12-31-1991

Implementing computer numerical control machine tools in a job shop environment

Rajesh Shah
New Jersey Institute of Technology

ABSTRACT

Title of thesis: Implementing Computer Numerical Control Machine Tools in a Job Shop Environment.

Rajesh D. Shah, Master of Science in Manufacturing Engineering, 1991.

Thesis directed by: Dr. Keith O'Brien
Professor of Mechanical
Engineering Department

Computer Numerical Control is one important phase to overall application of computer on the shopfloor. Today a large variety of CNC machine tools are offered by manufacturer following different standards. This thesis is organized with the purpose of comparing various technical and economical considerations for CNC machine tool purchase and application. The main purpose of study is to mention various features of CNC machine tools and its possible integration which can reduce product lead time and improve quality. General replacement minimum cost model is discussed with case study for economic justification of machine purchase. While discussing technical features emphasis is given for networking considerations right from the first CNC purchase. Various CNC programming techniques and tool management technique are discussed for effective tool control which affects greatly to CNC productivity. Role of management and required planning before CNC procurement is discussed. Successful application of these techniques results in achieving CNC from machine control to management control.

IMPLEMENTING COMPUTER NUMERICAL CONTROL MACHINE TOOLS IN A JOB SHOP ENVIRONMENT

Submitted by:
Rajesh Shah

Thesis submitted to the Faculty of the Graduate School of The New Jersey Institute of Technology in partial fulfillment of the requirements for the degree of Master of Manufacturing Engineering
1991

APPROVAL SHEET

Title of Thesis	: Implementing computer Numerical Control Machine Tools in a Job Shop Environment
Name of Candidate	: Rajesh D. Shah Master of Science Manufacturing Engineering, 1991

Thesis & Abstract Approved

DR. KEITH O'BRIEN — Date
Professor of Mechanical Engineering

Signature of other thesis committee members

DR. NOURI LEVY — Date
Associate Professor of Mechanical Engineering

PROF. STEVE KOTEFSKI — Date
Assistant Professor of Engineering Technology

VITA

NAME: Rajesh D. Shah

PERMANENT ADDRESS:

DEGREE AND DATE TO BE CONFERRED: MS MnE, December 1991.

DATE OF BIRTH:

PLACE OF BIRTH:

SECONDARY EDUCATION: Govt. Higher Secondary School, Gandhinagar, INDIA

COLLEGE INSTITUTIONS ATTENDED:

COLLEGE	DATES	DEGREE
New Jersey Institute of Technology, NJ	09/89 - 12/91	MS MnE
L. D. College of Engg. Ahmedabad, India	08/83 - 06/88	BS ME

POSITIONS HELD:

COMPANY NAME	POSITION	DATES
New Jersey Institute of Technology	Graduate Assistant	01/91 - 12/91
Allied Signal Aerospace Eatontown, NJ	Manufacturing Engineer	09/90 - 12/90
The Ahmedabad Electricity Company Ltd., India	Assistant Engineer	07/88 - 06/89

ACKNOWLEDGEMENT

I wish to express my sincere thanks to Dr. Keith O'brien, Professor of Mechanical Engineering, and my thesis advisor, for his valuable guidance. His insistence on utilization of the most recent state-of-art compelled me to exploit my full potential. His valuable guidance has very much helped me to organize my work and to represent in thesis work.

I wish to express my thanks to Dr. Nouri Levy, Associate Professor of Mechanical Engineering, Prof. Steve Kotefski, Assistant Professor of Engineering Technology, for their precious time to go through my work and giving valuable suggestions.

I wish to acknowledge all the help and facilities made available to me at New Jersey Institute of Technology, which has a major role in completion of this thesis.

Last but not least, let me express my warmest thanks to my beloved family members and friends in India and in the United States of America, for their overwhelming encouragement.

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CHAPTER 1

INTRODUCTION

After the development of the first numerical control machine tool at the Massachusetts Institute of Technology in 1952, numerical control has progressed rapidly, in line with advancements in computer and electronic technology. Today, sophisticated computer numerical control (CNC) machine tools are available, with many advanced computerized systems being used in machine control units. The advent of numerical engineering has not only made a remarkable change in the manufacturing sector, but also in production, planning and design.

1.1 History of Numerical Control

Major advances within the realm of control devices have extended the applications of automation technology in the latter half of this century. Also involved is the use of logic (control), data processing and communication within electronics technology. Soon after the second world war, digital numerical control (NC) technology was introduced and it is from its development that modern-day automation is proceeding. NC technology originated primarily for use with machine tools but robots, testing equipment, process controllers, transfer lines, etc. operate on a similar logic. With the rapid advancement in electronic industry, tremendous changes were made to control units, servomechanisms, machine tool feedback systems and programming techniques. Nowadays, highly sophisticated NC machine tools are available with capabilities for tape editing, tape storage and control of the machine tool functions by software.

The first generation of NC systems was available commercially in 1954[12]; the control unit was constructed of analogue hardwired circuitry and valve based systems. This type of control system was unreliable when fitted to conventional machine tools, and this lead to high rate of wear and inaccuracy. The majority of numerical control machine tool (NCMT) at this stage was of the point to point type.

In 1959 the second generation of NCMT was introduced, constructed of digital circuitry using individual transistors and other discrete components. The machines were designed to overcome backlash and wear and to achieve better accuracy for contouring and point to point machining.

The third generation of NCMT, with integrated circuit boards, was introduced in 1965. This advancement provided easier maintenance and better utilization. Machine tools were functionally better designed and cheaper machining centers were developed.

By early 1970s, the development of the minicomputer, the invention of the eight bit microprocessor and the continued reduction in hardware costs provided the means for a wider diffusion of NC systems in manufacturing. This gave flexibility in that changes could be implemented in software; hardwired NC tools now have been almost totally supplemented by programmable logic control (PLC) systems, computer numerical control (CNC), both in individual machine and group of machines, and direct numerical control (DNC). This fourth and fifth generation of minicomputers and microprocessors has brought greater memory and software flexibility to NC.

These developments in machine flexibility have an important impact on the sixth generation of NC, the integrated manufacturing system (IMS). This system is the combination of NC, CNC and DNC, with integration of transfer lines between machines and robot manipulation.

The evolving CAD/CAM technology will result ultimately in the integration of many diverse technical areas that have developed separately over the past thirty years. Initially, CAD systems were primarily automated drafting stations in which computer controlled plotters produced engineering drawings. The systems were later linked to graphic display terminals where a geometric model describing the part shape could be created, and the resulting database in the computer was used to produce drawings. Now, advanced systems based on interactive graphic terminals have analytical capabilities which permit the part to be evaluated with techniques such as the finite element method. Kinematic programs allow the motion of mechanisms to be studied.

Concurrently with the development of CAD technology, CAM advances were also being made, mostly in numerical control. Until recently, experienced programmers were required to produce and verify NC instructions. But now, instructions can be produced automatically for complex shapes, and tool paths can be verified quickly with computer simulation. In addition, these systems may also have limited process planning features for determining the sequence of fabrication steps and factory management capabilities for directing the flow of work and materials through the factory.

A major milestone was the combination of the CAD features - geometric modelling, drafting, finite element analysis, and kinematics - into a unified system with the CAM capability of automatic NC tape preparation. This advancement finally bridges the gap between the two technologies and made it possible for an engineer to go from an initial concept to the finished part with one system.

Not only have Computer Aided Design (CAD) / Computer Aided Manufacturing (CAM) capabilities increased dramatically over the years, but the cost of these systems has decreased, allowing what was exotic and prohibitively expensive a few years ago to become commonplace. The combination of economic and technical development has led to the gradual permeation of CAD/CAM into general industry.

1.2 Purpose of This Thesis

CNC machine tools are very important part of modern manufacturing industry. NC is the primary and most prevalent function found in the concept whereby the complete preplanned and programmed design and production functions will be processed, stored, and finally executed with the aid of a computer. CAD and CAM are becoming part of design and production. It is leading industry to the development of CIM (computer integrated manufacturing). CNC is one important phase to overall application of computers on the shopfloor. It is no more just a machine tool, but is an important management control tool. However CNC machine tool industry is offering such a large variety of machine tools following different standards. At the same time the variety in machine tool features, rapidly advancing programming techniques and very large range of price to buy these equipments is confusing to someone who is first time introducing CNC machine in this competitive and quality conscious industry. This thesis is organized with the purpose of discussing important technical and economical features of CNC machines. While discussing technical features care is taken to mention planning and precaution required for computer integrated manufacturing right from first machine purchase.

It also discuss various programming considerations and tooling techniques in order to reduce product lead time and to improve quality. The management responsibilities with changing environment is also discussed. This thesis is organized with purpose to supply keys of understanding so that implementation of CNC machines results in successful experience and keep the factory in line with rapidly advancing manufacturing technology.

1.3 Organization of This Thesis

In chapter 1, the historical development of NC, CNC, CAD and CAM is discussed. This chapter also emphasis the need for these technologies in today's manufacturing environment.

Chapter 2 is meant for novice, to explain important concepts of NC and CNC. It explains the basic components, various features and capabilities of NC over conventional machine. It briefly explains the possible application of CNC and benefits that can be gained using CNC machine.

Chapter 3 explains the economic considerations for CNC machine purchase. It describes one of the most widely used method to evaluate conventional machine and CNC machine purchase. This method can also be used to evaluate between two different types of CNC machine purchase. A case study is carried out to economically justifify machine purchase for various part configurations.

The very important issue for CNC purchase is to evaluate its technical features. Usually first CNC purchase is followed by purchase of more and more CNC machines. The next step companies takes is to integrate for DNC, CAD and CAM. For integration to take place, the participating computers, machines, controls, sensors, terminals and auxiliary devices must be able to communicate with each other. Chapter 4 explains various technical aspects for CNC networking, interfacing, interfacing protocols and evaluation of CNC post processors. A case study is carried out for networking consideration in a plant.

Chapter 5 discuss important features of NC programming and considerations before writing a program. The newer programming systems and controls make part program creation, editing and revising a much less complicated process. This chapter also describes the latest programming techniques that can be used.

Whether its a single NC machine tool, cell, or system, effective cutting tool control is a critical element. Chapter 6 discuss tool management for various cutting tools, latest techniques used for tool data collection, storage and retrieval, application of which results in productive CNC machine tool.

Chapter 7 discuss management concern while introducing CNC machine tools into shop. It covers selection of machine, parts, methods and support services, and key personnel training. It also gives brief idea about computer integrated manufacturing (CIM), for which CNC machine tool is one of the basic building block.

Chapter 8 contains conclusions.

CHAPTER 2

INTRODUCTION TO NUMERICAL CONTROL AND COMPUTER NUMERICAL CONTROL

2.1 Numerical Control (NC)

Numerical control is the technique of giving instructions to a machine in the form of a code which consists of numbers, letters of alphabet, punctuation marks and certain other symbols. The machine responds to this coded information in a precise and ordered manner to carry out various machining functions[1].

Instructions are supplied to the machine as blocks of information. A block of information is a group of commands sufficient to enable the machine to carry out one individual machining operation. Each block is given a sequence number for identification. The blocks are then executed in strict numerical order. A set of instructions forms an NC program. When the instructions are organized in a logical manner they direct the machine tool to carry out a specific task-usually the complete machining of a workpiece or "part". It is thus termed as part program. Such a part program may be utilized, at a later date, to produce identical results over and over again.

Automatic control of NC machine tools relies on the presence of a part program in a form that is external to the machine itself. The NC machine does not posses any memory of its own and as such is only capable of executing a single block of information fed to it, at a time. For this reason part programs are normally produced and stored on punched tapes.

While machining a part automatically, the machine control unit will read a block of information, then execute that block, and so on. With the punched tape installed it is also possible to "single step" a part program by instructing the machine tool to pause after the execution of each block. This is semiautomatic operation. It is also possible to enter data manually, by setting dials and switches, at the machine console. After each setting the machine will carry out the instruction and wait for the next setting. Thus it is possible to effect control by manual data input.

2.2 Basic Components of Numerical Control

NC system consists of following three components:

1. Program of instructions.
2. Machine control unit.
3. Processing equipment.

The general relationship among the three components is shown in figure 2.1.

The program of instruction is a detailed step by step command that directs the processing equipment. In its most common form, the commands refer to the positions of a machine tool spindle with respect to the worktable on which the part is fixtured. More advanced instruction includes selection of spindle speeds, cutting tools, and other functions. The program is coded on a suitable medium for submission to the machine control unit. The most common medium used over the last several decades has been 1 inch wide punched tape. However more recently magnetic tapes and floppy disks are used.

The machine control unit consists of the electronics and control hardware that read and interpret the program of instruction and convert it into mechanical actions of the machine tool or other processing equipment.

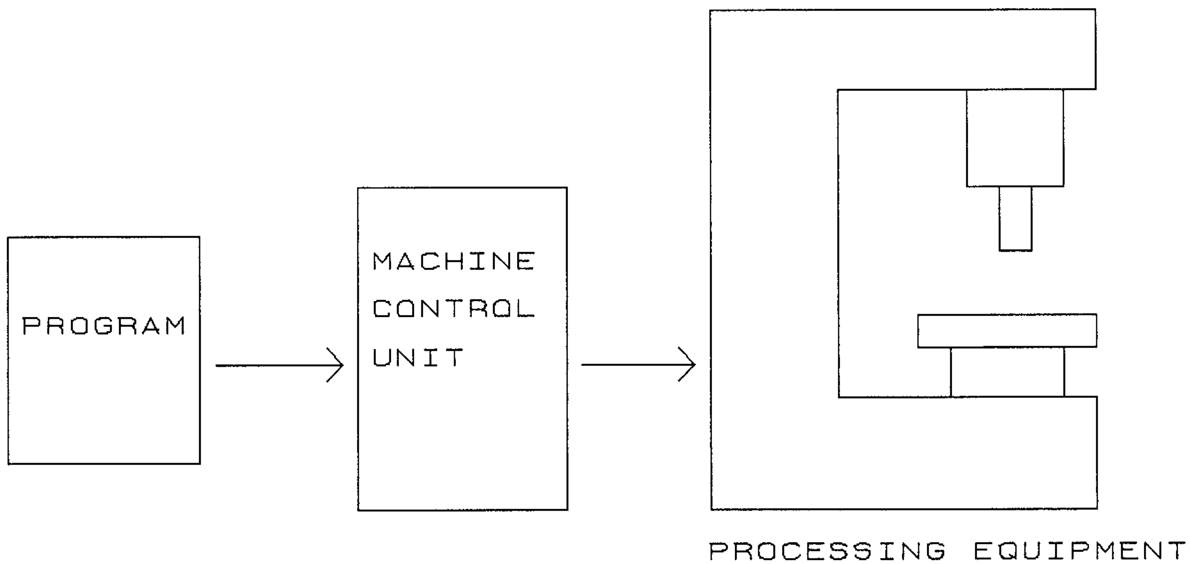


Fig. 2.1 BASIC COMPONENTS OF NC SYSTEM

The processing equipment is the third basic component of an NC system. It is the component that performs the useful work. In the most common example of numerical control, the processing equipment consists of the worktable and spindle as well as the motors and controls needed to drive them.

2.3 Tape Formats

The organization of words within blocks is called the tape format. Three types of tape formats are most popular.

1. Word address format
2. Tab sequential format
3. Fixed block format

The tape format refers to the method of writing the words in a block of instructions. Within each format there are variations because of differences in machining process, type of machine, features of the machine tool and so on.

2.3.1 Word Address Format

In this format a letter precedes each word and is used to identify the word type and to address the data to a particular location in the controller unit. The x-prefix identifies an x-coordinate, s-prefix identifies spindle speed, and so on. The standard sequence of words for a two axis NC system is n-word, g-word, x-word, y-word, f-word, s-word, t-word, m-word and EOB.

However the tape is designated by the prefix letter, the word can be presented in any sequence. Also if word remains unchanged from the previous block or is not needed, it can be deleted from the block.

2.3.2 Tab Sequential Format

This tap format derives its name from the fact that words are listed in a fixed sequence and separated by pressing the tab key when typing the manuscript on a flexowriter. Since the words are written in a set of order, no address letter is required. The order of words within the block follows the previously mentioned standard. If a word remains the same as in the previous block, it needed not be retyped. However the tab code is required to maintain the sequence of the words.

2.3.3 Fixed Block Format

This is the least flexible and probably the least desirable of the three formats. Not only the word in each block be in identical sequence, but the character within each word must be of the same length and format. If a word remains same from the block to block, it must be repeated in each block.

2.4 Numerical Control Words

Following is a list of different types of words used in the formation of block. Not every NC machine uses all the words. Also, the manner in which words are expressed will differ between machines. By convention, the words in a block are given in the order below:

(a) *Sequence Number (N-Word).* This word is used to prepare controller for instruction that are to follow. The preparatory word is needed so that the controller can correctly interpret the data that follows in the block. Some typical examples of g- words are given below.

Code	Preparatory Function
g00	Send with contouring systems to prepare for a point to point operation.

g01	Linear interpolation in contouring systems.
g02	Circular interpolation - clockwise.
g03	Circular interpolation - counterclockwise.
g04	Dwell.
g05	Hold until operator restarts.
g08	Acceleration code, causes machine to accelerate smoothly.
g09	Deceleration code, causes machine to decelerate smoothly.

(b) *Coordinates (X, Y and Z words)*. These gives the coordinate positions of the tool. In two axis system, only two of the words would be used. In a four or five axis machine, additional a-words and/or b-words would specify the angular positions.

(c) *Feedrate (F-WORD).* This specifies the feedrate in a machining operation.

(d) *Cutting Speed (S-word)*. This specifies the cutting speed of the process, the rate at which the spindle rotates.

(e) *Tool Selection Word(T-WORD).* The T-word specifies which tool is to be used in the operation. This word would only be needed for machines with a tool turret or automatic tool changer.

(f) *Miscellaneous Function (M-WORD).* The m-word is used to specify certain miscellaneous or auxiliary function which may be available on the machine tool. A partial list of miscellaneous function is given in table below.

Code	Miscellaneous Function
m00	Stop the machine; Operator must restart.
m03	Start spindle in clockwise direction.
m04	Start spindle in counterclockwise direction.
m05	Stop spindle.

m06	Execute tool change, either automatically or manually. Does not include selection of tools, which is done by t-word or by operator.
m07	Turn coolant on.
m09	Turn coolant off.
m13	Start spindle in clockwise direction and turn coolant on.
m14	Start spindle in counterclockwise direction and turn coolant on.
m30	End of tap command, Which tells tape reader to rewind the tape.

2.5 Computer Numerical Control (CNC)

Computer numerical control (CNC) retains the fundamental concepts of NC but utilizes a dedicated stored program in the computer within the machine control unit. CNC is largely the result of technological progress in microelectronics, rather than any radical departure in the concept of NC. CNC systems for machine tools make part programming easier and enable units to communicate with other computers[6]. Figure 2.2 shows general configuration of CNC system[1].

CNC attempts to accomplish as many MCU functions as possible within the computer software which is programmed into the computerized control unit. This greatly simplifies the CNC hardware, significantly lowers purchase cost, and improves reliability and maintainability.

CNC control units, like the computers on which they are based, operate according to a stored program held in computer memory. This means that part programs are now able to become totally resident within the memory of the control unit, prior to their execution. No longer do the machines have to operate on the "read block/execute block" principle. This eliminates the dependency on slow, and often unreliable, tapes and tape reading devices - probably the weakest link into the chain. Programs

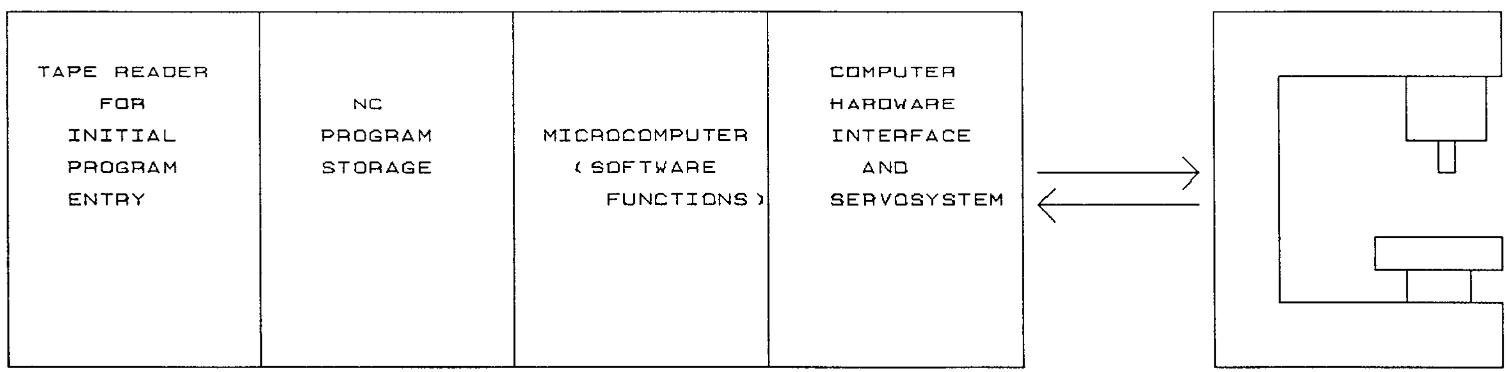


Fig. 2.2 GENERAL CONFIGURATION OF CNC SYSTEM

can, of course, still be loaded into the CNC machine via a punched tape, but only one pass is necessary to read the complete part program into the memory of the control unit. Figure 2.2 shows general configuration of CNC system.

