 1975

SUBJECT: NCS Software Committee Request for Information

TO: Numerical Control User Companies

The NCS is a professional technical society founded to provide opportunities of contributing to, and learning about, the applications and technologies of CAM/Numerical Control in industry. It is dedicated to the advancement and distribution of knowledge in the practical use of this technology. For these reasons, the NCS Software Committee urges you to respond to the enclosed tape verification questionnaire and to the post processor survey request. The replies will be processed, then the summarized results will be sent to appropriate governmental agencies. They will also be made available to those who participated in the survey at 50% of the general distribution price.

These surveys do not solicit proprietary information. Any answers which even approach this category should not be given. Please process and return these surveys on or before September 30, 1975 to:

Mr. Edwin C. Hurd
GM/Detroit Diesel Allison Div (N2)
P.O. Box 894
Indianapolis, Indiana 46206
(Phone: 317/243-4231)

Each of the surveys is self-explanatory. We urge your cooperation and prompt attention to this matter. Thank you.

Sincerely,

Edwin C. Hurd

Edwin C. Hurd
Chairman of Software Committee
NUMERICAL CONTROL SOCIETY

ECH:djk
enclosures

POSTPROCESSOR SURVEY

This dynamic survey idea enables one to efficiently disseminate numerical control (N/C) information throughout industry, and helps reduce redundant effort in the software field. This is accomplished by processing the most pertinent postprocessor information from questionnaire forms, into IBM cards, then periodically listing the cards. These lists are then reproduced and distributed to the various participating companies.

This information indicates who has what postprocessors available for the asking, which in turn saves user companies time and money in obtaining needed postprocessors. Active participation in this cooperative effort will help us all do a better job for ourselves and for Uncle Sam.

This concept applies to postprocessors for any N/C computer-aided system, but for illustration purposes, we will consider the Automatically Programmed Tools (APT) system. This is an exotic computer system for preparing the input media (usually punched tapes) for a given machine tool control unit. The functions of this system are subdivided into two categories: the APT processor and the APT postprocessor. The responsibilities of these two sections are separate and distinct. Functions of both the processor and postprocessor will be discussed. So that the reader can better understand the role the postprocessor plays in the overall system flow, a diagram of the system flow is shown in figure 1.