2.5.1 CNC Machine Tools

Many CNC machine tools still retain many of the constructional and physical design aspects of their NC counterparts. However, many new control features are made available on CNC machines. Such new features include:

(a) *Stored Programs*. Part program may be stored in the memory of the machine. The CNC can then operate directly from this memory, over and over again. Use of the tape reader is virtually eliminated. For long production runs the part program may be retained in the memory, even when the power is removed, by the use of battery back up facilities that keep only the memory supplied with power. Often, more than one program may be resident in the control unit memory at one time with the ability to switch between them.

(b) *Editing Facilities.* Editing can be carried out on the part program held in memory. Thus errors, updates, and improvements can be attended to at the machine. Such edits are stored in computer memory and override the tape information as read in. A new and corrected, tape may then be punched directly from the CNC control unit. This ensures that the most up-to-date version of the part program is retained as current.

(c) *Stored Patterns.* Common routines such as holes on a pitch circle, pocketing sequences, drilling and tapping cycles can be built in and retrieved many times. There is facility for user defined sequences to store and retrieve in the same way. Only certain parameters have to be specified and the computer control will carry out the necessary calculations and subsequent actions.

(d) *Sub Programs*. For repetitive machining sequences, sub program may be defined once and then be repeatedly called and executed as required. This considerably shortens part programs by eliminating the need to repeat sections of identical program code.

(e) *Enchanted Cutter Compensation.* When a part program is written, it is normally done with a particular type and size of cutter in mind. The positioning of cutter relative to work piece will need to take into account of the dimension of the cutter. It may be the case that, when the part program comes to be run on the machine, the particular cutter specified is not available. CNC control unit allows "compensation" and "offsets" to be made for the difference in diameter between the actual cutter and the specified cutter. Thus the part program is now independent of the cutter specified when writing the program. This facility can also be brought into play in case of tool breakage during the machining cycle, when different cutters may have to be reloaded to continue the machining sequence.

(f) *Optimized Machining Condition.* The extremely fast response of computer technology, coupled with sophisticated calculation ability, enables machining conditions to be constantly monitored by the control unit.

(g) *Communication Facilities.* The utilization of computer technology within the CNC control unit offers the advantage of being able to communicate with other computer based systems. Part programs may thus be downloaded from other host computers. Such host computers may be simple database of different part programs or sophisticated computer aided design systems.

(h) *Program Proving Facilities.* Many modern control systems contain software that will process the resident part program information and indicate the component shape that will be produced before machining takes place. This is often displayed graphically on a visual display unit on the operating console.

(i) *Diagnostics.* Most modern CNC machines comes equipped with comprehensive diagnostic software for the self checking of its electronic operations. For example, there might be a diagnostic routine to check the operation of the memory chips. It would write a known test pattern into memory and read it out again, checking it for validity. Any discrepancy could indicate a memory fault.

(j) *Management Information.* Since the CNC system controls nearly all functions from the resident computer, much useful information on machine utilization can be assessed.

In addition many modern CNC machine tools are now capable of automatic tool changing without manual intervention. A number of standard cutting tools may be loaded into a rotating turret or carousel, and called up under the control of the part program.

2.5.2 Economic Benefits of CNC

(a) Conventional machining relies on a skilled operator to manipulate the machine tool handwheels to produce a required component. The operator has to examine the drawing many times during the operation, to determine the dimension that apply and must decide by how much each handwheel must be turned to produce the desired result. Since only one handwheel can be controlled at a time, with any degree of accuracy, controlling is limited unless special attachments are utilized. These attachments must be acquired, attached to the machine and duly set up. This can be a time consuming activity in itself.

Very often, metal removal requires a series of cuts before the final results is achieved. Measurement of the part must be carried in between these cuts. It is almost impossible to predict the final condition of the part during multiple cuts, even though the handwheels have calibrated scales.

(b) Because of limitations involved in the design of conventional machine tools, much tool changing, tool setting and workpiece resetting is often involved during the machining cycle. It is apparent that time required to machine a part, and hence the time during which the machine and the operator are engaged on the job is much greater than the actual cutting time. These disadvantages are compounded when the operator has to make a number of similar parts from the same drawing. If their nature does not permit loading and clamping into jigs or fixtures, then inevitable errors of varying size, position and form will result.

In addition many conventional machine tools have speeds and feeds governed by mechanical design features such as fixed speed gearboxes. Thus, the choice of a feed or speed is a compromise depending on the gear ratios built into the machine tool. Optimum cutting machining condition are rarely realized. These approaches are characterized by extremely long set-up times by specialist setters. This meant that, once setup, the machine has to run for long periods and produce many thousands of part to justify the long setup times. It was common to over-produce while the machine was tooled up. This meant increased work in progress and working capital tied up in stock. Very often production bottlenecks due to jobs queueing for machines disrupts production schedules.

By contrast, CNC machines offer complete control of all axes, under optimum cutting conditions. Extremely short setup times are possible since standard tooling is all that is required. The need for jigs and fixtures is almost eliminated. Indeed their presence can be an encumbrance to the flexible countering facilities of CNC machines.

(c) Part programming is often carried out by specialist part programmers, away from the machines. The facility to prepare new jobs away from the machine means that the machine tool spends a greater proportion of its working time actually cutting metal.

(d) Extremely good accuracy and repeatability of the component enables a greater uniformity of production. There are also attendant reductions in fitting costs, assembly costs, inspection costs and the elimination of scrap and rework items. Moreover once a job has been machined, the data of that job can be retained, saved and loaded back to produce identical parts at a letter date.

(e) The quality of finished job is no longer under the control of the operator but under the control of computer run part program. This ultimately translates into lower cost per part and much reduced lead times[3].

2.5.3 Profitable Application of CNC

For many of the above reasons, CNC finds greatest application in small batch quantities or complex one-offs. Traditionally, it is these jobs that prove the most difficult and costly to implement within a production environment. CNC is certainly not intendant to compete with mass production techniques. This should not be the only criteria on which the decision to adopt CNC should be based. There are numerous other applications to which CNC may be profitably applied. Examples include:

1 Where reliable, high-quality components are required.

2 Where operations or setups are numerous or costly.

3 When machine run time is disproportionately low, compared with set-up time.

4 When lead time do not permit conventional jig and fixture manufacture.

5 Where the part is so complex that quantity production involves the possibility of human error.

6 Where design changes, or individual variations are required on a family of parts.

7 When inspection costs form a large proportion of total costs.

8 When tooling costs are significantly high, or where tool storage is a problem.

2.5.4 CNC As a Management Control

It is often quoted that CNC is not machine control, but a management control. CNC is primarily an automatic machine or process control discipline. However its intelligent adoption also greatly increases the potential control that management has over the process. Management is concerned with the planning, organizing, and efficient usage of all factors and resources that are available. Most manufacturing organizations that fail to do so not because of an inability to manufacture, but because of ineffective management. Indeed, the responsibility for success or failure rests fairly and squarely with management.

(a) *CNC and Design:* In times of design change or modification, a simple edit at the machine may be all that is required. A current production tape can then be re-punched directly from CNC machine control unit. Re-tooling or re-jigging can be alleviated, possibly eliminated.

(b) *CNC and Process Planning:* The need for decision making on the shop floor, is largely eliminated as optimum speeds, feeds, travel times, tool selection, etc. are inherently built into the part program. Moreover, optimum machining conditions can be monitored and maintained by the CNC machine itself. Thus optimum machining conditions can be specified and imposed more accurately by the adoption of CNC technique.

(c) *CNC and Production Planning:* The greatest application of CNC is in the small to medium batch production runs. Advantages are reaped in the very short changeover time that can be accomplished between jobs. Thus lead time and production times are optimized, becomes reliably predictable, and downtime is reduced to a minimum.

(d) *CNC and Quality Control:* Because of uniformity of the products, the process of fitness and assembly can possibly be streamlined. Scrappage and re-work costs should be almost eliminated.

2.5.5 Economic Benefits to Management

The economic benefits to management may be summarized as follows:

1. Better machine utilization since the machine spends more of its time actually cutting metal.
2. Cycle times are considerably reduced.
3. The numbers of component produced is controlled by the machine and not by operator; therefore delivery forecasts and production planning can be more accurately determined.
4. Small batch quantities are as economical as large batches.
5. Savings on tooling, jigs and fixtures.
6. Accuracy is controlled by the machine; therefore better interchangeability, easier fitting and assembly, and reduced inspections are achieved.
7. Less scrappage and re-work.
8. Extended tool life since optimum cutting conditions are realized.
9. CNC machines may work unattended, in the dark and other unsocial times. They can be integrated with other facets of the production process.

10. CNC machines can provide useful management information automatically.

11. Since machining time is more predictable, accurate costing data for financial control and estimating is more reliable.

12. The investment of time and skill in part programming can be saved.

13. Adopting CNC puts the control of production back into the rightful hands of management.

2.6 CAD/CAM and CNC

NC development is just one phase in the overall application of computers in the manufacturing environment. Manual part programming is very time consuming. The tape generated has to be proved in to the machine and each machine has a different subset or slight variations in the definitions of the effects due to the codes. Programmer extracts the data from engineering drawing, and then at the terminal remote from the machine, specifies the motions required of the tool in a higher level language than the machine tool codes. These devices running the high level languages require the use of 'post processors' to convert high level code generated into machine tool code instructions. Each particular type of machine tool and controller will have its own particular post processor because of its particular geometry and the particular actions and sub-set of machine tool codes implemented on that machine.

Machine tool part programs can be generated directly from CAD description of the part. This is what is usually known as CAD/CAM, the link between computer aided design and computer aided manufacturing[4]. The most basic form of CAD is interactive computer aided two dimensional drafting. However three dimensional representations are increasingly being used as representations of the object and as the starting point for control program generation for NC. By capturing the engineering drawings there is already a great deal of data representing the form of product in a computer. It will be efficient to use this data for other tasks within the organization requiring product data rather than generating this data again. The ultimate application of CAM occurs when the various operations and routings needed to allow production of the product are automatically developed from the CAD data, a process commonly referred to as computer aided process planning(CAPP)[5]. Instructions can be generated by a program, called a post processor, to allow tapes to be generated for NC machines that produce the product automatically. In more and more instances, direct numerical control (DNC) allows a central computer to send the controlling instructions directly to the machine tools, bypassing the tape step, once the machine tool operator dials a predetermined code to the computer room to signify that setup for the part has been accomplished. Of course, an integrated CAD/CAM system can be very expensive and may not be justifiable in many instances. A true CIM system will have a common design and manufacturing data base whereby manufacturing constraints, could be feed back to the designer so that the design reflects manufacturing capability.

CHAPTER 3.

ECONOMIC JUSTIFICATION FOR THE PURCHASE OF CNC MACHINE

3.1 Justification Procedure

Any discussion of the justification of NC equipment should stress the importance of distinguishing between economically justifying the introduction of numerical control and economically justifying the acquisition of a particular NC machine tool. The first NC machine tool should not be expected to pay for (although it might do so) a stand-alone computer system hardware and software - for part programming or the cost of a sophisticated tool - length gage for the toolroom for instance, if the intent is to acquire a half-dozen NC machines over several years. Likewise, some of the potential savings may not be realized by acquiring just a single machine. But a group of machines that would permit all turning to be done by NC would have a synergistic and very measurable effect. The savings thus realized could be legitimately apportioned to the individual machine.

There are three basic approaches to industrial equipment justification. Each is distinct and each involves a fundamental policy design as to how old equipment will be replaced or new equipment acquired. Choosing one or more of the three is a critical management decision.

The first is one of caution and is best termed "defensive". With this concept, no capital equipment is purchased until something wears out and is beyond a point of service. It is simply replaced with a like kind to do the same job. No thought is given to making any basic changes or improvement in method. Defensive justification is easy, but in the long run it will lead to mediocrity and oblivion.

The second approach is "cost saving" and it has the virtue of lending itself to easy calculation while at the same time offering a degree of overall progress. In this basically conservative approach, equipment will be replaced with a like kind offering some degree of improved performance. But there is no disciplined effort to see if perhaps an entire operation could be changed.

The third type of justification is "aggressive". It questions whether or not the present methods are really the best. Aggressive justification may involve substantial change, often complete changes in concept or methodology. Utilization of this approach offers the greatest possibilities for really significant changes in a manufacturing process and for real progress, but may be the most difficult to translate into a dollars and cents justification formula. Aggressive justification may be the only one that will create whole new earning and development opportunities for the shop. Aggressive justification is not easy to establish, but the rewards are great.

Numerical control acquisitions will almost never fit into a defensive justification pattern; some will be cost saving, but the majority will be aggressive. Because of its far reaching effects, the return on investment (ROI) of NC equipment has been very hard to analyze, and the greatest potential generators of ROI are often overlooked because they are often beyond the immediate manufacturing environment.

The heart of the problem lies in the tendency to approach NC equipment justification in the same manner as that used for conventional machines. In reality, the return on investment with NC machines comes from many more and different areas than the return generated by conventional equipment.

First, a good beginning is a complete review of the machined product itself and such elements as engineering and design that influence the performance and marketability of the end product. Will NC help produce a better product that can be more easily engineered for real market needs? Second, a close look should be taken at the manufacturing engineering functions. Probably at the top of the list will be jig savings. With the NC machine, jigs are not necessary and the expense of either manufacturing them or purchasing them is eliminated. The required fixturing is simpler and less costly. Third, a review must be made of the operational or production phase of the business, which involves the direct running of production equipment and the assurance of quality.The NC machine is capable of being set up for a job much more quickly than the manual machine without cumbersome fixed tooling. An analysis of how many different setups would be required in a year, and the time saved on each gives a good estimate of the dollars to be saved in setup alone. The fourth and final category is concerned with the more subtle financial effects of the NC equipment. The justification study should include the potential reduction of both work in process and finished goods inventory. In the reduction of the standard economic lot size, the amount of inventory being processed at any time is similarly reduced. This is a direct financial savings and must be accurately estimated.

3.2 Finding All the Sources of Return on Investment

Considerations beyond machining are complex and difficult for technical management to express in dollar value. Even financial management has no magic formula for doing so. Many plants have been able to successfully place dollar or percentage figures on the various sources of ROI. Each plant must establish its own figures. The following guidelines can help to identify these generators of potential savings[7].

1. Savings in direct labor. One NC machine's output is commonly equal to several conventional machines. It is achieved by combining operations on one machine where automatic features provide a high ratio of in-cut time. There is less total set-up time due to fewer machines visited by the part in production; therefore, fewer setups. In figuring labor savings, the ability of NC machines to hold closer tolerances and better surface finish that may reduce or eliminate subsequent operations should not be overlooked.

2. Savings in operator training expense. Less time is required to train an NC machine operator.

3. Savings in shop supervisory costs.

4. Savings due to tighter, more predictable production scheduling, fewer stock chaser, less lead time, and faster throughput time.

5. Reduced floor space, due to need for fewer machines.

6. Reduced power consumption per piece, due to fewer machines needed and higher proportion of metal removal time on NC, meaning less total motor idling time.

7. Savings in closer cost estimates and better pricing of product.

8. Savings due to elimination of precision jigs construction, maintenance and storage costs.

9. Savings due to reduced fixturing needs-construction, maintenance and storage costs.

10. Savings in tool engineering/design time and related documentation.

11. Savings in cutting tool costs due to NC contouring capability, which frequently eliminates need for special form tools, special boring bars and special thread cutters.

12. Savings in reduced cutting tool inventories due to use of simple, multi use catalog tools and use of carbide indexable inserts.

13. Reduction in cutting tool costs due to longer and predictable tool wear life and less tool breakage, using carbide indexable inserts.

14. Reduced cutting tool maintenance cost, tool and cutter grinding cost.

15. Reduced inspection time. Dimensional relationships held very close on NC machines. High repeatability of NC eliminates most inspection beyond 100 percent first piece checkout by coordinate measuring machine or equivalent. Only spot checking of critical areas is usually done by machine operator without loss of machine time.

16. Reduced rework costs.

17. Reduced assembly and field service costs. More consistent accuracy and repeatability of NC reduce hand work and speed up assembly of matching and mating parts.

18. Reduced wear and tear on gaging instruments due to reduced inspection.

19. Reduced maintenance costs per unit produced, because of the NC machine's higher productivity. One NC machine replaces several conventional machines.

20. Reduced maintenance costs in many cases because of on-line, in-process machine/control diagnostics that issue alert signals and may take other action automatically in the event that abnormal conditions develop.

21. Reduced work-in-process inventory levels. With NC the throughput is much faster, workpieces don't have to visit as many machines for individual operations, meaning less time in queues at the different machines, less time waiting to be moved, less time in transit.

22. Reduced finished-goods inventory because of lower economic order quantity (EOQ) made possible by slashed setup costs, faster through-put time, and greater predictability of production schedules.

23. Reduced unit value of work-in-process and finished goods inventories, because of lower manufacturing costs; therefore, less money tied up in inventory.

24. Savings in inventory obsoletes and raw stores, resulting from lower EOQ and reduced finished-goods inventory. The company can work closer to the just-in-time concept.

25. Tighter dimensional and surface finish control on rotating and sliding members and the ability to more economically machine harder and tougher materials may permit upgrading product performance specifications.

3.3 General Replacement Minimum Cost Model

One of the nost widely used model for economic justification of CNC machine purchase is General replacement Minimum Cost Model.

The model shown below can be used to develop minimum costs for both the present and proposed investment. However, to calculate minimum costs, it must be assumed that exact costs of present equipment can be collected and future costs of the proposed equipment can be predicted with some degree of accuracy.

To develop data for the model it is desirable to use present worth and capital recovery factors. This use allows for the recognition of the time value of money. In essence, it is simply an application of principle of simple interest. The use of this economic discipline reflects the factors:

1. Cost of funds
2. Risk

The cost of fund is a variable. A dollar received today has greater value than a dollar received one year from now. This discounting is accomplished through the use of present worth factors. In addition, once the total present worth of a time series is known, time adjusted annual costs can be calculated through the use of capital recovery factor.

Risk may be defined in the present context as an exposure to loss. This loss should be evaluated in monetary terms, if possible. Where the risk is not known, it may be estimated and added as an input cost or it may be considered to be an irreducible factor in making the decision. The uncertainty of estimated cost data is part of the risk; the uncertainty of estimating the useful economic life of the equipment is part of the risk; other risk factors include the investment of funds in this particular category, socio-economic problems, and technological change and obsolescence.

In any comparative study between two or more alternative purchases, similar activities should be used for the cost comparison. Also, sometimes it is meaningless to compare one plant's cost with another's because various cost factors of one plant may not be true for another. Data collection remains a difficult problem for any quantitative approach. Refined methods of cost analysis suggest collecting detailed cost data on both conventional and NC machines for making a typical part provided by the company. Three important parameters appear to be batch size, workpiece complexity, and operator wage rates. The operating time data can be obtained by stopwatch measurement, by predetermined time systems, and by time study measurements previously made by the company.

The first calculations is to transform the capital costs of depreciation and interest on the investment to equivalent uniform annual costs for both NC machines and the conventional machine. The calculation procedure is explained in table 3.1, 3.2 and 3.3[8].

Once results have been obtained for conventional and NC machine, results of dollars per running hour can be used from table 3.3 to calculate the piece cost when the standard time per piece is known. Standard time per piece can be determined by splitting all operations into elements and carrying out time study for those elements. Using these element data, the length of time can be determined for production of any number of units. The time elements can be divided into two categories: Fixed element and Variable element. Fixed elements are those which are performed regardless of number of units (like setup time, teardown time, etc.), while variable elements are those which are performed once for each unit production. These data can be used to develop prediction equations for the operations. The prediction equation generally takes the following linear form.