A P T   S Y S T E M   F L O W

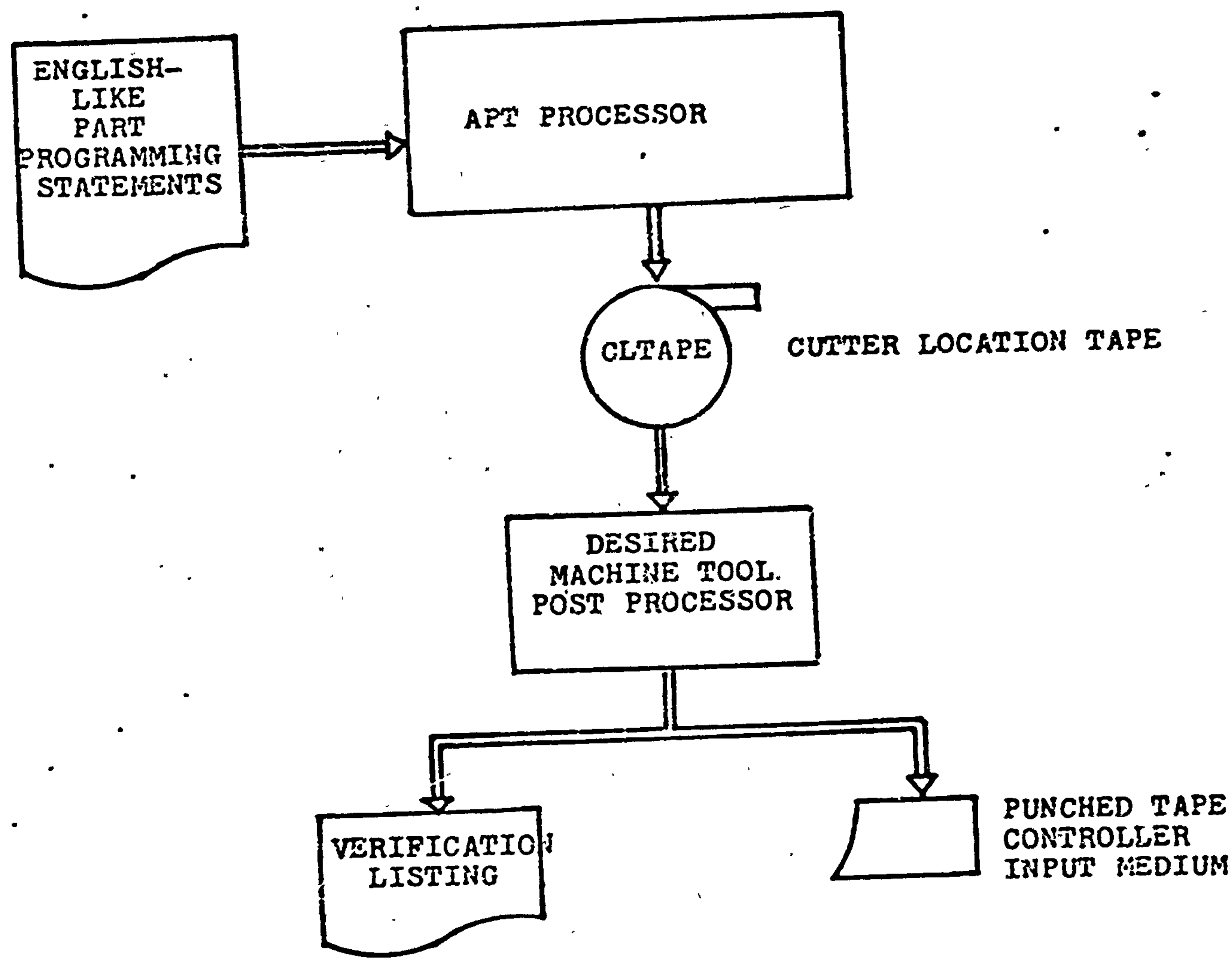

Figure 1

The APT processor translates the English-like part programming statements into a more convenient form for further processing, checks legality of spelling and format within these statements, then calculates cutter locations and stores them on tape for subsequent use by the desired post processor. An APT postprocessor converts the control data generated by the APT processor to a form and format that is acceptable to a specific type of N/C equipment. Thus, the APT postprocessor reads CLTAPE records, determines acceptability of records, processes those which are acceptable in a manner consistent with their APT definition, then prepares the controller punched tape with a verification listing.

Postprocessors must be oriented to the particular machine tool and control system they are intended to serve, thus a given system will usually require several postprocessors. Processors can be obtained from the computer manufacturers, but then each company is confronted with the problem of obtaining and implementing suitable postprocessors for their contemplated N/C hardware. The most logical ways of obtaining a required postprocessor are:

1. request it from a company which already has it. When this is possible, there seldom is a purchase price involved.

2. make it a condition of purchase in your purchase order, that the machine tool builder (as prime contractor for your order) will provide it. This usually involves a nominal charge which represents a subdivided developmental cost among the various users. This expense, when compared to the overall development cost, or when compared to the hardware investment is relatively minimal.

When considering the purchase of a N/C tool-control combination, one of the factors of consideration should be the availability and/or cost of a suitable postprocessor. It is conceivable that when a given tool is desired, and the competition is keen as to which one of two or three control systems to marry with the tool, the postprocessor factor could appreciably influence the decision. For any contemplated N/C equipment purchase, the prospective buyer should "beat the bushes" to determine the availability of a suitable postprocessor.

It is highly desirable that companies with N/C activities, know what postprocessors are available for the asking, on a dynamic basis; and that they know enough about them, so they can intelligently determine their degree of applicability to their problems. It is also highly desirable to minimize duplication of effort in these software activities. For these reasons, this idea is being presented.

Admittedly, there have been several postprocessor surveys in the past, but they have been rather static in nature. The published results didn't reveal some of the pertinent facts needed by the user community, and what was published, soon became outdated. Some of these surveys solicited information concerning all postprocessors in existence, rather than those available for sharing with others. Hopefully, this activity will offset most or all of these disadvantages, but its success depends on the active participation and cooperation of as many N/C users as possible.

The initial step of this activity is to send questionnaire forms to the participating companies. This form is illustrated in figure 2.

POSTPROCESSOR QUESTIONNAIRE

1. How do you specify the postprocessor in the part program MACHIN statement?

   ____

2. Controller; make, type and model ______________________________

   ____

3. Point-to-point or contouring equipment? ______________________________

4. Is the tape format word address, tab sequential, or fixed sequential?

   ____

5. Machine tool: Make, type and/or function, and model ______________________________

   ____

6. Number of axes of motion ______________________________

7. Programming language used ______________________________

8. Computer on which implemented ______________________________

9. N/C system in which implemented ______________________________

10. Computer program checkout status ______________________________

11. Existing documentation: _____ Computer programmer manual
    _____ Part programmer manual

12. Comments ______________________________

    ____

- -

____
Name

____

____

____
Address

____
Phone Date

Please return this questionnaire to:

Edwin C. Hurd
GM/Detroit Diesel Allison Division (N
P.O. Box 894
Indianapolis, Indiana 46206

Figure 2

Participants should reproduce the questionnaire form, then return to me one sheet for each type of N/C tool-control combination serviced by their available postprocessors. Figures 3a, 3b and 3c illustrate completed forms for the MILWKE and SSAMMI postprocessors. Because SSAMMI services two different machines, there are two information sheets, representing two punched cards, therefore, two printed lines of information for SSAMMI. Notice also, that most of the answers to the first nine questions are included in the punched cards in an abbreviated manner. Figure 4 illustrates the punched card format, and Figure 5, the printed output.

POSTPROCESSOR QUESTIONNAIRE

1. How do you specify the postprocessor in the part program MACHIN statement?

   MILWKE

2. Controller: make, type and model

   Square D RAPAC static Logic control

3. Point-to-point or contouring equipment? point-to-point

4. Is the tape format word address, tab sequential, or fixed sequential?

   tab sequential

5. Machine tool: Make, type and/or function, and model

   Kearney & Trecker Series EA machine

6. Number of axes of motion 3

7. Programming language used FAP

8. Computer on which implemented IBM 7094 II

9. N/C system in which implemented APT III/VER9

10. Computer program checkout status checked out

11. Existing documentation: ____ Computer programmer manual
    __X__ Part programmer manual

12. Comments

Mr. Edwin C. Hurd
Name

GM/DDAD (N2)

P.O. Box 894

Indianapolis Indiana 46206
Address

(317)243-4231 2-12-69
Phone Date

Please return this questionnaire to:

Edwin C. Hurd
GM/Detroit Diesel Allison Division (N2)
P.O. Box 894
Indianapolis, Indiana 46206

Figure 3a

POSTPROCESSOR QUESTIONNAIRE

1. How do you specify the postprocessor in the part program MACHIN statement?

   SSAMMI, 211

2. Controller: make, type and model

   GE HPC controller

3. Point-to-point or contouring equipment? point-to-point

4. Is the tape format word address, tab sequential, or fixed sequential?

   tab sequential

5. Machine tool: Make, type and/or function, and model

   Kearney & Trecker model II; 360,000 position rotary table

6. Number of axes of motion 3

7. Programming language used Fortran II

8. Computer on which implemented IBM 7094 II

9. N/C system in which implemented APT III/VER9

10. Computer program checkout status checked out

11. Existing documentation: X Computer programmer manual
    X Part programmer manual

12. Comments The computer programmer documentation is comprised of GEMM documentation plus supplemental information.

Mr. Edwin C. Hurd
Name

GM/DDAD (N2)