$T = F + VP$ Where,
P = Number of parts.
F = Fixed Time (hours)
V = Variable time/part (hours)
T = Total time to produce 'P' parts(hours)

By synthesizing the basic element data, the time equations for the NC and conventional machines can be determined.

$T_C = F_1 + V_1P$ (Conventional machine)

$T_N = F_2 + V_2P$ (NC machine)

With the help of total cost in Table-3.3, and time equation derived above following equations can be derived.

For conventional machine,

TOTAL ESTIMATED TIME ADJUSTED CAPITAL COST

YEAR n	DOLLARS REALIZA- -BLE AT FIRST OF nth YEAR X1	DOLLARS DEPRECI- -ATION IN nth YEAR X2	INTEREST ON REA- -LIZABLE VALUE AT FIRST OF nth YEAR X3	DEPRECI- -ATION PLUS INTEREST IN nth YEAR X4	PRESENT WORTH FACTOR ++ X5	PRESENT WORTH OF CAPITAL COSTS IN nth YEAR X6	CUMULA- -TIVE PRESENT WORTH FOR n YEARS X7	C.R. FACTOR X8	TIME AD- -JUSTED CAPITAL ANNUAL COSTS X9	TIME AD- -JUSTED CAPITAL COSTS $/hr. X10
1	ORIGINAL COST + FREIGHT IN COST+ TOOLING COST + BACKUP TOOLS + MISCEL- -LANEOUS COST +++	X1 * (DEPRE- -CIATION RATE)+	X1 * (INTER- -EST RATE)	X2 + X3		X4 * X5	$\sum_{1=1}^{n} X6_1$		X7 * X8	$\frac{X9}{\text{WORKING HOURS PER YEAR}}$
2	$(X1)_{n-1} - (X2)_{n-1}$									
n										

\+ THERE ARE VARIOUS DEPRECIATION METHODS. ONE SHOULD USE THAT IS IN PRACTICE AT THAT FIRM.

++ THE PRESENT WORTH FACTORS CAN BE TAKEN FROM ANY ENGINEERING ECONOMY TEXT.[9]

+++ MISCELLANEOUS COST VARIES WITH PARTICULAR CASE.

TABLE 3.1

TOTAL ESTIMATED TIME ADJUSTED OPERATING AND MAINTENANCE COST

YEAR n	OPERATION AND MAIN- -TENANCE COST IN nth YEAR Y1	PRESENT WORTH FACTOR Y2	PRESENT WORTH IN nth YEAR Y3	CUMULAT- -IVE PRESENT WORTH IN nth YEAR Y4	C.R. FACTOR Y5	TIME ADJUSTED OPERATION AND MAIN- -TENANCE ANNUAL COST Y6	TIME ADJUSTED OPERATION AND MAIN- -TENANCE COSTS $/hr. Y7
	MAINTENA- -NCE COST + MACHINE OVERHEAD COST (PR- -OPERTY TAX, HEAT, POWER, FLOOR SP- -ACE ETC.) + DIRECT YEARLY LABOR COST		Y1*Y2	$\sum_{i=1}^{n} Y3_i$		Y4*Y5	$\dfrac{Y6}{\text{WORKING HOURS PER YEAR}}$
2							
n							

TABLE 3.2

SUM OF TIME ADJUSTED CAPITAL, OPERATION AND MAINTENANCE COST

YEAR n	TIME ADJUSTED OPERATION AND MAINTENANCE COST (ANNUAL)	TIME ADJUSTED OPERATION AND MAINTENANCE COST $/hr.	TIME ADJUSTED CAPITAL COST (ANNUAL)	TIME ADJUSTED CAPITAL COST $/hr	TOTAL COST (ANNUAL) Z1	TOTAL COST $/hr. Z2
1	Y6	Y7	X9	X10	Y6+X9	Y7+X10
2						
n						

TABLE 3.3

Total cost $C_c = T_c * Z_2$

$= Z_2 (F_1 + V_1 P)$ ------------A

(Z_2 can be obtained by developing table 3.3 for conventional machine)

For NC machine,

Total cost $C_N = T_N * Z_2$

$= Z_2 (F_2 + V_2 P)$-------------B

(Z_2 can be obtained by developing table 3.3 for NC machine)

By graphing equations A and B a comparison can be made of the cost per piece of each machine as a function of batch size (Refer figure 3.4). Also this graph gives the breakeven value. Figure 3.4 shown is highly dependent on batch size, different types of tooling, fixturing, workplace layout and complexity of workpiece.

3.4 Conclusions

With the help of method described above one can economically justify the right machine. However one should keep in mind some factors like programming time for NC machine. If the same program can be used to produce part next time, the fixed time element of programming can be considerably reduced. Above method can also be used for comparison of one NC machine with other NC machine. Moreover different types and rates of return could conceivably change the pattern of relative costs considerably. The company management must make these decisions before an economic analysis should be attempted.

Another method frequently used for evaluation of machine tool purchases is MAPI procedure. The MAPI refer to the Machinery and Allied Products Institute. Briefly, the concept makes use of expressions like the following

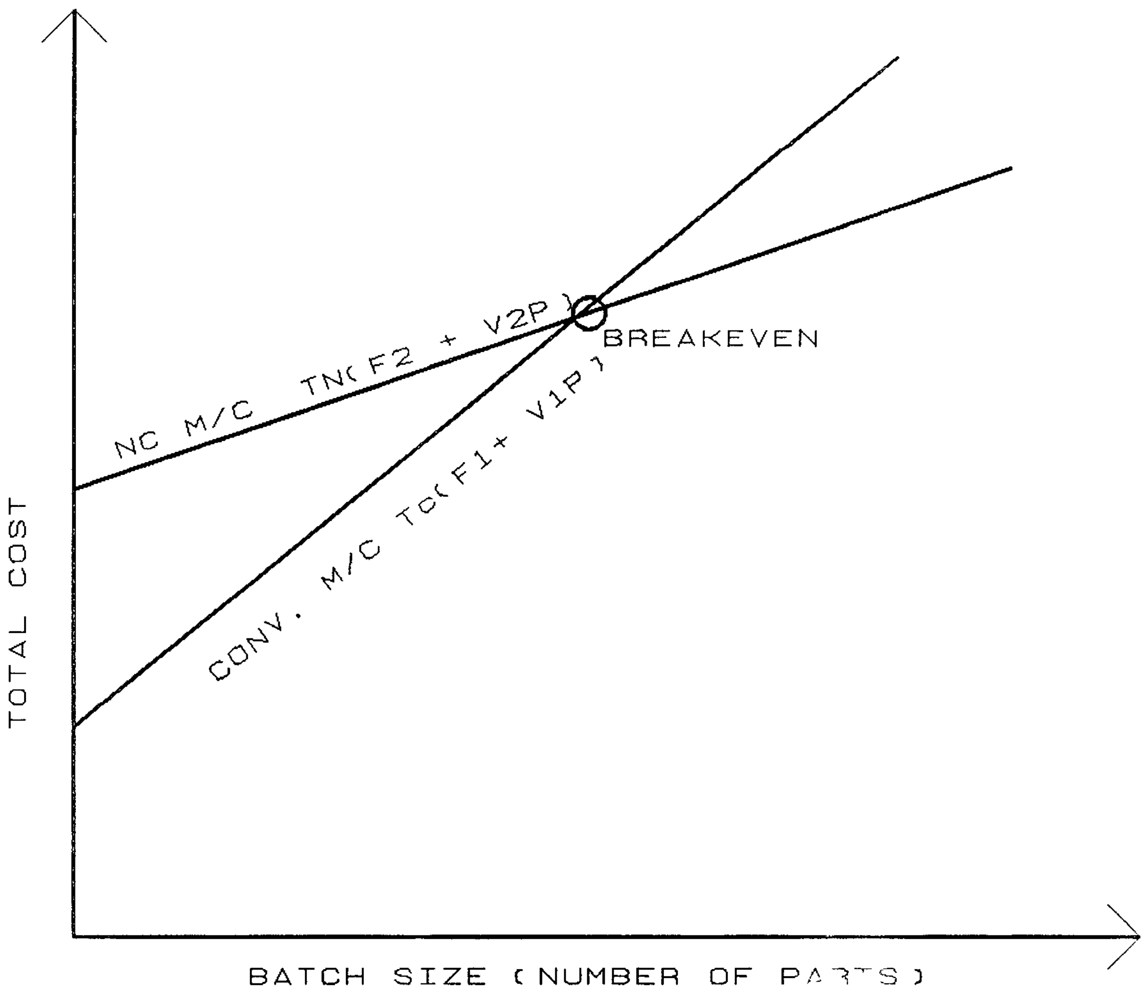

NC M/C TN(F2 + V2P)
CONV. M/C Tc(F1+ V1P)
BREAKEVEN
TOTAL COST
BATCH SIZE (NUMBER OF PARTS)

Fig. 3.1

1. Operating inferiority
2. Adverse minimum
3. Basic assumptions

Operating inferiority develops on almost any machine when it is composed with the best new identical machine available at any point in time. Deterioration and obsolescence varies considerably between various types of machine tools. Some machine tool suffer rapid obsolescence and very little deterioration. Whatever combination of these factors exists, an operating inferiority develops between the machine presently in service and the best available machine at the time horizon under consideration.

Adverse minimum consists of operating inferiority and capital cost. The objective is to find the proper proportion between these two in order to minimize their sum.
The two assumptions in theory are

1. That the future challenges will have the same adverse minimum as the present challenges.
2. That the present challenger will develop operating inferiority at a constant rate over its estimated service life. Thus the decision to replace is based on comparisons of the adverse minima between challenger and defender. The detailed MAPI procedure is described in 'Dynamic equipment policy' (McGraw-Hill) developed by Machinery and allied products institute.

3.5 CASE STUDY

A case study is carried out using General Replacement Minimum Cost Model for the following given data.

	Conventional Machine	CNC Machine (2 1/2 axis)
1. Purchase cost	$ 6750	$ 61500
2. Fright in cost	250	350
3. Tooling cost	1500	1600
4. Auxiliary cost (like compressor etc.)		1500
5.Installation cost	200	600
	----------	----------
	8700	**65550**
6. Maintenance cost per year.	1800	4000
7. Direct Labor cost	$ 8.00/hour	$ 10.50/hour
8. Overhead allocations to machine.		
Floor space	450	1200
Property tax	150	1200
Power, heat etc.	900	1200
	---------	------------
	1500	**3600**
9. Expected life	7 years	7 years

10. Depreciation method.	Fixed Percentage	Fixed Percentage
11. Interest Rate	20 %	20 %
12. Hours per workweek	43	43
13. Workweek per year	52	52

Calculating table 3.1 for conventional machine

Dollars realizable at first year	= 8700
Assuming salvage value of the machine \$ 1500	
Dollars depreciated in first year	$= 8700 * [1-(1500/8700)^{1/7}]$
Interest on realizable value for 1st year	= (20/100) * 8700
	= 1740
Working hours per week	= 43*52
	= 2336 hours.

Substituting these values in table 3.1, following results are obtained.

TOTAL ESTIMATED TIME ADJUSTED CAPITAL CCST FOR CONVENTIONAL MACHINE

YEAR n	DOLLARS REALIZA-BLE AT FIRST OF nth YEAR X1	DOLLARS DEPRECI-ATION IN nth YEAR X2	INTEREST ON REA-LIZABLE VALUE AT FIRST OF nth YEAR X3	DEPRECI-ATION PLUS INTEREST IN nth YEAR X4	PRESENT WORTH FACTOR++ X5	PRESENT WORTH OF CAPITAL COSTS IN nth YEAR X6	CUMULA-TIVE PRESENT WORTH FOR n YEARS X7	C.R. FACTOR X8	TIME AD-JUSTED CAPITAL ANNUAL COSTS X9	TIME AD-JUSTED CAPITAL COSTS $/hr. X10
1	8700	1984	1740	3724	0.8333	3103	3103	1 2	3724	1.67
2	6716	1531	1343	2874	0.6944	1996	5099	0.6545	3337	1.49
3	5185	1182	1037	2219	0.5187	1151	6250	0.4747	2967	1.33
4	4003	913	801	1714	0.4823	827	7077	0.3863	2734	1.22
5	3090	705	618	1323	0.4019	532	7609	0.3344	2545	1.14
6	2385	544	477	1021	0.3349	342	7951	0.3007	2391	1.07
7	1841	420	368	788	0.2791	220	8171	0 2774	2267	1.01

TABLE 3.4

Total estimated time adjusted operating and maintenance cost for conventional machine.

Maintenance cost	=	1800/year
Labor cost per year	=	Direct labor cost * Workhours per year
	=	8*2236
	=	17888
Overhead allocations	=	1500
Total operation cost	=	Total labor cost + Total overhead cost
	=	19400

Substituting above values in table 3.2, following results are obtained.

TOTAL ESTIMATED TIME ADJUSTED OPERATING AND MAINTENANCE COST FOR CONVENTIONAL MACHINE

YEAR n	OPERATION AND MAIN- -TENANCE COST IN nth YEAR Y1	PRESENT WORTH FACTOR Y2	PRESENT WORTH IN nth YEAR Y3	CUMULAT- -IVE PRESENT WORTH IN nth YEAR Y4	C.R. FACTOR Y5	TIME ADJUSTED OPERATION AND MAIN- -TENANCE ANNUAL COST Y6	TIME ADJUSTED OPERATION AND MAIN- -TENANCE COSTS $/hr. Y7
1	19400	0.8333	16166	16166	1.2	19400	8.30
2	19900	0.6944	13819	29985	0.6545	19625	8.40
3	20400	0 5787	11805	41791	0.4747	19838	8.50
4	20900	0.4823	10080	51871	0 3863	20038	8.58
5	21400	0.4019	8601	60472	0.3344	20222	8.66
6	21900	0.3349	7334	67806	0.3007	20390	8.73
7	22400	0.2791	6252	74058	0.2774	20544	8.80

TABLE 3.5

Substituting results of table 3.4 and table 3.5 in table 3.3, following results are obtained.

SUM OF TIME ADJUSTED CAPITAL, OPERATION AND MAINTENANCE COST FOR CONVENTIONAL MACHINE

YEAR n	TIME ADJUS-TED OPERATION AND MAINT-ENANCE COST (ANNUAL)	TIME ADJU-STED OPERATION AND MAIN-TENANCE COST $/hr.	TIME ADJU-STED CAPITAL COST (ANNUAL)	TIME ADJU-STED CAPITAL COST $/hr.	TOTAL COST (ANNUAL) Z1	TOTAL COST $/hr. Z2
1	19400	8 30	3724	1.67	23124	9.97
2	19625	8.40	3337	1.49	22962	9.89
3	19838	8.50	2967	1.33	22805	9.83
4	20038	8.58	2734	1.22	22772	9.80
5	20222	8.66	2545	1.14	22767	9.80
6	20390	8.73	2391	1.07	22781	9.80
7	20544	8.80	2267	1.00	22811	9.80

TABLE 3.6

Calculating table 3.1 for CNC machine

Dollars realizable at first year = 65550

Assuming salvage value of the machine $ 10700

Dollars depreciated in first year = $65550 * [\, 1-(10700/65550)^{1/7}]$

Interest on realizable value for 1st year = (20/100) * 65550

= 13110

Working hours per week = 43*52

= 2336 hours.

Substituting these values in table 3.1, following results are obtained.

TOTAL ESTIMATED TIME ADJUSTED CAPITAL COST FOR NC MACHINE

YEAR n	DOLLARS REALIZA- -BLE AT FIRST OF nth YEAR X1	DOLLARS DEPRECI- -ATION IN nth YEAR X2	INTEREST ON REA- -LIZABLE VALUE AT FIRST OF nth YEAR X3	DEPRECI- -ATION PLUS INTEREST IN nth YEAR X4	PRESENT WORTH FACTOR++ X5	PRESENT WORTH OF CAPITAL COSTS IN nth YEAR X6	CUMULA- -TIVE PRESENT WORTH FOR n YEARS X7	C.R. FACTOR X8	TIME AD- -JUSTED CAPITAL ANNUAL COSTS X9	TIME AD- -JUSTED CAPITAL COSTS $/hr X10
1	65550	14945	13110	28055	0 8333	23379	23379	1.2	28055	12.55
2	50605	11537	10121	21658	0 6944	38418	38418	0.6545	25145	11.25
3	39068	8908	7814	16722	0 5187	48095	48095	0.4747	22831	10.21
4	30160	6877	6032	12909	0 4823	54321	54321	0.3863	20984	9.29
5	23283	5309	4657	9966	0.4019	58326	58326	0.3344	19504	8.72
6	17974	4098	3595	7693	0.3349	60902	60902	0.3007	18313	8.19
7	13876	3164	2775	5939	0.2791	62560	62560	0.2774	17354	7.76

TABLE 3.7

Total estimated time adjusted operating and maintenance cost for CNC machine.

Maintenance cost	=	4000/year
Labor cost per year	=	Direct labor cost * Workhours per year
	=	10.5*2236
	=	23478
Overhead allocations	=	3600
Total operation cost	=	Total labor cost + Total overhead cost
	=	27080

Substituting above values in table 3.2, following results are obtained.

TOTAL ESTIMATED TIME ADJUSTED OPERATING AND MAINTENANCE COST FOR NC MACHINE

YEAR n	OPERATION AND MAIN- -TENANCE COST IN nth YEAR Y1	PRESENT WORTH FACTOR Y2	PRESENT WORTH IN nth YEAR Y3	CUMULAT- -IVE PRESENT WORTH IN nth YEAR Y4	C.R. FACTOR Y5	TIME ADJUSTED OPERATION AND MAIN- -TENANCE ANNUAL COST Y6	TIME ADJUSTED OPERATION AND MAIN- -TENANCE COSTS $/hr. Y7
1	27080	0.8333	22566	22566	1.2	27079	12.11
2	27580	0.6944	19152	41718	0.6545	27304	12.21
3	28080	0.5787	16250	57968	0.4747	27517	12.31
4	28580	0.4823	13784	71752	0.3863	27718	12.40
5	29080	0.4019	11687	83439	0.3344	27902	12.49
6	29580	0.3349	9906	93345	0.3007	28069	12.55
7	30080	0.2791	8395	101740	0.2774	28223	12.62

TABLE 3.8

Substituting results of table 3.4 and table 3.5 in table 3.3, following results are obtained.

SUM OF TIME ADJUSTED CAPITAL, OPERATION AND MAINTENANCE COST FOR NC MACHINE

YEAR n	TIME ADJUS--TED OPERATION AND MAINT--ENANCE COST (ANNUAL)	TIME ADJU--STED OPERATION AND MAIN--TENANCE COST $/hr.	TIME ADJU--STED CAPITAL COST (ANNUAL)	TIME ADJU--STED CAPITAL COST $/hr.	TOTAL COST (ANNUAL) Z1	TOTAL COST $/hr. Z2
1	27079	12.11	28055	12.55	55134	24.66
2	27304	12.21	25145	11.25	52449	23.46
3	27517	12.31	22831	10.21	50348	22.52
4	27718	12.40	20984	9.39	48702	21.79
5	27902	12.49	19504	8.72	47406	21.21
6	28969	12.55	18313	8.19	46382	20.74
7	28223	12.62	17354	7.76	45577	20.38

TABLE 3.9

Now above results are analyzed for various degree of machining complexity required and for various types of machine to economically justify machine purchase. Next step is to collect data for standard fix time and variable time for given part production in order to estimate production cost. Standard time per piece can be determined by breaking down the operation into elements and then carrying out time study for each element. Following analysis is carried out for three different types of parts having increasing complexity of machining. Following time study results are assumed for these parts.