P.O.Box 894

Indianapolis, Indiana 46204
Address

(317)243-4231 2-12-69
Phone Date

Please return this questionnaire to:

Edwin C. Hurd
GM/Detroit Diesel Allison Division
P.O. Box 894
Indianapolis, Indiana 46206

Figure 3b

POSTPROCESSOR QUESTIONNAIRE

1. How do you specify the postprocessor in the part program MACHIN statement?

   SSAMNI, 212

2. Controller: make, type and model

   GE NPC-NCC controller

3. Point-to-point or contouring equipment? both

4. Is the tape format word address, tab sequential, or fixed sequential?

   tab sequential

5. Machine tool: Make, type and/or function, and model

   Kearney & Trecker model II; 360,000 position rotary table

6. Number of axes of motion 3

7. Programming language used Fortran II

8. Computer on which implemented IBM 7094 II

9. N/C system in which implemented APT III/VER9

10. Computer program checkout status checked out

11. Existing documentation: X Computer programmer manual
    X Part programmer manual

12. Comments The computer programmer documentation is comprised of GEMM documentation plus supplemental information

---

Mr. Edwin C. Hurd
Name

GM/DDAD (N2)

P.O. Box 894

Indianapolis, Indiana 46206
Address

(317)243-4231 2-12-69
Phone Date

Please return this questionnaire to:

Edwin C. Hurd
GM/Detroit Diesel Allison Division
P.O. Box 894
Indianapolis, Indiana 46206

Figure 3c

POSTPROCESSOR CARD FORMAT

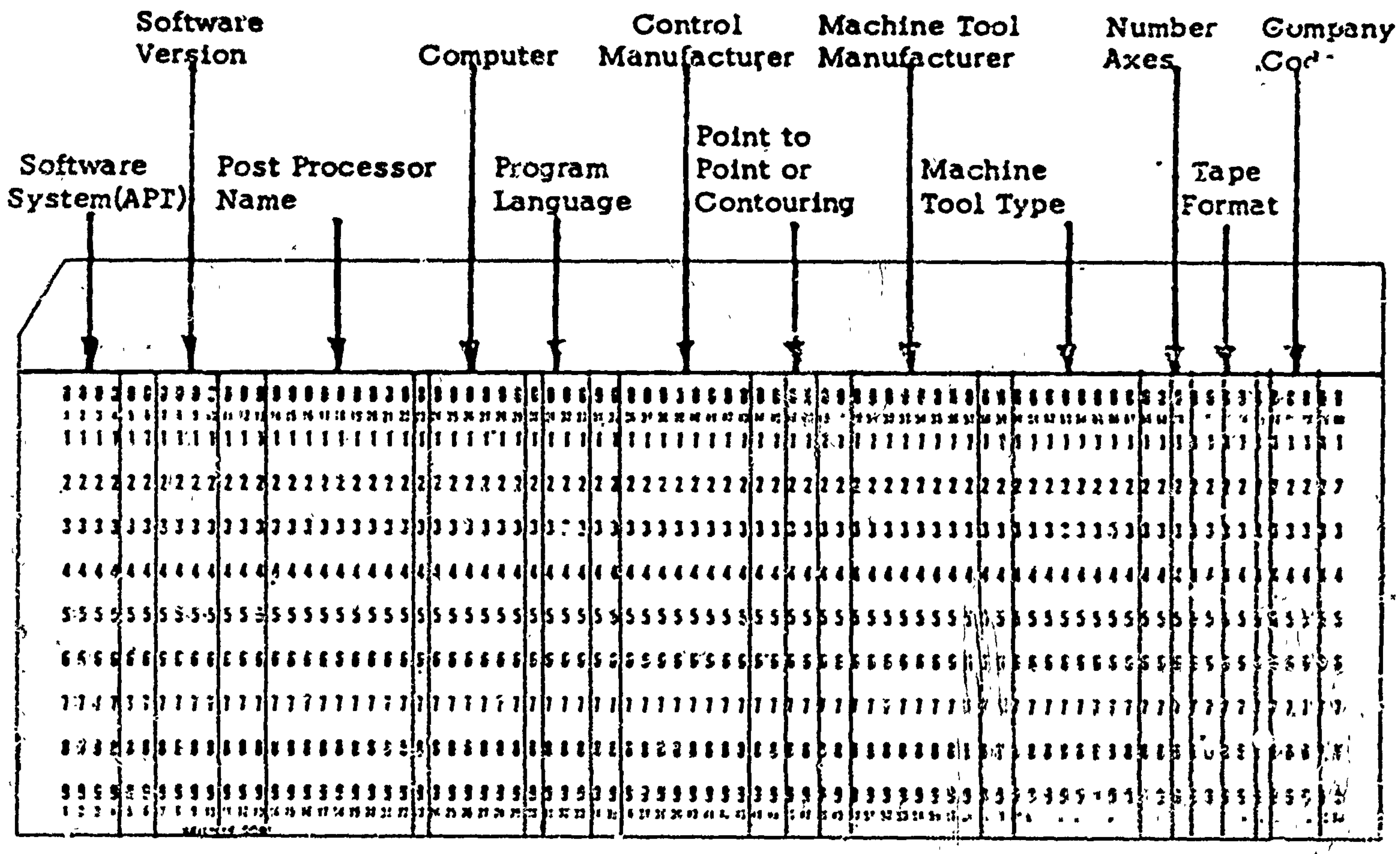

Figure 4

SAMPLE PRINTED OUTPUT OF POSTPROCESSOR CONTENTS
MARCH 10, 1969

SYS	VER	NAME	CMPTR	LANG.	CNTRL	PT-PT CONTR	TOOL MFG	TOOL TYPE	AXES	TAPE FORMAT	CO
APT	VER9	MILWKE	7094	FAP	RAPAC	P	K & T	MILLING	3	TS	GMA
APT	VER9	SSAMMI,211	7094	FT2	GEN ELEC	P	K & T	MILLING	3	TS	GMA
APT	VER9	SSAMMI,212	7094	FT2	GEN ELEC	PC	K & T	MILLING	3	TS	GMA

POSTPROCESSOR CONTACTS WITHIN PARTICIPANT COMPANIES

GM/ALLISON DIVISION (GMA) EDWIN C. HURD 317/243-4231

Figure 5

As additional postprocessors become available, they should be reported by submitting additional sheets. As the checkout or documentation status changes for a given program, a superseding sheet should be submitted. When a sheet supersedes one previously submitted, this should be stated in the comments section. Figure 6 summarizes the overall concept.

1. Issue questionnaire forms to participants.
2. Completed questionnaire forms returned to survey sponsor.
3. Survey sponsor processes information as follows:
   a. maintains file of completed questionnaire forms
   b. extracts most pertinent information, then formats this into IBM machine readable form
   c. maintains deck of postprocessor survey cards
   d. periodically lists the contents of the postprocessor survey cards
   e. reproduces the postprocessor survey listing
   f. periodically distributes copies of the latest postprocessor survey listing to each of the participants.
4. As participants report additions, deletions, or replacements, steps 2 and 3 are repeated, thus the survey results are dynamically kept up-to-date.

Figure 6

As changes become significant, superseding reports will be issued. These reports indicate what companies have what postprocessors available for distribution, and who within these companies should be contacted for further information or requests. The survey sponsor will not have the postprocessors, nor will he know much more than has been reported, so your requests for information and programs should be directed to the specified company contacts.