Time (hours)

Part A

	Conventional machine	CNC machine
A. Fixed Time		
Setup time	0.3009	0.9884
Teardown time	0.2505	0.2505
	--------	--------
Total fixed time	0.5514	1.2389
B. Variable Time	0.2177	0.1346

Time equation

$T_c = 0.5514 + 0.2177*P$ - Conventional machine

$T_n = 1.2389 + 0.1346*P$ - CNC machine

	Time (hours)	
	Part B	
	Conventional machine	CNC machine
A. Fixed Time		
Setup time	0.3009	0.9884
Teardown time	0.2505	0.2505
	------	------
Total fixed time	0.5514	1.2389
B. Variable Time	0.3977	0.1646

Time equation

$T_c = 0.5514 + 0.2177*P$ - Conventional machine

$T_n = 1.2389 + 0.1346*P$ - CNC machine

	Time (hours)	
	Part C	
	Conventional machine	CNC machine
A. Fixed Time		
Setup time	0.3009	0.9884
Teardown time	0.2505	0.2505
	------	------
Total fixed time	0.5514	1.2389
B. Total Variable Time	0.55	0.20

Time equation

$T_c = 0.5514 + 0.2177*P$ - Conventional machine

$T_n = 1.2389 + 0.1346*P$ - CNC machine

Total production cost per piece for part A.

$$\text{Total cost per piece} = \frac{\text{Total cost per hour} * \text{Time required to produce P parts}}{P}$$

$$\begin{array}{l}\text{Total cost per piece} \\ \text{for conventional machine}\end{array} = \frac{9.80*T_c}{P}$$

$$= \frac{5.4 + 2.13*P}{P}$$

$$\begin{array}{l}\text{Total cost per piece} \\ \text{for CNC machine}\end{array} = \frac{25.25 + 2.75*P}{P}$$

Above equations gives following cost per piece

	Cost Per Piece	
Batch Size	CNC machine	Conventional machine
1	28.00	7.53
10	5.28	2.67
50	3.26	2.24
100	3.00	2.18
1000	2.78	2.14

Above results shows that for part A conventional machine is more economical over CNC machine.

Total production time per piece for part B.

$$\text{Total cost per piece} = \frac{\text{Total cost per hour} * \text{Time required to produce P parts}}{P}$$

$$\begin{aligned}\text{Total cost per piece for conventional machine} &= \frac{9.80*T_c}{P} \\ &= \frac{5.4 + 3.90*P}{P}\end{aligned}$$

$$\text{Total cost per piece for CNC machine} = \frac{25.25 + 3.36*P}{P}$$

Above equations gives following cost per piece

Cost Per Piece

Batch Size	CNC machine	Conventional machine
1	28.61	9.30
10	5.89	4.44
40	4.00	4.01
50	3.87	4.01
100	3.61	3.95
1000	3.39	3.91

Above results shows that for part B CNC machine is not economical for batch size of less than 40.

Total production cost per piece for part C.

$$\text{Total cost per piece} = \frac{\text{Total cost per hour} * \text{Time required to produce P parts}}{P}$$

$$\text{Total cost per piece for conventional machine} = \frac{9.80*T_c}{P}$$

$$= \frac{5.4 + 5.39*P}{P}$$

$$\text{Total cost per piece for CNC machine} = \frac{25.25 + 4.08*P}{P}$$

Above equations gives following cost per piece

Cost Per Piece

Batch Size	CNC machine	Conventional machine
1	29.33	10.77
10	6.61	5.93
15	5.75	5.75
25	5.09	5.61
50	4.59	5.50
100	4.33	5.44
1000	4.11	5.40

Above results shows that for complex part (like part C) production CNC machine can be more economical even for small batch size.

Now if complex part like C is produced on 3 axis CNC machine instead of 2 1/2 axis, which can reduce operation time to 0.15 hour, following results are obtained. Suppose higher investment for 3 axis CNC results in total cost of \$ 21.59 instead of \$20.38.

Total production cost per piece for part C using 3 axis CNC machine.

$$\text{Total cost per piece} = \frac{\text{Total cost per hour} * \text{Time required to produce P parts}}{P}$$

Total cost per piece for conventional machine

$$= \frac{9.80*T_c}{P}$$

$$= \frac{5.4 + 5.39*P}{P}$$

Total cost per piece for CNC machine

$$= \frac{26.64 + 3.23*P}{P}$$

Above equations gives following cost per piece

	Cost Per Piece	
Batch Size	3 axis CNC machine	Conventional machine
1	28.61	9.30
8	6.56	6.07
10	5.90	5.93
50	3.76	5.50
100	3.50	5.44
1000	3.27	5.40

Above results shows that for complex part like C, 3 axis CNC machine can be more economical over conventional type and 2 1/2 axis CNC machine for batch size as small as 10 pieces.

CHAPTER 4

TECHNICAL CONSIDERATIONS FOR THE PURCHASE OF CNC MACHINES.

4.1 CNC Networking

Networking in the CNC machine environment has progressed along two paths of applications. First is the flexible manufacturing system (FMS) and second is the communications integrator of a non FMS grouping of various machines, usually referred to as " the DNC system ". The host computer of an FMS is referred to as the FMS computer rather than the DNC computer. But the networking considerations are shared by both. Significant cost reduction can result from single point updating capabilities, minimum data entry requirements and elimination of time lag errors[16].

Today's computers, CNCs, programmable logic controllers (PLCs) and peripheral equipments are all at a sufficiently high level of sophistication and reliability to permit undertaking a DNC/FMS project with considerable confidence. The major problems today center on software and collection of machine status data for management feedback. These areas require attention. Direct control of machines by the host computer in semi real time is still used in many older DNC systems. In these systems, the host emulates the tape reader and downloading of the part program to an MCU is slow. Data flow is paced by the machine's execution of the programmed instructions by the machine. In this mode, the host feeds the part program into buffer storage of the MCU, segment by segment, so as to keep only enough data in buffer to meet the peak rate demands of the machine. In this semi real time mode of operation, the MCU is constantly on line with the host computer.

Most new systems installed today follow the dictum which permits a part program to be run from memory and with multiple part program capability. This makes it possible to operate a machine independent of the host computer once the part program have been downloaded. This frees up more of the host time and capacity for other system tasks. These CNC capabilities along with increasing computer reliability, also are strengthening the belief that a punched tape reader on each MCU is no longer needed, even for standby purposes in a system.

Computer communications networking exists at two major levels - long-haul or wide-area or global, and local. The networking technology developed at each level has led to commercially available systems which have accelerated and expanded the practical applications of computers communicating with one another. Long-haul networks are those established for high speed data transmission between widely separated computers without any geographical limitations. Common carrier lines, satellite and microwave systems are utilized by such networks. Local area network (LAN) have come into existence to provide private, low cost, high-speed data communications capability between computers within building or close group of buildings. LAN technology has borrowed heavily from long-haul networking, especially the packet technology and from the input/output bus structures of computers.

LANs can be divided further into two categories: business and industrial. Although not clearly defined, business type LANs serves banking, insurance and other nonmanufacturing interests as well as being used in metal working industries to connect computers performing front office business functions. Industrial type LANs serves the more specialized technical needs of manufacturing from the accelerating CAD/CAM technology. Computers and software at this level are more application oriented then are the general purpose computers existing at the business level. There are many different LANs available commercially. Many are proprietary. Some are in business oriented category. A small number can be applied to both business and industrial needs. Possibly a subset of industrial LANs might be made up principally, or wholly, of programmable controllers.

4.1.1 Network Architecture

While selecting or designing a local computer network, a basic decision must be made as to centralized versus distributed computer processing and control. With the availability of low cost microprocessor, general trend in the metal processing industry is toward distribution of processing and control to the lowest possible level, yet retaining supervision, coordination, data integration and analysis, and policy at the higher level.

When there are many MCUs to be linked together, the use of satellite computers or subhost - each supervising a group of machines - provides for a better distribution of control. The commonalties of function within each subnetwork simplifies the handling of protocol and interfacing. Subnetwork should be as self-sufficient as possible so as to reduce the volume of data traffic with other networks.

In the eventual total integration of a large scale manufacturing enterprise, all network would be linked together. The interconnection of dissimilar networks, as may occur in linking a LAN into a long-haul network, is accomplished also by a computer and appropriate software. The computer in either case may be microprocessor based. Some important considerations while specifying networks are[18]:

* Volume of traffic in each direction along data links.

* Speed at which such data can be received.
* Whether the network is to be linked with other networks.
* Distances between locations.
* Sources and nature of data used or generated at each location.

Specifications of the network must also provide for transmission media, methodology for physically controlling transmission of data over the medium, the physical interfacing of computers into the system and specific protocol. LANs are designed and constructed in functional layers. These layers create a network architecture with each layer performing a specific function and service. The different layers interact to provide total end-to-end network operation. The network architecture created by most vendors in recent years has conformed to the ISO model for Open Systems Interconnection (OSI). Figure 4.1 shows ISO seven layer model for OSI. This seven layer reference model formalizes a developing consensus among communication network designers, provide the framework for layered networks, and introduces a uniform terminology for naming the various utilities involved.

4.1.2 LAN Wiring

The wiring media provides the physical link between networked devices, allowing for signal transmission. The wiring is an 8 to 15 year investment - perhaps the longest technological commitment. So it is important to select cabling that is versatile, easy to move and add to, and simple enough to change.

Coaxial cable consists of copper conductor surrounded first by insulation and than by a tube shaped conductor of copper, aluminum, or metal braid[10]. In some cases, the entire cable is then sheathed in insulation. Cable types range from flexible, thin wires similar to those used in phones to rigid, thick wires. Baseband coaxial cable

7	APPLICATION LAYER	user specified application software
6	PRESENTATION LAYER	Data format translation between applications
5	SESSION LAYER	Interfaces network (levels 4 and below) to application layer
4	TRANSPORT LAYER	Controls connections from one end to another
3	NETWORK LAYER	Routing of data from one location to another
2	DATA LINK LAYER	Error checking & correction access methods
1	PHYSICAL LAYER	Electrical transfer of data between nodes of network

Fig. 4.1
ISO/OSI MODEL FOR NETWORK COMMUNICATION

delivers a single set of signals, such as data, at one time. Broadband cable delivers multiple sets of signals - data, voice, and video - simultaneously and at different frequencies. Another type of cable called twisted pair, is comprised of two copper conductors, each covered with insulation. The two wires are interwinded to ensure they are both equally exposed to interference signals in the environment. The newest and most expensive media is fiber optics. Rather than wires, the transmission media consists of fine glass or plastic fibers. At one end, electrical signals are converted into light by a diode and introduced into the fiber. At the other end, the light detector converts the light back into an electrical signal. Signals travel in one direction only.

Most companies use coaxial (both thick wire and thin wire) cable in setting up networks: it transmits signals at 10 megabits/sec. over long distances and is fairly immune to electromagnetic interference (EMI). Twisted pair cable is less expensive; however, its signals don't travel as far nor does it provide as much EMI immunity as coaxial. Fiber optics provides error free signal transmission - at a maximum rate of 100 megabits/sec. for several miles and is immune to EMI, but it is very expensive. Companies often mix media in setting up a network. Ethernet, which specifies wire and software protocols - supports various media. Most engineering organizations, however, run Ethernet over thin wire or thick wire coaxial cable.

4.1.3 Network Topology

Topology refers to a method of connecting the work stations in a local area network. There are three basic network topologies: (A) star, (B) ring, and (C) tree or bus[11, 17].

(A) *Star Network.* A star network has a central device that supports the attached workstations (Refer fig. 4.2)[34].

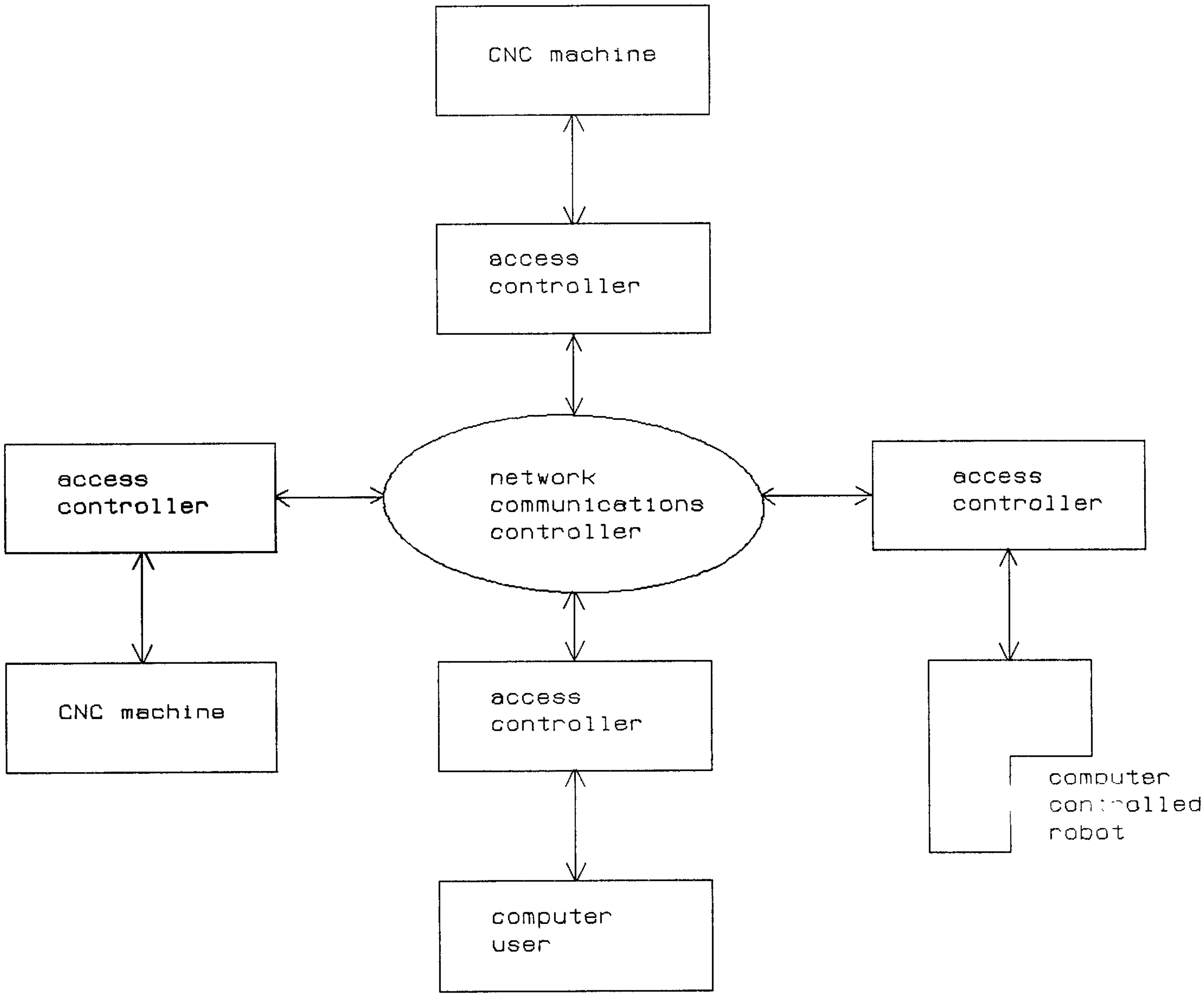


Fig. 4.2 STAR TYPE LAN

Advantages:

(1) Efficiency of having host controller maintain all the shared files and program for the network.

(2) It has good physical and software security because of centralization.

(3) Easy access to outside communication system.

Disadvantages:

(1) When the central host processor brakes down, all activities stops throughout the network.

(2) The central host processor creates a high overhead cost that must be absorbed by the user.

(B) *Ring Network.* When work stations and other peripheral equipment are arranged in a ring network, the pattern resembles a circle (Refer fig. 4.3)[34].

Advantages.

(1) Control is centralized at each workstation rather than at a central processor.

(2) Reliability is greater, because central processor is not required.

Disadvantages

(1) Failure of one relay node on the ring may isolate sections of the ring from further operation.

(2) Expansion is complex; it may involve hardware and software modifications at every work station.

(3) Data security is dependent on the physical security of all the work stations.

(C) *Tree or Bus Network.* A very common form of connection is the tree or bus network. In, fact it is the most widely used connection scheme. In this type of network the stations are attached to coaxial or fiber optic cable (Refer fig. 4.4)[34].

Advantages

(1) It does not require central controller.

(2) If one or more of the stations fails, the system will continue to operate.

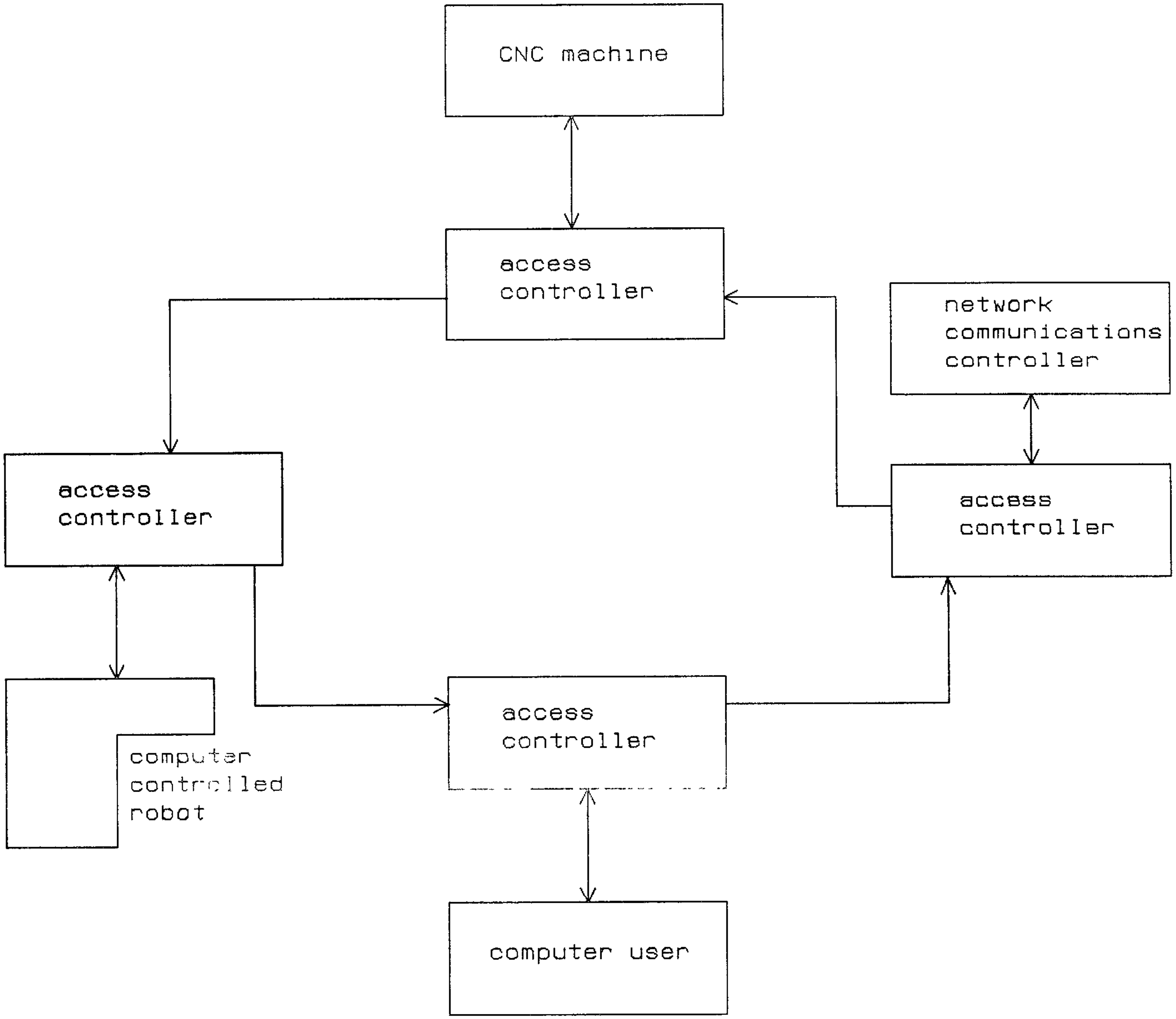


Fig. 4.3 RING TYPE LAN

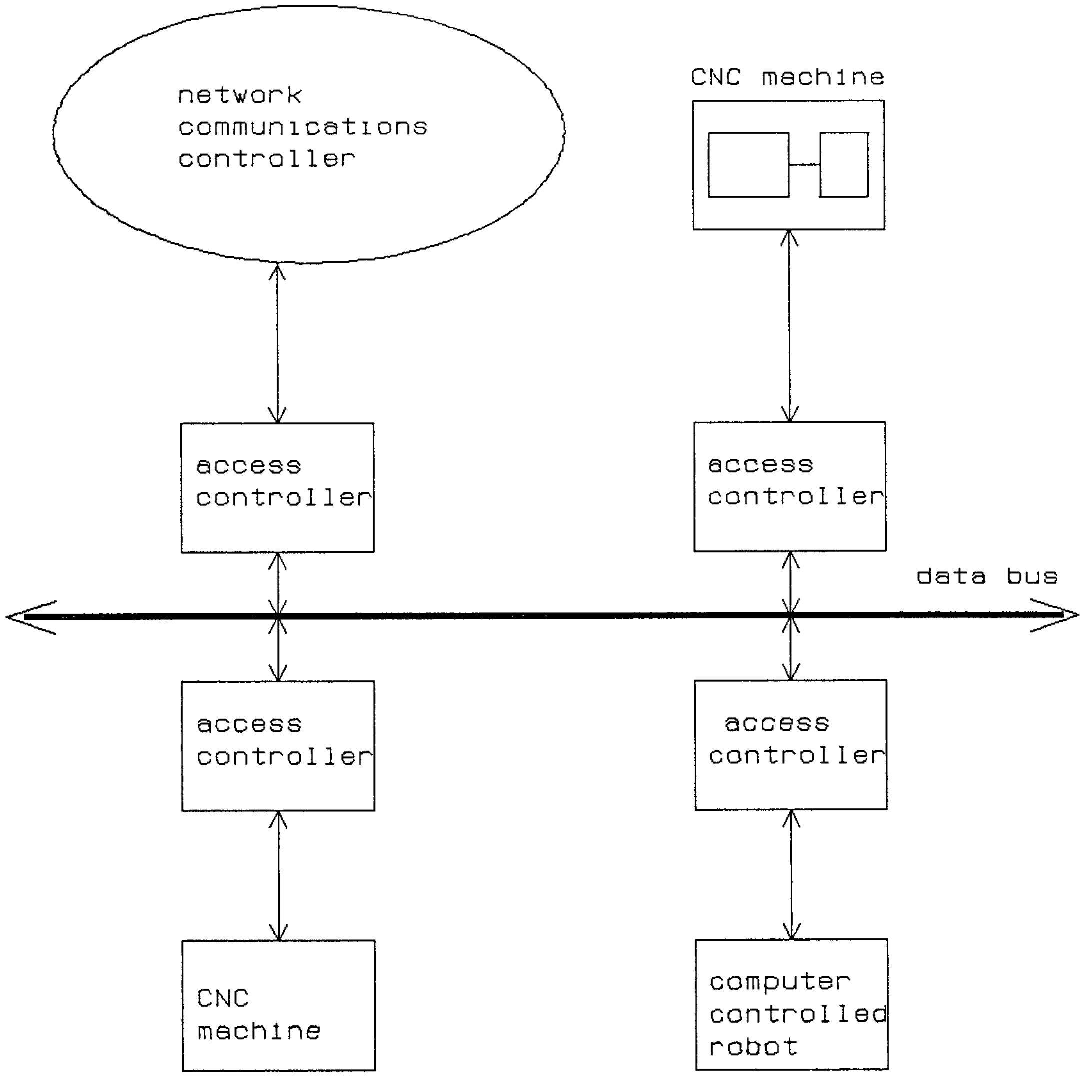


Fig. 4.4 BUS TYPE LAN

(3) Bus system can be easily modified for expansion.