The success and value of this endeavor will be directly proportional to the degree of active participation we experience from the user companies. We all realize that the output of this or any other endeavor, cannot be any better than the input information received.

A blank questionnaire form is enclosed separately for reproduction and subsequent use in this survey. Your cooperation will be greatly appreciated.

POSTPROCESSOR QUESTIONNAIRE

1. How do you specify the postprocessor in the part program MACHIN statement?

   ____

2. Controller: make, type and model ____________________

   ____

3. Point-to-point or contouring equipment? ____________________

4. Is the tape format word address, tab sequential, or fixed sequential?

   ____

5. Machine tool: Make, type and/or function, and model ____________________

   ____

6. Number of axes of motion ____________________

7. Programming language used ____________________

8. Computer on which implemented ____________________

9. N/C system in which implemented ____________________

10. Computer program checkout status ____________________

11. Existing documentation: _____ Computer programmer manual
    _____ Part programmer manual

12. Comments ____________________

    ____

- -

____
Name

____

____

____
Address

____
Phone Date

Please return this questionnaire to:

Edwin C. Hurd
GM/Detroit Diesel Allison Division
P.O. Box 894
Indianapolis, Indiana 46206

TAPE VERIFICATION QUESTIONNAIRE

Corporation/Division name of your installation..

____

Name and address of individual answering questionnaire.

____

____

____

____

____

This questionnaire is topically subdivided into six sections as follows:

A. general NC input questions
B. manual vs. computer-aided punched tape preparation
C. check of part program (input data) for NC computer-aided systems
D. checking the physical condition of the punched tape
E. graphic checking of coordinate data
F. check of machining functions

The questions will be numbered by a letter (denoting the section) and two digit system so that the participants can more quickly and easily extract the information of interest from the summarized results.

There should be one and only one answer to each multiple choice question. You should indicate your answer by <u>circling</u> the appropriate lower case letter.

A. General NC Input Questions

Concerning the different kinds of NC controller input being used in your installation, please indicate the percentage use of the following types:

A01) Punched tape

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

A02) Magnetic tape

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

A03) Punched card

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

A04) Direct computer control

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

A05) Other (please specify type) ________________________

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

A06) If you use other than punched tape input for your NC control units, please specify the mode of input and briefly describe your verification procedures prior to production cutting.

____

____

____

____

A07) How many part programmers do you have at your installation?

____

A08) How many NC machine tools do you have at your installation?

____

A09) How many computer programmers do you have in your NC systems analysis and development group?____________________

A10) How many NC machine tools are run by direct computer control at your installation?____________________

A11) How many computer-aided systems are currently being used at your installation?____________________

With one exception, the remaining questions deal with punched tape verification techniques.

B. Manual vs. Computer-aided Punched Tape Preparation

B01) What percentage of your NC tapes are prepared manually?

a. 0 - 20%
b. 21 - 40%
c. 41 - 60%
d. 61 - 80%
e. 81 -100%

B02) Of your NC tapes prepared via computer-aided methods, which system is used predominantly?

a. APT	f. ACTION	k. GSHAFT	p. NEL2CL
b. ADAPT	g. COMPACT	l. LTTP	q. ECMA
c. AUTOSPOT	h. SHOP	m. SNAP	r. CONAPT
d. SPLIT	i. NUFORM	n. REMAPT	s. AUTOPROGRAMMER
e. CAMP	j. RCAPS	o. EXAPT	t. PARTSGENERATOR

u. Other (please specify processor name)________________

Concerning the different computer-aided systems you may employ, indicate the percentage use of the following systems (with respect to your overall computer-aided tape preparation).