Disadvantages

(1) Data and physical security are dependent upon the security of each work station.

4.1.4 Interfacing Protocol

Interfacing is of multilayer nature, subject to standards at each layer. Because of many different organizations involved and their special interests, multiple standards exists at each layer. These standards in communications terminology are referred to as protocol - a formal set of rules governing message exchange between computer devices. The fact that communications interface exists in a computer or CNC does not necessarily mean that data transfer can exists, and therein lies a potential problem.

Three layers of protocol are of particular importance to NC oriented shops. Layer 1 has had greatest amount of attention by standards group which defines the physical requirements of an interface the electrical parameters such as: voltage levels, size of wire, numbers of wires, shielding, connector type, and so on. The most common standard is EIA (Electronic Industries Association) RS-232. Because of transmission distance limitations of RS-232, RS-422 and RS-423 are increasing in favor as a plant wide standard for serial interfaces. Layer 2 covers those protocol which defines how data is to be formatted, what characters should be used for control of data transmission and what checking procedure should be used. The 7th layer has drawn considerable interest in the NC community because it deals with the applications. This layer defines what data can be transferred: part program, tool data, probe status and so on.

4.1.5 Interfacing NC to Host Computer

EIA standard such as RS-232, RS-422 and RS-423 that cover many of the basic physical requirements of DNC interface, but there is no general standard that covers the functional data that must flow in and out of the control. The EIA has addressed this to some extent with standards RS-484 and RS-511. The services provided by RS-511 within the application layer of MAP 3.0 are generic in that they specify how messages are assembled and sent but do not provide application specific information (Refer fig. 4.5)[4]. That information is intended to be provided by companion standards, envisioned for each specific class of application. However tape from one manufacturer's control cannot be successfully transferred to another manufacturer's control without purchasing a special software emulation feature, even though control builder had adhered to EIA-274D (which defines interchangeable perforated tape format standard). This is due to the different feature content on the controls and different control design philosophy required for programming identical features. So, it stands to reason that an RS-232 interface from two control builders will not necessarily interface to a host computer exactly the same way. In fact, unless detailed planning and preparation are done, it is almost certain that both interfaces will not be software compatible with the same host computer. The user may also find that his purchase has very limited capability with the interface in the control. For example it may not provide the capability to get data out of the control such as machine control status, probe data, operator initiated data to the host, and so on. It also may not handle downloading of any information to the control except the part program data itself. As an alternate, the control builder should be notified complete interface specifications by the user. If specifications does not match up with the capability of the control builder's standard interface, then a custom interface may be considered. The interfaces are almost always expensive to develop. If no specific techniques are used internal to the

Layers	*Function*	*MAP Specification*
User program	Application programs (not part of DSI model)	HMFS/EIA 1893A
Layer 7 Application	Provides all services directly comprehansible to application programs	ISO Case kernel
Layer 6 Presentation	Transfers data to/from negotiated standardised formats	Null at this time
Layer 5 Session	synchronise and manage data	ISO session kernel
Layer 4 Transport	Provides transparent reliable data transfer from and to and node	ISO transport class 4
Layer 3 Network	Performs message routing for data transfer between non-adjacent nodes	ISO CLNS
Layer 2 Data link	Error detection for messages moved between adjacent nodes	IEEE 802-2 Link level control class 1
Layer 1 Physical	Encodes and physically transfers messages between adjadent nodes	IEEE 802.4 Token access on broadband or carrierband modulation on coaaxial media

Physical link

Fig. 4.5 THE GENERAL MOTORS MAP SPECIFICATIONS control of CNC that would keep generic communications software from working, then one can establish networking (for RS-232-C) using following method[35, 14, 15].

One need to buy communications software package available in most software stores. This software should be capable to manipulate RS-232-C related variables like baud rate, stop bits, hand shaking, parity, word length and computer communication ports. Then set the communication software for the PC compatible computer to the proper setting. The communication software must be tailored for the type of handshaking CNC needs. This information can be obtained from CNC machine manual. Now set the RS-232-C related parameters of CNC control to the same values as that of computer. CNC machine's RS-232-C communications port should be connected to PC serial port by a cable. One can use the wordprocessor on the computer to view/edit CNC programs right at the computer. One can also type new program on computer and then transmit it. However program to be sent to the machine must be sent in ASCII format.

There are three degree of interfaces rapidly evolving toward MAP standards or subset of MAP: BTR (behind the tape reader) interfaces, DNC interfaces and FMS interfaces.

BTR interface normally handles downloading of part program only. The control will function in the same way as connected to a tape reader. In fact, control is not normally aware that the data source has changed. The advantage of BTR interface is its minimal cost since there are no software changes required in the control. It's greatest disadvantage is that it provides no capability for sending to the host such information as machine/control status, operating keyboard entries or fault messages.

DNC interface employes higher level of capability than BTR interface. With DNC interface, two way communication is expected, with upload and download capability. In the upload mode, an operator can communicate to the host using the control CRT and keyboard. The type of information that an operator would normally send up to the host would be job related such as a request for a part program, a request for new tool, waiting on parts and so on.

An FMS interface is the highest level of communications interface requiring significant hardware and software interrelationship between the control and host computer. High level communications is required in order for machines to function under unmanned or lightly manned conditions. In order for an FMS machine to operate in either of these conditions, the interface will be required to:

* Download part program data; tool data; and informative messages to setup personnel or roving operators.
* Upload broken tool information, probe values for decision making in the host, expired tool life, machine status, control status.
* Communicate cycle start and stop signals at the appropriate time in the machining cycles.

To achieve such a level of data flowing in and out of a control system a significant amount of additional developmental work is required for most controls. It is not practical to implement all levels of an FMS system in a short time period because of its impact on the shop. Interface specification should be planned in such a way that beginning level of utilization can be achieved in a reasonably short time and can be expanded to additional level as per user requirements.

4.1.6 Manufacturing Automation Protocol (MAP)

MAP is a LAN based on open standards. It is rapidly becoming the communication network standard for shopfloor. It was initiated by General Motors (Refer fig. 4.5) and is now endorsed by broad base of users worldwide as well as computer product vendors. MAP is having a major impact on industry as a force for accelerating the implementation of all forms of CIM including DNC and FMS. MAP is developed on the base of ISO/OSI seven layer reference model. The ISO model however only specifies function. Compliance to the model does not assure multivendor communications capability, while MAP has universal support of a selected protocol specifications at each of the seven layers.

Independently, Boeing Aircraft had taken a similar initiative to establish a universal standard specification for technical and office protocol (TOP). Since manufacturing computer networks must eventually be linked with front office networks in order to implement CIM, MAP and TOP, proponents are now working through a MAP/TOP users group toward a universal specification.

4.1.7 MAP Interface

Most computer products including CNCs, computers and other programmable devices designed since the emergence of the MAP interface are making provisions for providing a MAP interface directly into the backplane. For earlier designed computer equipment, the interfacing may be accomplished through Network Interface Unit (NIU). Where a network interface unit is used to interface in to a MAP network, NIUs provide a serial interface for making the connection to the control[26]. Most control devices, such as CNCs and programmable controllers, currently support this type of interface but with various capabilities. The network side of the NIU provide a connection into the MAP network. The major drawback of using the NIUs is cost and limited capability that has been designed into most serial interfaces.

4.2 CNC Postprocessor

Another very important consideration while CNC machine purchase is its postprocessor. Most part programming computer languages have separate sections to perform different activities. First section known as general processor handles the cutter path calculations which defines the intersections of cutter center line with the cutter end. It determines cutter path regardless of peculiarities of specific machining equipment. It ascertains the shape of the part as defined in the manuscript and then calculates the cutter path coordinates. However, the non cutter path parameters (auxiliary function statements such as feeds and speeds, tool change etc.) are not handled computationally or logically by the general processor. Second section, known as the post processor adapts the cutter path data to the special conditions and demands of each machine and control combination. The post processor produces the correctly formatted cutter location data coordinates with the proper feedrates and auxiliary commands which meet the specific equipment requirements. Thus for identical part manufacturing, the part programmer uses general processor only once, but will use several post processors, each in line with peculiarities of individual machine control (Refer figure 4.6).

The processor is a computer software written in more specialized language such as APT, COMPACT, SPLIT, and so on, which provides the basic tools to the programmer for efficient computer assisted part programming. Processors are available to the end user from computer manufacturers, control and machine tool builders and independent software firms. A processor language is usually based on a particular compiler language and use of that processor requires the computer to be preloaded with a compiler of the same language. Thus a part program written in FORTRAN based APT is produced on a computer preloaded with the FORTRAN compiler. The use of a powerful NC processor is essential to achieve the higher efficiency in computer assisted part programming.

An NC processor has four major tasks: (1) to decode manuscript information and to check syntax for errors (2) to calculate all coordinate data (3) to generate CL and (4) to do the required post processing. The CL data defines in rectangular coordinates where the centerline of cutter with given size and configuration will have to be located in order to machine the part to the desired geometry and dimensions. This will define the path which the cutter will follow. A postprocessor take into account the features of the particular machine tool/control unit combination and converts processor output into the proper codes and format required by the MCU. Computer processing of the part manuscript information generally occurs in two stages. First the processor does its work and output the CL data, usually directly to the postprocessor. The latter completes development of the part program and output it in a physical form acceptable to machine tool's control unit. Any manuscript information not acted upon by the processor is passed on through the postprocessor. In some cases, the postprocessor immediately acts on the as it is generated, without waiting for the CL file to be completely executed. However it is generally possible for the computer operator or programmer to call for the processor to first complete its work, providing an output of the CL file in a form that would permit checking of geometry or even providing the cutter path on the plotter, for example before proceeding with the postprocessing. The processor provides a general solution to a machining problem; the postprocessor adapts this solution to a particular machine tool/control unit combination and complements it with additional data that may be required. The main elements of post processor are defined to be INPUT, MOTION, AUXILIARY, CONTROL and OUTPUT.

Input reads the calculated cutter path data and the machine management codes. Then it performs a series of inspections to determine their acceptability. If the general processor output is in acceptable manner, the input element transfers the incoming data to the proper elements of the post processors.

The motion element performs coordinate transformation and linearization when necessary in the case of 4 and 5 axis machine tools. Linearization is the computation by the post processors of the resulting geometric path within the programmed tolerance which will occur when a combination of linear and rotary motion takes place. It also computes the increment of allowable motion and permissible feedrate as determined by the dynamic response of the machine tool. It identifies any commands that exceeded the machine's physical limits and checks to see that the cutting tool path will not collide with a machine component. It also establishes permissible cornering velocities so that the resulting part will be machined without undercut or overcut and within the tolerance specified.

The auxiliary element contains logical procedures for properly coordinating and coding the programmer's miscellaneous (m codes) and preparatory statements (g codes) with correct associated functions. When such functions are called out for the part program, the auxiliary element searches the computer memory to find the appropriate control tape codes for the function specified. Properly coded commands are transferred to the postprocessor's output element. It also interprets and evaluates other manuscript statements such as machine tolerances, feedrates, spindle speeds and directions and tool or turret selection information, all of which establishes modal conditions within the post processors.

The output element converts the information from the motion element into the proper motion data and coded feedrates, which are then output in acceptable order and format. It also accepts miscellaneous preparatory function data and other nonmotion information produced by the auxiliary element and merges this information into the postprocessor's output in a properly coded form at the appropriate time.

The control element orchestrates the flow of information between all post processor elements. It controls the timing of the information transfer and insures that diagnostic comments appear in the proper sequence.

4.2.1 Evaluating Processor Languages

One of the most significant decisions an NC equipment user will ever be called upon to make is selection of processor language. There are three broad areas the user must investigate to arrive at the best NC processor language for his/her particular needs. The first and more obvious is the geometric capability of the language. It should have the ability to generate machine motion instructions for the type of parts that are now being machined or likely to be machined in the near future. Next consideration is of specific machine control. The language should be capable to easily handle required machine motion on a particular machine tool. The language should be capable to generate the shapes on the machine tool involved in the user's present and foreseeable future operations.

Secondly, there is the area of how the language is made available. Is it limited to time sharing? Is it only available for use on an in-house computer? Does the user buy the language or only rights to its use? What back up and support are available? How are language updates and improvements distributed to the user? What rights does the user have, if any to source documentation and to make changes? The user should have a very clear understanding of how and under what circumstances he/she obtain the outright possession or use of the language.

The third area is that of programming trials or tests. The user should select approximately eight parts representing the type of work now he/she is doing and that he/she will be doing in future. These parts should then be planned and programmed for the existing NC machine tools and any on order. The trial should proceed right through to the part program that will direct the machining of the part. In this manner, both the candidate processor and post processor will be fully tested in the user's environment. It would even be wise to include few programming errors in the test to check out the processor language's capability at error detection and diagnosis. The considerations for the processor language, itself, are equally applicable to the all-important processors which must not be over looked or taken for granted.

Each machine tool has its own individual characteristics. The variables are almost endless. The same is true for MCU that runs the machine. The postprocessor stores such information and uses it accordingly in tailoring or customizing the part program. For instance, an MCU may have a circular interpolation. Where this feature is applicable in a part program, the post processor will normally call for its use, inhabiting the corresponding detailed data in the CL file except for a simple definition of arc or circle by start point, end point and radius. Also any unprocessed

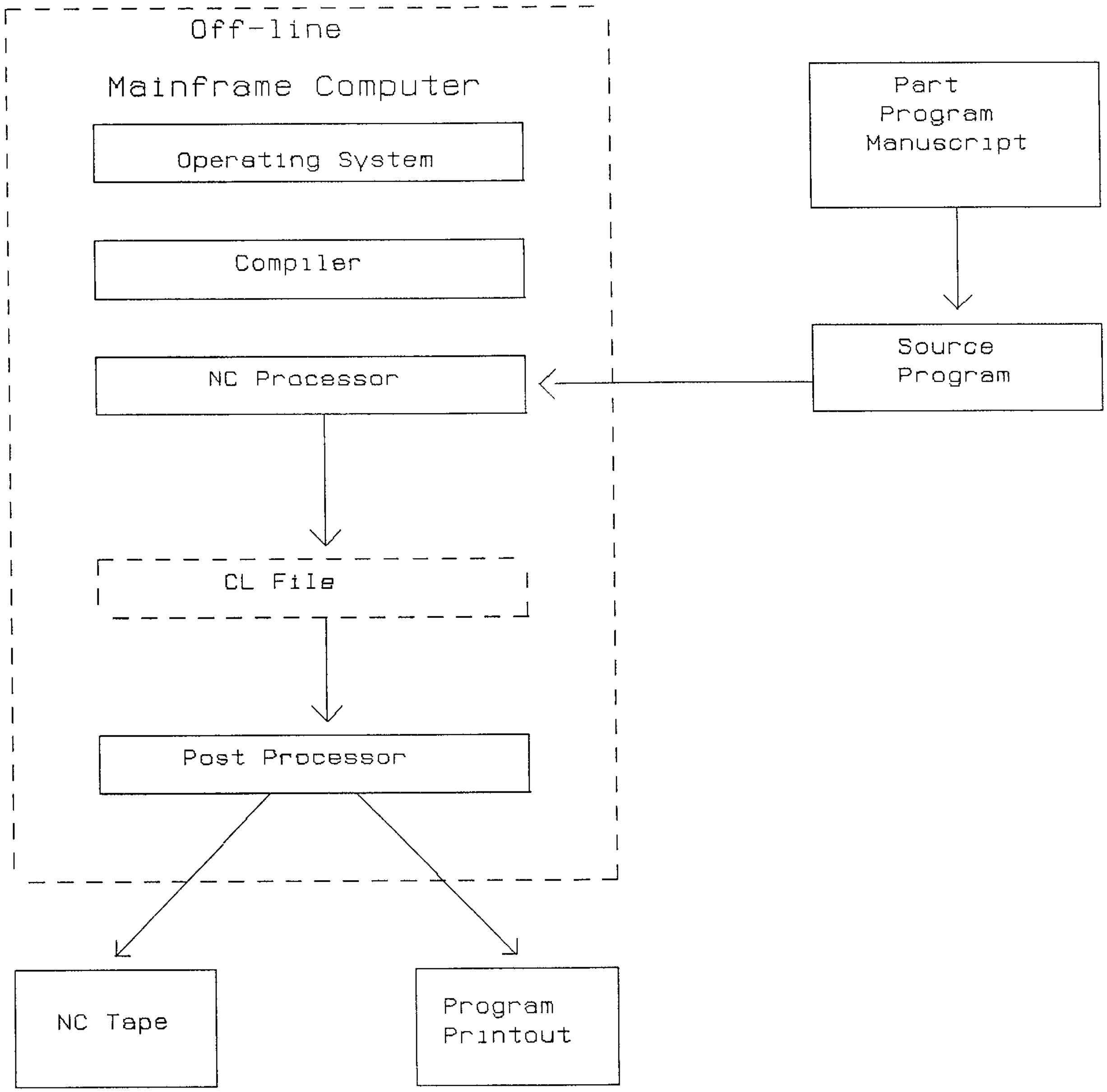


Fig. 4.6 Various levels of software involved in computer assisted NC part programming

part program information, such as tool data, passed through with the CL data will be acted upon by the processor and incorporated into its output. If the processor is tailored to run on IBM 360/370 mainframe computer, post processor must be also.

The machine tool builder may offer the postprocessor as a standard option only in a certain processor language, most commonly APT, and only for certain mainframe computers, most commonly on IBM 360 or 370. The postprocessor may be available in another language or for another computer but at a special price. Some so-called universal or general purpose postprocessors are available to cover a family of machine/control configurations. The user should always make certain that machine or control features for which he paid extra won't be wasted by not being taken into account by the postprocessor. In some cases, once a user has a builder's basic postprocessor for a machine tool family, he need not buy an add-on module for each new machine/control version.

4.3 Binary Cutter Location(BCL) Input Controls

Another concept - that of BCL input controls - is aimed at the problems of postprocessor proliferation and the related lack of exchangeability or portability of NC part programs. Such controls are similar to other CNCs, their unique characteristic being the added capability of accepting CL file output of the mainframe computer's processor, suitably formatted. A BCL convertor is added to the mainframe computer's software to structure the CL file output properly.

A shop's machine and/or controls may be similar, yet different, due to being purchase from different builders at different times, or merely with different feature content to suit a specific prime mission at time of installation. Thus the more NC machines a shop has, the greater is the number of processors and greater the magnitude of associated problems. There is substantial cost and confusion involved with maintaining a large library of postprocessors needed by the computer used in the programming of parts, and with the lack of exchangeability of part programs between machines. The fact that each program and therefore part to be produced, is dedicated to just one or possibly few identical machines and control puts restrictions on production scheduling.

Flexibility exists but is adversely affected by the cost and time delay constraints imposed by postprocessing. In the event of machine downtime or impending imbalance in machine loading, the scheduler may be able to transfer the job to another machine. But he can do so only if the part program is rerun through the computer that is loaded with the processor appropriate for the new machine/control combination, and the program again debugged and verified. There will be further problems in maintaining multiple versions of the same program.

If a machine is ever retrofitted with later version machine or control feature, or is replaced by a new machine, existing programs must be updated. Where the user manufactures multi-sourced machine parts, part programs are not fully portable from site to site. This lack of part program exchangeability and portability is a major obstacle to achieving the full benefits of CIM. It slows response time and is a deterrent to implementing effective JIT policies.

The BCL concept of moving the postprocessor function from the mainframe and into the machine control unit addresses all such problems and is now approaching the maturity needed to justify universal attention. With a growing recognition of its potential role in fully computer integrated manufacturing, BCL has won increasing interest in recent years. The key to any broad acceptance and application of the concept was the development and adoption of universal input format standard. Industry consensus was finally achieved with adoption of standard EIA-494 32 bit binary CL Exchange input format for numerically controlled machines. Existing installation consists almost entirely of profile milling machines and machining centers. Even in these areas, not all machines or control builders offer the BCL capability. EIA-494 at present covers basic NC functions. Enhancements are needed to facilitate use of touch probe, adaptive control, tool management and possibly other features that presently are not accessed by BCL part programming. Enhancement of the standard are needed to expand its application to other classes of machine tools.

Since postprocessing is done in real time as the part program is run, considerable demand is made on the CNC's memory and logic sections. This might exclude some existing controls. However there are standard CNCs that need only be modified with disk reader or for input via electronic data line and loaded with new executive software including the postprocessor. Some users favour having the dual capability of running established part programs from punched tape or new programs from BCL formatted floppy disks.

For shops that must stretch out the changeover to BCL, processor unit are now available that can be linked behind the tape reader to a conventional CNC. Such a processor accepts BCL input on floppy disk and converts it into a conventional NC program format.

4.4 CASE STUDY

A company is using CNC machines on shopfloor and PCs in marketing department. It is planning for expansion with introduction of computers in engineering department and introduction of some more CNC machines on shopfloor. A case study is carried out about possible technical considerations for purchase of new CNC machines and computers in order to network CNC machines and computers in the engineering department and in the marketing department. Specifications of existing hardwares in the plant are as follows.

PCs in marketing department

Type: IBM PS/2

Model 70-A21

CPU 25 MHz 80386

Transfer rate: 10 Mbites/sec.

Operating System: DOS OS/2

Hard disk size 120 MB

RAM 4 MB

CNC Machine

Type: Anilam Crusader

Baud Rate: 300

Parity: Even

Data Bits: Seven

Stop Bits: One

Strip Line Feed: No

Code Format: Ascii

Cable: 9 pin and 25 pin computer control

Required data transfer speed in network is 1 Mbites/sec.
Maximum distance between engineering department and shopfloor CNCs: 15 meters
Maximum distance between engineering department and marketing department: 50 meters
Network should be capable to: File transfer, Virtual terminal connection, Remote data file access.

Computer Hardware Selection

The very first decision required is to buy what kind of workstations or PCs for engineering department.

In terms of processing power, the 80386 based machines qualify as low end workstations. The key element in this growth is constantly improving speed and the capability of new processors available for PCs, in particular Intel 80386 and Motorola 68020 and 68030. The newly developed PCs like Compaq Deskpro 386/25, Macintosh IIx, IBM PS/2 model 70-A21 and so on are truly powerful system having fast hard disks, several megabytes of fast memory, powerful floating point processor, high resolution and high speed video, and a multitasking operating system; all standard features available in the workstation. Table 4.1 compares the important functional elements of most widely used three PCs and two low end workstations.

The plant is already using DOS OS/2 operating system, so it is preferred to buy new computers supporting same operating system. If computers with another operating system are bought, then interfacing software should be developed. Studying table 4.1, Compaq deskpro 386/25 and IBM PS/2 supports DOS OS/2. So one of these should be selected for engineering department.

COMPARISION OF TECHNICAL WORKSTATIONs AND PCs

FEATURES	Apple & PCs Macintosh IIx	Compaq Deskpro 386/25	IBM PS/2 Model 70-A21	Sun 386i Model 250	Apollo DN4500
CPU	16 MHz 68030	25 MHz 80386	25 MHz 80386	25 MHz 80386	33 MHz 68030
MIPS	2.5	5	5	5	7
FPU	16 MHz 68882	25 MHz 80387	25 MHz 80387	25 MHz 80387	33 MHz 68882
Video Resolution	640 X 480	640 X 480	640 X 480	1153 X 900	1024 X 800
Number of Colors	16/64	16/64	16/64	256/16.7 M	256/16.7 M
Screen Size	12 inches	13 inches	14 inches	16 inches	19 inches
Disk System	SCSI	AT/IDE	ESDI	SCSI	ESDI
Transfer Rate	8 Mbites/sec	10 Mbites/sec	10 Mbites/sec	14 Mbites/sec	28 Mbites/sec
OS	Multifinder A/UX	DOS OS/2, UNIX	DOS OS/2, UNIX	SUN OS:UNIX 8086 DOS apps	Domain/OS: Unix Apollo AEGIS
Hard Disk Size	80 MB	110 MB	120 MB	91 MB	155 MB
RAM	4 MB	4 MB	4 MB	8 MB	8 MB
RAM cache	On-chip 256 byte	Intel 82385 32 KB	Intel 82385 64 KB	Intel 82385 62 KB	64 KB
Available Slots	6	2:8 bit 4:16 bit	1:16 bit 2:32 bit	1:8 bit XT 3:16 bit AT	1.8 bit XT 6.16 bit AT
Network	10 Mbites/sec Ethernet	10 Mbites/sec Ethernet	10 Mbites/sec Ethernet	10 Mbites/sec Ethernet	12 Mbites/sec Token Ring
List Price Dollars	11,000	16,000	16,000	21,000	28,000

TABLE 4.1

Network Selection

Next decision to be made is about what type of network to be introduced.

Basically there are two types of networking: Long haul and Local. Longhaul is preferred when multi vendor networking is required with very high speed of data transfer (above 10 Mbites/sec) between computer at very long distance (located miles apart). LAN is preferred for multidevice, multidepartmental communication requiring data transfer speed upto 10 Mbites/sec. Looking at the present status of above plant and physical distance between its various departments LAN is preferred.

After deciding for LAN, next step is to decide network topology. It is not desirable to use star type LAN, as efficiency of network is dependent on central processor, which if breaks down can stop the activities in all the departments in the plant. Bus type LAN is good upto 1.5 mile cable length. Also at high loads, the presence of collision becomes a major problem and can seriously affect the throughput. Its protocols are extremely complex and is preferred when it is required to transmit not only the data but also the voice and graphics. Ring type LAN uses point to point connections, means that engineering is easy and fully digital. Also it is cheaper than Bus type LAN. As ring type LAN satisfies communication requirements of above plant, the plant should
use ring type LAN.

Selection of CNC Machine

There are number of companies offering CNC machines, each having its own hardware specifications. It is very important to study its hardware specifications along with machining features, if company is planning for networking. The 7th layer of ISO model defines what data can be transferred between machines. It is possible that tape format from one manufacturer's control can not be successfully transferred to another manufacturer's control directly, even both control builder had adhered to EIA-274D. This is due to different feature content on the controls and different control design philosophy used for programming identical feature. Thus detail planning and preparation is required, to ascertain that all CNC machines can interface with the same host computer.

In order to study various CNC machine's built in communications capabilities and limitations, hardware features of various CNC machines available in the market is carried out. Some important specifications are summarized in table 4.2.

As plant is already having Anilam Crusader CNC machine, the most economical consideration for buying next CNC machine is to buy one with similar PST file specifications. Studying table 4.2 GE 1050, BOSS SERIES (4&6), DYNAPATH SYSTEM 10 and 20, FANUC OT postprocessors are of similar specifications except baud rate. So management should consider machines supporting above mentioned postprocessors. By comparing machining features suppose management decides to buy machine supporting FANUC OT postporcessor. But baud rate of ANILAM is 300 and of FANUC OT is 1200. So buffer should be provided in line communicating from FANUC OT to ANILAM.

PST SPECIFICATIONS FOR VARIOUS PROCESSORS

PROCESSOR	BAUD RATE	PARITY	DATA BITS	STOP BITS	STRIP LINE FEEDS	CODE FORMAT	COMPUTER CONTROL CONNECTION	
							9 PIN	25 PIN
ANILAM CRUSADER	300	EVEN	SEVEN	ONE	NO	Ascii	3,2,5 2,3,7	2,3,7 2,3,7
BOSS SERIES (4,5,6)	110	EVEN	SEVEN	ONE	NO	Ascii	NEEDS BENDIT END CONNECTOR	
DECKEL DIALOG III, IV	2400	EVEN	SEVEN	TWO	NO	Ascii	3,2,5 3,2,7	2,3,7 3,2,7
DYNA MECHTRONICS 2200, 2400, 3000, 4000	2400	NONE	EIGHT	ONE	NO	Ascii	DO NOT SUPPORT	2,3,5,4,7 3,2,4,5,7
DYNAPATH SYSTEM 10, 20	1200 OR 4800	EVEN	SEVEN	ONE	NO	Ascii	DO NOT SUPPORT	1,2,3,7 1,2,3,7
FACIT 4046, 4047	4800	EVEN	SEVEN	ONE	NO	Ascii & EIA	DO NOT SUPPORT	1,2,3,7 1,3,2,7
FANUC 10M	1200	EVEN	SEVEN	TWO	NO	Ascii	3,2,5 3,2,7	2,3,7 3,2,7
FANUC 11M, 10TF	1200	EVEN	SEVEN	TWO	NO	Ascii	3,2,5 3,2,7	2,3,7 3,2,7
FANUC 0T	4800	EVEN	SEVEN	ONE	NO	Ascii	3,2,5 3,2,7	2,3,7 3,2,7
GE 1050T	2400	EVEN	SEVEN	ONE	NO	Ascii	3,2,5 3,2,7	2,3,7 3,2,7
OKUMA OSP500G	4800	EVEN	SEVEN	TWO	NO	Ascii	3,2,5 3,2,7	2,3,7 3,2,7
SERVO MICROMILL	9600	EVEN	SEVEN	TWO	NO	Ascii	DATA NOT AVAILABLE	

TABLE 4.2

LAN Wiring

Both thick and thin wire coaxial cables are capable to transmit signals at 10 Mbites/sec. Fiber optics can transmit at a maximum rate of 100 Mbites/sec. These all cables satisfies plants data transfer speed requirements. So price should be deciding factor.

Network Interface

The interface between computer or terminal and the modem, must specify in detail mechanical, electrical, functional and procedural interface.

EIA RS-232C specifications are: 25 pin connector, 4704 +/- 0.13mm wide with top row having 13 pins and bottom row having 12 pins. Data rates upto 20 kbites/sec are permitted. Cable length upto 15 meters is permitted.

It commonly occurs that two computers must be connected using RS-232C. Since nither one is a modem, there is an interface problem. This problem can be solved by connecting them with a device called a null modem, which connects the transmit line of one machine to the receive line of the other.

EIA-RS-422A uses balanced transmission in which each of the main circuit requires two wires, with no common ground. RS-422A can be used at speed upto 2 Mbites/sec. over 60 meters cable length. It can transmit even at higher speed at shorter distance. It needs 9 pin connector and 37 pin connector.

The distance between engineering department and marketing department is 50 meters. RS-422A supports this distance and data transmission speed requirement of the plant. While RS-232C satisfies CNC interface requirements both by baud rate and pin connection. Thus RS-422A should be used for interface between engineering department and marketing department and RS-232C should be used for CNC interface.

Above results are schematically shown in fig 4.7.

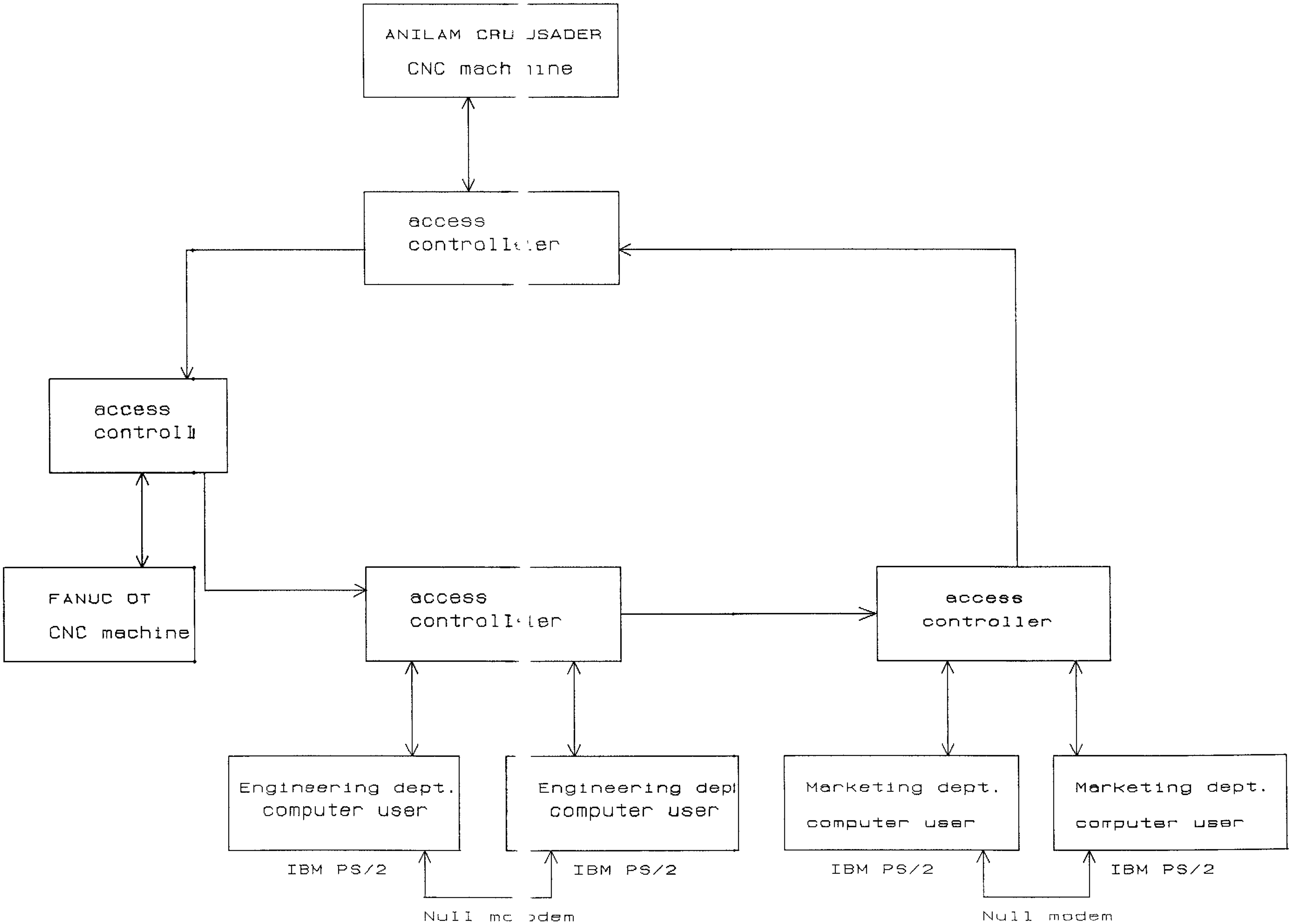

ANILAM CRUSADER
CNC machine
access
controller
access
controll
FANUC OT
CNC machine
access
controller
access
controller
Engineering dept.
computer user
IBM PS/2
Engineering dept
computer user
IBM PS/2
Null modem
Marketing dept.
computer user
IBM PS/2
Marketing dept.
computer user
IBM PS/2
Null modem

Fig. 4..7

From above case study Networking characteristics are generalized and summarized below.

CHARACTERISTIC	ENTERPRISE	PLANT	WORKCELL
Function	Integration of enterprise	Integration of work group or department	Automation
Distance	Many miles	> 1000 ft	100ft
Typical media physical connection	LAN: X2.5, CCITT, Satellite, Microwave	LAN: Ethernet, token ring, broadband	Serial lines, PLC LANs, Bitbus, MAP
Typical speed	56 Kbit/s to 1.5 Mbits/s	10 Mbit/s	<19.2 Kbits/s
Typical Protocol	DECNET SNA	DECNET/Ethernet TCP/IP, XNS	Many proprietary
What is connected	Mainframes, Departmental computer	Minicomputers Mainframes PC	plant floor, PLC, robot, CNC,
Number of nodes	Thousands	Hundreds	< 10
communication functions	File Transfer Program to program, Virtual terminal connect., Remote data file access, Network Management, Resource sharing	File Transfer, Program to program, Virtual terminal connect., Remote data file access Network Management	Read/write Start/stop device, Upload and download control Device ststus

CHAPTER 5
NC PROGRAMMING

5.1 NC Coordinate System

Nothing has been found that replaces the use of Cartesian coordinates and polar axes definitions as the basis for all NC programming. The combination of inexpensive computers and improved software has largely eliminated the need for punch tapes and extensive input that were formally needed to NC part programs.

Part programming is of paramount importance in determining how successful plant will be with numerical control. Advancing computer technology and the increasing sophistication of NC software are having major impacts on part programming function. But even though the use of computer assistance is extensive, parts are still being programmed manually. For the less common part geometries, especially where two axis positioning machines are applicable, manual programming still is used extensively as is computer assisted programming. The part programmer must determine how to process the part, what operations are required and in what sequence, and what tools to use. The unique requirement by NC is that this knowledge must be communicated in a way that is meaningful to machine control. At the heart of that knowledge is the sound understanding of coordinates.

Machine tool construction is normally based on two or three perpendicular axes of motion plus an axis of rotation. The simple drilling machine normally has a table and saddle that moves on ways perpendicular to each other. It may have a spindle head that moves on vertical ways perpendicular to the plane in which the table moves, or it may have only a quill which moves perpendicular to the table plane.

Much NC work is done with a two axis dimensioning system. The depth to which tool will travel is determined by the operator or by limit switches set when the job is placed on the machine. A part program of the required motion is stated in terms of X and Y axes positions. Any kind of advanced work is going to involve the third major NC axis, which is perpendicular to plane established by X and Y axes. Not only X and Y axes are perpendicular to each other but they are also in the same plane. Any point can be located from any other point on a workpiece by the use of three mutually perpendicular axes. Virtually all NC is based on rectangular coordinates.

The polar concepts is the basis for calculating and defining rotary and angular movements. With polar coordinates, the position of a point is defined by its distance and direction from a fixed reference point or origin having zero value. A designer may find it convenient to use polar coordinates to show angular relationship of two or more holes. The polar coordinates must be keyed to the basic rectangular coordinates. For instance the center of a bolt circle should be located by X and Y coordinate dimension from the workpiece zero point, and the polar axis of the circle should be parallel with the X axis of the workpiece. It is not necessary to have full circle of holes. The angular relationship of just two holes establishes part of a circle, when one hole is assumed to be the center of the circle. The principle is employed most frequently in NC programming in calculations related to contouring and particularly manually programming a complex offset cutter centerline path.

5.2 Off Line Programming

In the most instances, as the number of NC machines increases and the mix of parts expands, the course of action will be in the direction of centralized off-line programming. This can be manual or computer assisted.