B03) APT

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B04) ADAPT

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B05) AUTOSPOT

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B06) SPLIT

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B07) CAMP

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B08) ACTION

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B09) COMPACT

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B10) SHOP

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B11) NUFORM

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B12) RCAPS

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B13) GSHAFT

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B14) LTTP

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B15) SNAP

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B16) REMAPT

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B17) EXAPT

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B18) NEL2CL

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B19) ECMA

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B20) CONAPT

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B21) AUTOPROGRAMMER

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B22) PARTSGENERATOR

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

B23) Other (please specify processor name)

____

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

C. Check of Part Program (Input Data) for NC Computer-aided Systems

Where several different kinds of input data for your NC computer system are used, please indicate the percentage use of the following modes:

C01) Punched cards

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

C02) On-line console

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
c. 100%

C03) Image scanner

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

C04) Photogrammetry - type procedure

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

C05) Other (Please specify input mode)____________________

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

C06) Are your keypunched cards verified?

a. yes, almost always
b. yes, occasionally
c. no

C07) Prior to submitting input cards to a computer, do you manually inspect a card listing for obvious errors?

a. yes, almost always
b. yes, occasionally
c. no

C08) Does your NC computer system perform legality checks?

a. yes
b. no

D. Checking the Physical Condition of the Punched Tape

Concerning the spacing and alignment of punched holes in tape:

D01) Do you spot check several sections of the tape visually?

a. yes, almost always
b. yes, occasionally
c. no

D02) Do you spot check the tape visually against a templet?

a. yes, almost always
b. yes, occasionally
c. no

D03) Do you use a sophisticated gage to check an entire tape automatically?

a. yes, almost always; briefly explain logic
b. yes, occasionally; briefly explain logic
c. no

____

____

D04) Do you perform parity checks on your punched tape?

a. no
b. yes, with a Friden Flexowriter
c. yes, by running the tape through the machine control backwards
d. yes, by a different method; briefly specify logic

____

____

D05) Do you use a special purpose program to perform hole checking functions?

a. yes, almost always; briefly specify logic
b. yes, occasionally; briefly specify logic
c. no

____

____

E. Graphic Checking of Coordinate Data

E01) For manually prepared tapes, how do you currently check the coordinate information?

a. list the tape on a flexowriter then analyze the listing
b. manually plot the positions or the tool center-line path
c. rely almost entirely on machine tool check-out with very few preceeding configuration checks
d. other; briefly explain logic

____

____

e. does not apply; we don't manually prepare NC tapes

What percentage of your manually prepared tapes receive configuration checks by:

E02) Analysis of a flexowriter listing

a. 0 - 20%
b. 21 - 40%
c. 41 - 60%
d. 61 - 80%
e. 81 -100%

E03) Manual plots

a. 0 - 20%
b. 21 - 40%
c. 41 - 60%
d. 61 - 80%
e. 81 -100%

E04) Machine tool checkout

a. 0 - 20%
b. 21 - 40%
c. 41 - 60%
d. 61 - 80%
e. 81 -100%

E05) Other inhouse methods as specified in E01

a. 0 - 20%
b. 21 - 40%
c. 41 - 60%
d. 61 - 80%
e. 81 -100%

E06) Do you plan on employing more sophisiticated configuration checks on your manually prepared tapes within the next two years?

a. yes, briefly explain method

____

____

b. no

E07) What type of automatic equipment do you presently use to perform configuration checks on tapes generated by a computer?

a. graphic display device in computer system such as a plotting unit
b. On-line graphic display scope
c. NC drafting machine
d. other; briefly explain logic

____

____

e. does not apply; we don't use a computer to prepare NC tapes

What percentage of your computer prepared tapes receive configuration checks by:

E08) A plotting unit

a. 0 - 20%
b. 21 - 40%
c. 41 - 60%
d. 61 - 80%
e. 81 -100%

E09) On-line graphic display scope

a. 0 - 20%
b. 21 - 40%
c. 41 - 60%
d. 61 - 80%
e. 81 -100%

E10) NC drafting machine

a. 0 - 20%
b. 21 - 40%
c. 41 - 60%
d. 61 - 80%
e. 81 -100%

E11) Other inhouse checks as specified in E07

a. 0 - 20%
b. 21 - 40%
c. 41 - 60%
d. 61 - 80%
e. 81 -100%

E12) If you are presently using a plotter for configuration checks, please specify what kind.