Manual off-line part programming has its greatest usage on relatively simple parts such as flat work to be drilled or punched-essentially two axis positioning applications. It is also used to some extent on two axis contouring of simple parts and on some three axis machining center applications. Manual programming is an easy, low investment way to get started if the shop has a relatively simple type of NC machine tool and relatively simple parts to be machined, a relatively stable product design, and relatively large lot sizes and/or long cycle times and/or high frequency of repeat runs.

Computer assisted part programming software addresses four major tasks: Part description, machining strategy, postprocessing and factory communication[25]. Computer assisted part programming utilizes a higher level programming language which eases handling of complex configuration or high work content, and for programming a high volume parts. It relieves the programmer of most tedious detailed calculations, saves time, cuts down error, and reduces the need for the programmer to be intimately familiar with each machine and MCU. It greatly increases programmer productivity and tape reliability provided the rigid discipline of working in a computer oriented system is followed.

5.3 Special Programming Needs

Before a programmer starts task, he/she needs to be familiar with the part to be produced. It is quite likely that he/she will have nothing more than the engineering drawings and specifications in front of him. First task is to visualize the necessary machining sequences required to produce the part. His/her visual concepts must then be put into a written manuscript from which a part program can be developed. It is the part program that will be captured in tape, diskette, or other medium. Once satisfied by machine and workpiece relationship, one need then to list each machining instruction on a program manuscript. Programmer decides operations and it's sequence.

It is important that part programmer exercise extreme care to list instructions in a format that can be utilized by a particular control unit / machine tool combination on which complete program is to be run. Working within the necessary frame of reference, the programmer should list on a program manuscript indicating all the appropriate machine operations and functions. Any function that is not part of the machine operator's set of part programmed instructions, should be given explicate explanation. It is assumed that machine operator will not make any change without being so directed. The control of every phase of machining rest with the part programmer. Upon being satisfied that part program is correct and complete, the programmer will release manuscript to the operator, who will convert the part program into machine readable form on punched tape or other appropriate medium.

Present day most of the MCU are equipped with 'floating zero' or 'zero shift' which enables the programmer to establish fixed zero to the particular part in the most convenient location. This provides more freedom. On engineering drawings, it may be more logical to state some relationships in absolute dimensions and other in incremental. If the zero is fixed on the machine and the workpiece reference point does not match the machine zero, allowances will have to be made by the programmer.

Some of today's MCUs that work either in absolute or incremental mode provides dual readout capability. The command position is always displayed as input, but the actual slide positions are displayed in absolute terms, no matter whether the input is absolute or incremental. And in some cases, the control adds up all incremental plus and minus moves which must balance upon previous program point or at the end of program to ensure that no data were lost. These two features helps ensure program integrity.

If incremental and absolute are used in their optimum, it gives full freedom to the design and drafting departments to function in an unrestricted and creative manner. The programmer can then pick up their established database. When programming a contour, an appropriate feedrate must be incorporated into the program. The feedrate is determined by the type of the tool, the material being cut, and even mechanical dynamics of the machine tool. For example, cut in aluminium with a good wear resistant tool might be made with a very high speeds provided the machine tool can deliver the required feed rates, spindle speeds, and horse power.

The programmer must take into account tool length and diameter, since the basic reference point of the machine tool is almost never the cutting edge of the tool. For example, the basic reference of the common drilling machine is usually the centerline of the spindle and the end of the spindle nose. All cutting tools extend beyond that point, and the nominal distance for each type of tool must be known. Serious collision will occur if the programmer fails to take this tool extension into account. Most control units now have a tool length storage feature that permits the part programmer to program as if all tools were of the same length.

The machine tool that uses the milling cutter for sculpturing or contouring presents additional problems. It is not the center of cutter, but some point at the periphery that actually does the machining. Different portions of the cutter may do the machining, depending on the orientation of the cutter to the workpiece surface. If a one inch end mill is utilized to profile an outline, the programmer will have to maintain a half inch diameter offset normal to the surface. The half inch offset represents the distance between the spindle centerline, which is the basic machine reference, and the edge of the cutter that actually generates the chips. However, the type of situation in figure 5.1[27] presents a higher level of complexity and, if the same example was a three axis contouring job, the complexity can get quite sever. It will be noted that offset for cutting tool geometry must always be made perpendicular to the surface being machined, regardless of the direction that surface faces. To determine offsets not parallel to a machine axis will at least involve trigonometric calculations. Some later generation MCU feature part surface programming, which internally calculates the cutter centerline offsets.

When the programmer, with or without computer assistance calculates the tool centerline path, he has one cutter diameter in mind. But the cutter available for the given run of the program may have been resharpened to the different diameter. Most contouring MCU have operator entry capabilities to compensate for the variable diameters of the cutting tools. Such cutter diameter compensation (CDC) features are great for two axis plane, but may not be entirely adequate on the sculpturing cut requiring more than two axes. Figure 5.1 can serve to illustrate operater's attempt to manually offset in one axis, but the problem is more complex.

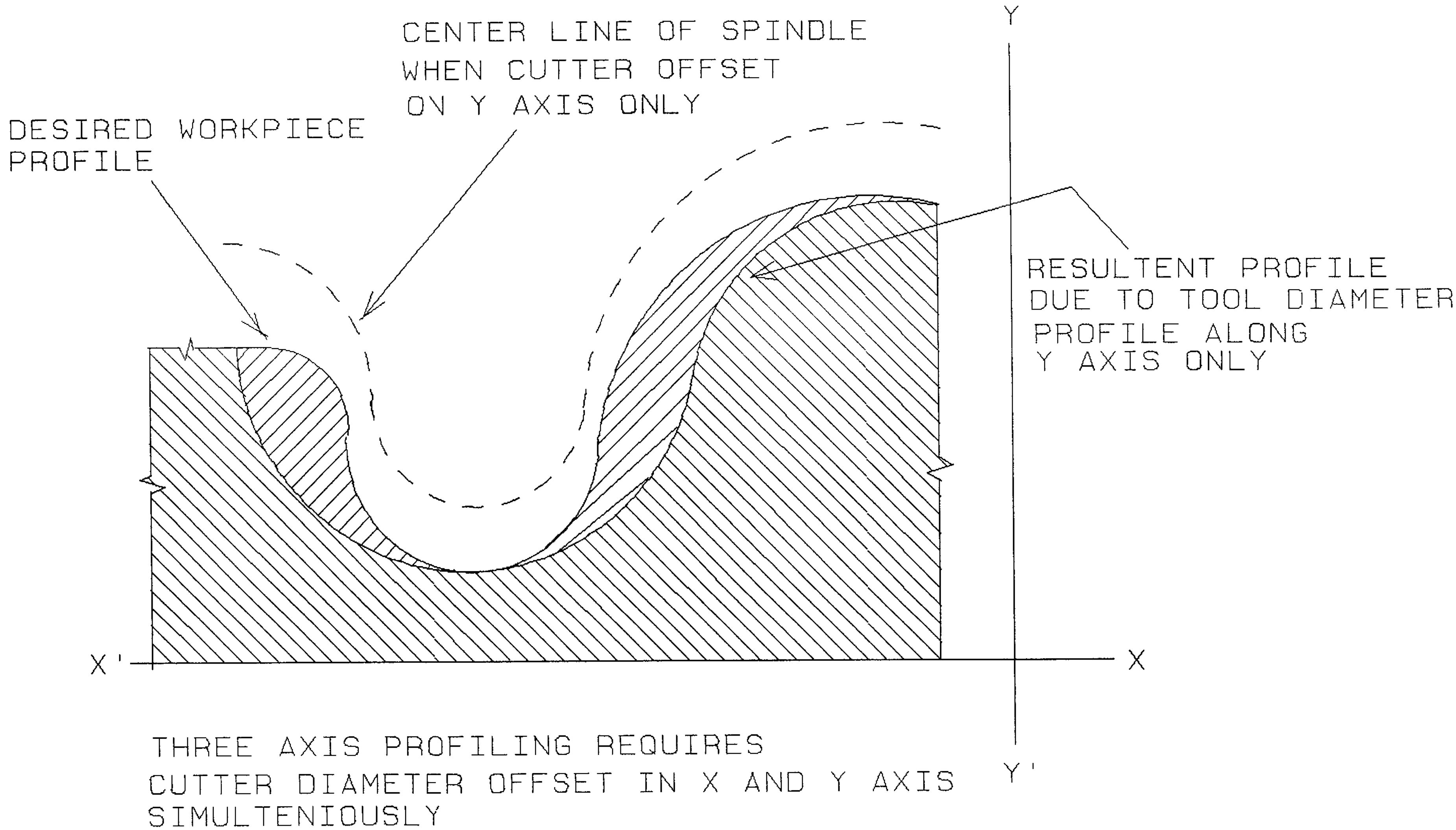

CENTER LINE OF SPINDLE
WHEN CUTTER OFFSET
ON Y AXIS ONLY
DESIRED WORKPIECE
PROFILE
Y
RESULTENT PROFILE
DUE TO TOOL DIAMETER
PROFILE ALONG
Y AXIS ONLY
X'
X
Y'
THREE AXIS PROFILING REQUIRES
CUTTER DIAMETER OFFSET IN X AND Y AXIS
SIMULTENIOUSLY

Fig. 5.1

Where the CDC feature is applicable, a single program may be used with different diameter cutters. The operator simply enters the proper cutter compensation value. Thus there is a point where manual programming becomes totally impractical. It is not that the human mind is inadequate, but the physical effort and time required to calculate and list thousands of coordinate positions with any degree of accuracy completely rules out a manual approach.

5.4 Factors to Consider Prior to Programming a Part

1. Types of dimensioning system. The first step is toselect the best for particular job. After selecting aappropriate machine tool, determine what type of dimensioningsystem the machine uses-either an absolute or incremental system.
2. Types of tape format. The majority of NC machine toolsuse either word address or tab sequential as the tape format.The machine tool selected determines which tape format to use.
3. Axis designation. The most important factor in axis designation is the location and position of spindle. At thistime the part programmer also determines how many axis areavailable on the machine tool, that is X, Y, Z, a, b, c and soon, and whether the machine tool has a continuous path or point to point control system.
4. Miscellaneous functions available. With the wide varietyof NC equipment available, there are also a number of optionsand miscellaneous available. The parts programmer mustdetermine what options and functions are available on the selected machine tool.
5. Machine tool zero point system. A zero point is areference on the machine tool with which the mountedworkpiece must be in a correct relationship, so all machiningoperations can be completed accurately. NC machines use either a fixed or floating zero system.

5.5 Other Programming Techniques

5.5.1 Digitizing

Digitizing is a method whereby a scaled drawing may furnish the necessary coordinate data to develop a suitable NC program. Most digitizing units consists of tables that have a reticle or probe connected to an arm or arms to which are attached transducers. As the reticle or probe is placed over a position on the drawing, the transducers record the location and upon the signal, transfers it to a tape punch or other suitable processing unit. Most digitizing equipments also permits entry of auxiliary input by operator to allow establishment of reference points or to insert additional data. Many digitizing units can work with drawings 10 or 20 times larger than the actual workpiece so that any drawing error will be reduced to the same factor. In some instances, it is also possible to scale up from a smaller drawing. This is quite often done in the cutting of large structural elements.

5.5.2 Scanning

Many products are not designed to basic mathematical formulas or data, like automobile sheet metal contours. Somehow everything must be made to fit the pleasing contours. The mathematics come in after the basic styling is determined. The growing practice is to scan the model with a probe, and to feed the analog path data into a computer which automatically calculates enough discrete digital point to produce a satisfactory program that will machine the die. There are many examples far less complicated than auto body dies which do not need a complex scanning system. Many digitizing and scanning also have capability to edit or revise the basic data that is gathered, to refine it with an overriding corrective input. For instance, the design of the surface may call for an arc but model may not be near the required tolerance. It may be possible to scan and gather the rough data and then call for a computer routine to smooth the rough data to a perfect arc.

5.5.3 Graphics

Computer graphics was originally created as design tool. As the design elements are created and dimensioned, they appear on a screen. It is often possible for a designer to rotate, enlarge, zoom in on specific design features, translate, scale, and complete many other design functions in a fraction of the time that it would take with traditional drawing means.

In the process of designing, the product designer is building a workpiece database. The same database can often serve to aid the NC part programmer. If the length of the line is already stored as part of workpiece database, it is much simpler for the NC programmer to call a line and direct a cutter move along it then to recalculate it and translate that data into machine axis data command. Computer graphics is an extensive and complex subject. However the very fact of designing a part with computer has spilled over to also using the same system, with additional programming software, to develop the program that will direct the machining of that part.

5.5.4 Shop Floor Programming

With the more advanced computer based manual data input(MDI) control units, part programming is done right at the machine tool with the control unit itself aided by an integrated, limited or full graphics capability. Such units have a key board in which programming commands may be entered as primary input and processed internally. This program is stored in MCU's memory and is executed directly from memory. If it is desired to keep the program in a permanent file, some MDI units have an output unit that can produce a punched tape, enter the data on a magnetic tape cassette or transmit it to a central computer. Such information can be read back into the MCU at later date.

There are some cautions that should be noted concerning shop floor programming. The success of NC, to a large degree came about due to strict discipline enforced by having a centralized programming department. This removed from the machine operator the responsibility for selecting tools, designing the cutting process, and interpreting the part drawing. With shop floor programming, there may be major differences in a part run on two different machines programmed by two different operators - even though the two parts are programmed from the same drawing. This problem can be minimized if the CNC have the capability to output the internally generated part program to be stored for further use on the same machine or a similar machine. The specific machine operator's possibly limited knowledge of parts processing, tool selection and basic programming is still another hindrance and problem which must be resolved. There may also be limitations to the power that an shop floor programming system has for creating part programs. If shop floor programing is an optional feature on the specific control being considered, it is important to verify that the operator be able to access all machines and control features through shop floor programming. If the control does not have the foreground/background feature, loss of production time on the machine due to programing should be deciding factor.

CHAPTER 6

NC TOOL MANAGEMENT

6.1 Tool Management Program

The best NC machine tool cannot remove metal from a workpiece unless there is a cutting tool in its spindle or turret or unless there is a fixture or chuck to hold the workpiece. And a machine will not be so productive without a great deal of thought and planning going into the proper selection and proper use of the tooling. Good tooling is not only required, it is essential to reaping the full benefits of NC. Complete tooling systems are available from various suppliers. A particular system will have a several basic styles of toolholder (arbor, fixed block, collat) to accommodate a broad range of cutting tools that may be needed. Adapters may or may not be needed for specific tools. Developers of tooling are constantly striving to improve their products. In making a selection, one consideration should be the simplicity of tool holding. Theoretically, one piece tooling between workpiece and spindle should be the target in order to minimize problems of rigidity and of compression under load that might shorten the effective tool length.

Tool management involves good tooling policies, cost effective part programming, strategic use of tooling on the machine and sound tool related practice in toolroom, part programming, tool design, purchasing and possibly other off-line operations. The tool management program, offcourse should embrace fixturing as well as cutting tools and other small tooling.

Considerable softwares now exists to facilitates the various tasks of tool management. Sophisticated computerized tool management software packages have been developed which includes features as: tool databases, tool simulation, allocation and scheduling, and tool life monitoring[24]. By the very nature of NC, most of the responsibility for success or failure of an individual part program rests with the programmer. He/she must have the same confidence in the policies and the standards concerning tooling as in those concerning machine tool and any computer software that will be employed.

6.2 Cutting Tool Policy

The important point to consider is the vital necessity to have standards and procedures that are completely understood by the part programmer, shop supervisor, setup man, operator, and all others. The role and responsibility of each in determining that the right cutting tool gets in the machine tool should be established as the matter of policy. The standards and procedures should all be firmly established before the NC machine is ever made operational. A sound cutting tool policy is stated in the following four basic rules:

(1) There should be a set of cutting tool dimensional standards and all tools should be purchased to these standards and regrounded to the next size standard. Some companies pays extra to have their NC tools ground to precision tolerances by the vendor before they arrive at the purchaser's plant. The important consideration is to give programmer a set of tool standards he can count on.

(2) Shortest and the most rigid cutting tool that can be applied to the job should be used. More loss of accuracy on NC machine comes from twist drills that walk because of improperly ground points, from long weak drills that bend and wander, and from long end mills that flex and subsequently machine out of tolerance. Thus, cutting tool standards should concentrate on short, rigid tools.

(3) Policies about tool setting, regrinding and compensation should be determined, like who has the right to make the tool compensations, set grinding standards and established setting may be argued. And whether settings are to be made on the

machine by the operator or setup man or toolroom may be debated. But the fact remains that there should be clearly defined policies that are understood by the entire manufacturing division.

(4) Carbide and especially indexable insert type tools should be used wherever possible in preference to high speed steel. The potential high productivity of NC machine tools, and the investment in such equipment demands the longer and more constant wear life of carbide. Usually some of this inherent longer wear life is sacrificed for higher rates of metal removal. By using indexable inserts the user can eliminate a lot of time in regrinding tools and substantially reduce tool setting time.

6.3 Spindle Type Tooling

The programmer must be familiar with each of the tool that he/she can specify and the machining center equipped with. The contouring capability on many modern MCUs permit end mills to be frequently substituted for large special boring tools in finishing large IDs. This approach is generally more economical. A contouring is designed and written for a clearly defined diameter, length and style of end mill. Every programming statement is based on a specific tool geometry. If the wrong end mill is placed in the spindle, the part will either be oversized, undersized or misshaped. In some instances, only certain dimensions of a cutting tool are important. For example if a drill is slightly longer than that assumed by the programmer and is being used to drill a through hole, it will present no particular problem provided that the length is not so erroneous that the drill is feed into the part at rapid traverse rather than a feed rate. In many respects, the cutting tool determines the final dimensions of a workpiece. Consider a boring bar. The NC control unit may position the centerline of the boring bar exactly as it should be for machining the part. However if the cutting tool insert has been improperly set, the bore will be either of undersize or oversize. Because an expensive machining center carries a high burden rate and because the setting of tools on the machining center may involve long periods of time, it is often deemed advisable to preset all tools of this type off the machine by a qualified person. The tools are preset into holders that are precision made so that when the holders are inserted into the machine tool spindle, the entire holder and cutting tool setup will be well within the programmer's working tolerance.

High quality tool holders will last long time, but not forever. Many times an end mill is blamed for not holding tolerances, where it was actually the fault of the worn tool holder or its setscrews. Over time, the holder's bore may become bell mouthed and/or elliptical. Consequently all tool holders and setscrews need to be inspected periodically. When taking heavy cuts in sand castings and other tough materials, step milling cutters are often used for less chatter. A number of configurations exists that mount teeth or blade irregularly, such as wavy fluted end mills, steeped blade face or shell mills or differential blade face mills.

6.4 Hole Making Tools

Drills are the most common cutting tools used in the NC. HSS twist drills can be the most troublesome if the user do not insist on the best precision drills versus standard drills. A standard drill can vary considerably in lip height, flute spacing, web thickness, straightness and contouring of drill point. Even if its diameter is within tolerance , its going to walk if its drill point is off center. Precision drills are a must, and sharpening of worn drills must be done to the same high standards.

Most successful NC users employ carbide insert drills wherever possible. Other than permitting higher feeds and/or providing longer life, a major advantage of carbide insert drills and other tools is that the tool is of constant length. When dull, the inserts are indexed to a new edge and tool is returned to service. When all cutting edges are used up, the insert is replaced. The tool and tool holder are both left intact. A number of carbide insert drill configurations are available. They do not all cut holes to the same tolerances. In this respect, the tolerance achieved by one drill type may vary 30 to 50 percent from another. There will be times when it is more efficient to go in with such a tool and clean up with other.

Some very real limits to spindle speeds are set by the problems of heat dissipation and chip disposal. The avenue of greatest potential is in increasing the feed rate. Most handbook feed values have been obsoleted by modern NC machine tools; they are set for 8 hour drill life and considerable tool wear. A one hour drill life would be more realistic and would permit a significant increase in feed rate. Even when each NC machine is to be manned regularly, much of the inherent benefits of NC can be lost if the operator must be constantly concerned with chip breakage and with chip clearance from the tool. Greater attention must be given to avoid such problems so that the shop can progress eventual lightly manned status.