____

E13) Do you plan on employing more sophisticated configuration checks on your computer prepared tapes within the next two years?

a. yes, briefly describe philosophy

____

____

b. no

The following questions should be answered, only by those who use an <u>NC drafting machine</u> to help verify the configuration accuracy of punched tapes.

E14) Concerning multi-axis configurations, do you perform checks on rotary table swivel or tilt motions?

a. yes; briefly explain logic

____

____

b. no

E15) Please specify your control and drafting machine manufacturers
control mfg. ___________________________________

drafting machine mfg. ___________________________________

E16) Do you "multi-postprocess" through your computer-aided system to obtain two independent tapes (one for the drafting machine and the other for the cutting tool)?

a. yes, almost always
b. yes, occasionally
c. no; briefly explain how the drafting machine input tape is prepared

____

____

E17) Do your verification drawings contain symbolic notation to improve the readability?

a. yes
b. no

E18) Do your verification drawings contain arrowheads to improve the readability?

a. yes
b. no

E19) Does your drafting machine postprocessor have a "built-in" capability for alleviating the clutter problem (too many lines or curves per unit area which complicates the interpretation process)?

a. yes; briefly describe logic

____

____

b. no

E20) In addition to obtaining orthogonal projections, do you obtain perspective or other views?

a. yes, automatically from our NC computer system
b. yes, upon data request from our NC computer system
c. yes, occasionally from a separate computer program
d. no, we use orthogonal views almost exclusively

E21) If your answer to question E20 was a, b, or c, what kind of views do you receive?

____

E22) Does your drafting machine software permit variance of the kinds of lines that are drawn, i.e., solid lines, normal dash lines, center-lines, etc?

a. yes
b. no

E23) Our orthogonal drawings usually show:

a. all motions of the machine tool
b. only the machining motions of the tool within a specified 3D region (software logic is implied)
c. selected regions in a DRAFT/$^{on}_{off}$ fashion
d. none of the above; we usually use non-orthogonal views

E24) Do you have "programmable" pen control to permit different line colors and/or widths?

a. yes
b. no

E25) Can your drafting machine software create a part drawing from the cutter path?

a. yes, automatically
b. yes, upon data request
c. no

E26) Assuming that your NC drafting machine is used for automatic drafting functions as well as NC tape verification, approximately what percentage of its use is for NC tape verification?

a. 0 - 20%
b. 21 - 40%
c. 41 - 60%
d. 61 - 80%
e. 81 -100%

E27) Do your part programmers watch their verification drawings being made?

a. yes, almost always as standard procedure
b. yes, occasionally when the need arises
c. no

F. Check of Machining Functions

Concerning the different kinds of simulated production runs employed in your installation, please indicate the percentage use of the following modes:

F01) Machine tool simulator (such as Polyckek for Milwaukee-matics)

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

F02) Measuring machine probe (such as Ferranti)

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

F03) Dry run of tape with dummy stylus in spindle, tracking a model work piece in the fixture, of the NC machine

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

F04) Cutting "air" with the actual cutter in the NC machine

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

F05) Cutting rigid, foamed plastic (such as styrofoam) with the actual cutter in the NC machine

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

F06) Cutting a fine-grain wood with the actual cutter in the NC machine

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

F07) What percentage of the time do you <u>initially</u> attempt to fabricate the actual work peice on the NC machine, then inspect it?

a. 0%
b. 1 - 35%
c. 36 - 65%
d. 66 - 99%
e. 100%

F08) Do you use an adaptive control device for feedrate and spindle speed overrides?

a. yes
b. no

F09) Do you use simulated adaptive control software for feedrate and spindle speed overrides? This question implies software functions beyond "normal" postprocessor tool dynamics checks.

a. yes
b. no

F10) How many NC inspection machines do you have at your installation?

____