6.5 Feed Out Boring Heads

The efficient machining of parts featuring of large bores with an intricate profile has always been a challenge. In order to speed up production on boring mills, a class of boring heads that feature an adjustable diameter tool slide perpendicular to the spindle centerline came into existence. The tool can be mounted to perform ID operations or OD operations. Tool diameter settings are achieved either manually or automatically by NC. With manual type heads, settings are usually achieved by vernier handwheel. Radial feed of the tool slide is achieved manually or on some other models, by power feed. These manual type feed out boring heads have been used on milling machine and jig borers for some time. More recently much attention have been given to broadening the application of feed out boring and facing heads to various NC machines, including machining centers with automatic tool changing. The goal has been to fully program the U-axis tool slide and coordinate its slide and coordinate its feed with feed of the Z axis machine spindle to produce tapers and counter bores. Combining the operations of boring and facing on a machining center permits a mostly prismatic part to be completed in one setup. Thus reducing tooling and increasing productivity. Using a standard machining center tool holder adapter, one popular model feed out head can be interchanged in and out of the machine spindle just as any other tool assembly. To provide power to the head's tool slide, an auxiliary compact DC servo drive and feedback unit is mounted permanently to the machine adjacent to the spindle. When the head is loaded into the spindle, it also engages the drive unit, which secure the main body of the head in nonrotating oriented position. Radial motion of the tool slide then can be executed by U-axis command from the CNC, like any other machine axis.

On some CNCs which do not provide for a U-axis, control of feed out head's tool slide is shared with another axis. This usually limits the application of the head to straight bores and facing operations. To perform contours and tapers, the control must provide simultaneous U-axis and Z-axis interpolation.

6.6 Tool Data Input

When the part programmer first faces a new job and determines how to process the part, operation by operation, he/she makes up tool list selecting each tool on the basis of tool type, class and grade of cutting edge material, nominal size, required toolholder, and so on. In some cases, the omission of all tool data, except a tool number, from the part program would provide greater flexibility. Most MCUs now permit a separate tool data tape input to provide information tied to tool number or program sequence number. Such additional data could include storage pocket location, whether to be loaded into spindle automatically or manually, tool cycle time, speed and feed override, tool length, cutter diameter and tool compensation values. Some newer MCUs provide for several separate internal tables of tooling information - such as the primary tool data, tool location, and tool wear life.

The efficient tool management software should involve complete tooling inventory management and control through storage, transport methods and software programming. The system has to bring tooling inventory under control and maintain that control by monitoring usage, flow on the shop floor, inventory levels, and purchase orders[21]. Some of the following MCU tool management features that may be available to tie in with the tool data input feature or may be used independently are discussed below.

6.6.1 Remote Tool Management Terminal

This hardware/software item, located at the tool load station and interface with the MCU, is especially useful on larger machines, where the tool load station is isolated from the MCU, and where 60 or more tools are carried in the storage matrix. If the tool data tape has been loaded into the MCU, as each tool pocket is indexed into load position, the remote console will read out the identification number of the next tool to be loaded into that pocket. Or, if tape input of tool data is not available, the operator may use a numeric keypad on the remote console to input the tool identification number, the tool pocket and the tool length.

6.6.2 Tool Identification

With each machining center, the part program calls up tools from the storage matrix identified by coded rings on the tool holder, using a special reader on interchange device. Today an MCU feature permits the part program to call up a tool from a storage matrix by a tool assembly number - usually 5 to 8 digit long. Each number applies to a uniquely different tool. The tool assembly number is assigned to a specific pocket in the tool storage matrix either by tool data tape by the operator via MCU keyboard or by remote tool management console. The use of tool assembly identification in this manner permits identical tools, with the same ID to be assigned to different pockets in the tool matrix, providing the basis for redundant tool selection.

6.6.3 Automatic Tool Identification

Two methods of automatic tool identification has come now into use. The first is bar code designation. It is very similar to the bar codes on the products used in the stores with modern checkout lanes. As the code is passed over a scanner, it is read and name and price of the item is automatically calculated and displayed. When used on machining centers, a bar code is established for each tool classification. The bar code is either imprinted on the paper or myler and then fastened to the tool with adhesive, or it is engraved on the tool. With the latter method, the tool is permanently identified. However with an affixed code, the tool ID can be changed, if necessary. When the part program calls for a specific tool, the control unit searches for a particular tool code rather than calling for a specific location in the tool matrix. In this manner, the tool location on the matrix can be random. The tool does not have to be placed in a designated pocket.

The second automatic tool identification method makes use of a computer microchip embedded in the tool or in the holder shank. The microchip is programmed off line with the tool identification number and other special information such as length or diameter compensation factors. The microchip is read by a special sensor to identify the tool.

6.6.4 Cutting Tool Length

Today's CNCs offer several software features that simplify the task of assuring that tool dimensions are properly accounted for. Now while programming machining center, part programmer usually does not include the tool length directly in the program. He/she may specify a tool having a minimum length based on the maximum depth it must travel in Z to do that particular operation. Otherwise, he/she programs as though the tool has zero length and as though the spindle/tool gage line and the tool point coincide. Programmer calculates the Z axis travel at feed rate from an imaginary R-plane set 0.100 inch from the work surface as shown in figure 6.1, and factors in any extra travel that any workpiece or fixture features may demand in order to avoid any tool, holder or spindle interfaces. Now, the actual tool length is usually entered separately.

6.6.5 Electronic Tool Gage

Various instruments are available for speeding up the measurement of tool length and cutter diameter. Some are strictly tool room devices. Some are usable for measuring and/or tool presetting. Introduction of the probe made it possible for machines to manage their own accuracy by measuring and responding to each individual workpiece[23]. Some portable instruments are available, which can be used in the toolroom or at the machine tool when tools are loaded into storage matrix, can be interfaced with the MCU and the tool length can be entered automatically by pressing the single button, or the length or diameter can be read from visual display units and manual input via MCU keyboard or remote console.

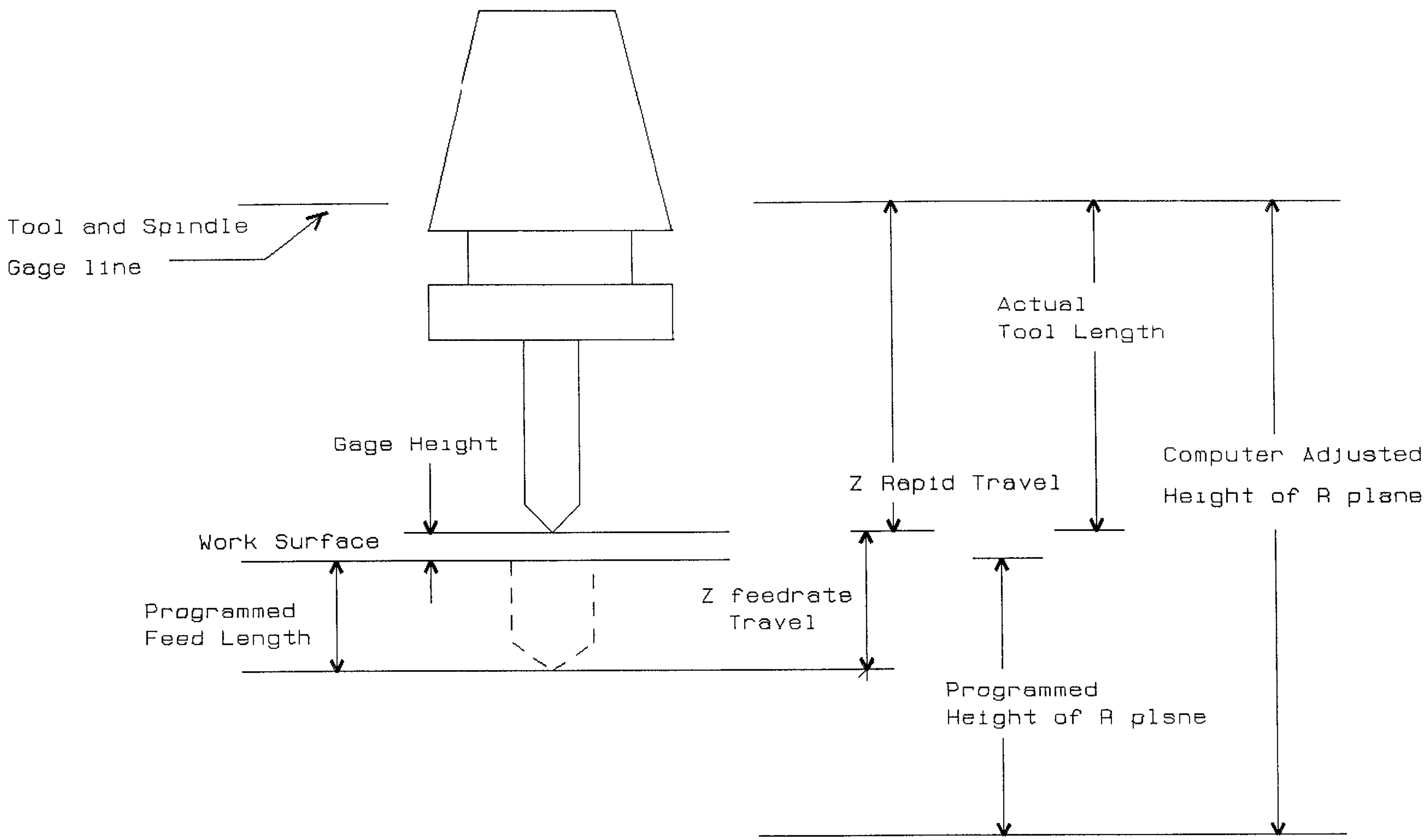


Fig. 6.1 NC hole making programming parameters

6.6.6 Tool Length Storage

This software feature provides flexibility as to when and where the actual tool length is entered into MCU memory. The toolroom, when making up the tool kit in advance for a new job, can measure the exact length of the tool and include this in the tool data to be input to the MCU at the time of loading a new array of tools in the storage matrix. Typically, tool length storage provides for a six digit input - in 0.0001 inch increments up to +/- 99.9999 inches. In most cases, it is best to have tool length measured offline and include with the tool data when transmitted to the MCU by tape or dataline.

6.6.7 Automatic Tool Compensation

Precision surface sensing probes are also coming into use. In one type of application, the cutting tools are directed against the machine mounted probes. At the moment of contact, the position of machine tool slide(s) is recorded in the CNC and that data is processed by the control's computer to relate the tool's cutting edge to the programmed dimension.

In another instance, the probe itself is mounted in a tool holder and placed in the machining center's tool storage matrix. When called for, it is transferred into the machine spindle and directed to probe a feature of the workpiece such as a surface or hole. The probed information is then processed by the CNC to either redirect the cutting tools to compensate for any deviations or to relate the cutting tools to the physical location of the workpiece. Such probing application requires a CNC with a special compensating software routine as part of the control unit's executive program.

6.6.8 Semiautomatic Tool Compensation

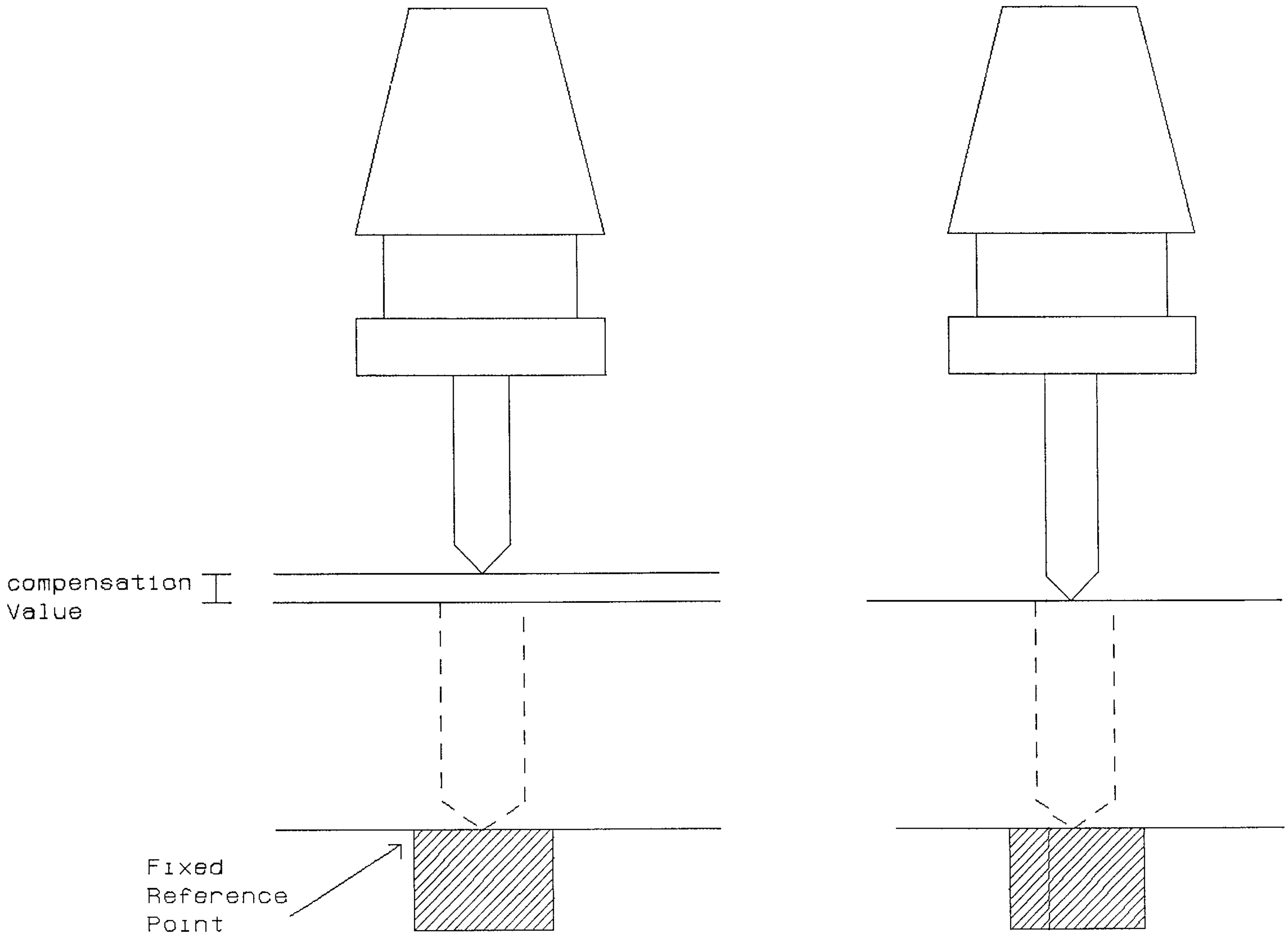
Some CNC units offer another method of setting tool compensation. A tool is mounted in spindle or turret station and then brought into machining position. The operator jogs it against a reference stop and its position is automatically recorded in the control. With this information the control's computer modifies all part program statements to take into account the length of the drill, diameter of the end mill, location of the insert, and so on. Figure 6.2 illustrates such feature.

6.6.9 Assignable Tool Trims

This software permits a certain number of Z-axis compensation or correction values for fine tuning of tool length or more commonly for minor part or setup variations. The trim value is typically allowable in increments of 0.0001 inch up to +/- 1.000 inch and is input by the operator. Depending on the particular machine control unit, the tool trim is applied to a tool number, to a pocket location, or is designated by part program where the programmer anticipates that any variation in unmachined part or setup, or distortion during machining, could adversely affect closed tolerance part. Figure 6.3 illustrates tool trim on a machining center, where they are programmed as D words[28]. The programmer could assign one tool trim, say D01, on certain operations and different trim say D02, on certain other operations. The operator would then run the first piece of a lot, would have it inspected, and then input the actual trim values. A trim value when input to the control remains for the duration of that setup.

6.6.10 Cutter Diameter Compensation

This feature basically alters a milling cutter's programmed centerline path to compensate for a small difference in cutter diameter. On most modern MCUs, it is effective on virtually any cut made using either linear or circular interpolation in the



With semiautomatic tool compensation, programmer figures the same basic tool length for all tools and the operator at setup time aligns each tool in turn against a fixed reference point on the machine

Fig. 6.2 VARIOUS TOOL COMPENSATIONS

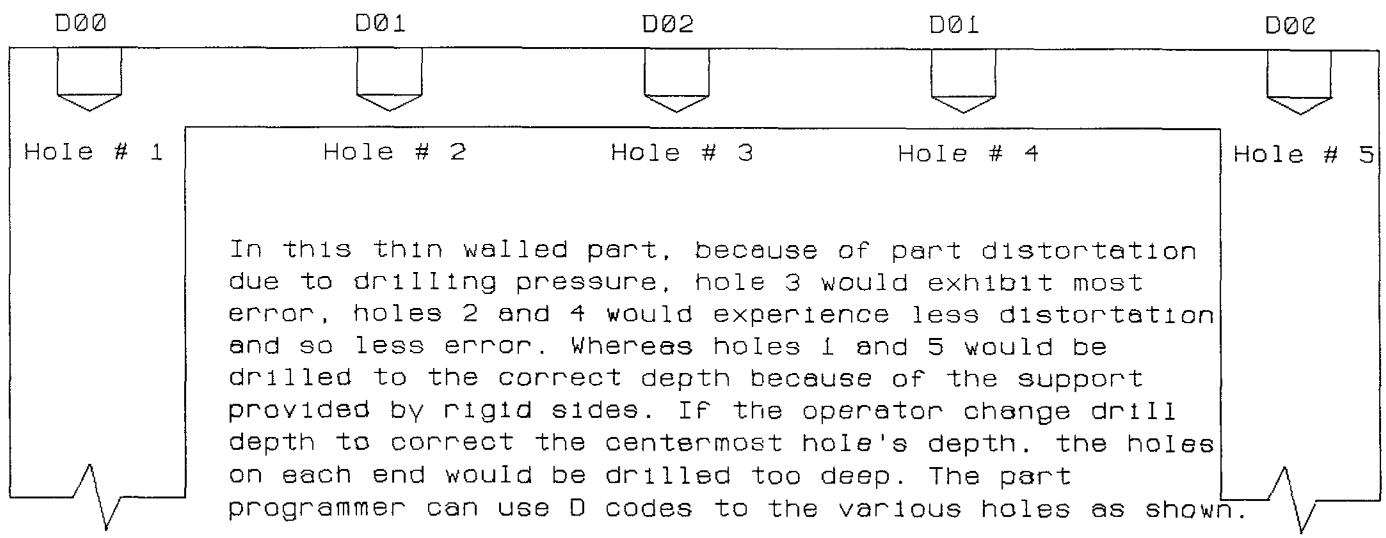


Fig. 6.3 TOOL TRIMS USING CNC MACHINING CENTER

X-Y plane but does not affect the programmed third axis move. Usually there are as many Cutter Diameter Compensations (CDC) available as there are tool pockets in the storage matrix.

Normally, the operator can enter the CDC value through the keyboard on modern MCUs. If the tool data tape feature is used, the CDC value may be optionally entered at the tool room or higher level. On, older MCUs, there were sever limitations on the types of cuts that could be successfully milled using either the cutter radius feature or the CDC feature. The CDC feature may also (1) permit use of a larger or smaller tool already in the machine's storage matrix, (2) permits backing off for a preliminary rough cut where excessive stock is present, (3) permit compensation for unexpected tool or part deflection, if the deflection is constant throughout the programmed path.

6.6.11 Tool Usage Monitor

This software feature enables the MCU to keep track of the total time spent in actual feed cycle by each tool on the machine. By continuously accumulating this time and comparing with life expectancy value programmed into the MCU for that tool, the remaining tool usage time is computed automatically. When that time runs out, an alert message is displayed signalling that action must be taken. If the MCU contains the tool data tape feature, then the life expectancy value can be entered into the system automatically.

6.6.12 Redundant Tool

With this software feature, tools that are common to most part programs which see heavy usage can have identical backup tools in tool storage matrix. Combined with tool usage monitor, this feature causes the MCU to automatically substitute an identical tool at the first opportunity when a tool's usage has expired.

With redundant tool and tool usage monitor, manual replacement of worn tools in the storage matrix can be delayed until a convenient time so as not to interrupt production. Management can decide, When to replace worn tools - at shift change time, or at specific time staggered throughout the shop. With the tool data feature, the operator can call up and review the unexpired life of any tool, order replacement when necessary, and then load all at one time into storage. The redundant tool feature could also be linked to torque sensing or some other sophisticated device for indicating need for tool replacement. This is more economical and safer than using a predetermined tool life expectancy.

6.7 Multiple Tool Handling

There are numerous schemes for multiple tool storage on or at the machine and for replacement of tools in the storage matrix. In most cases, the tools are manually exchanged one by one at a tool load station at the back end of the storage matrix. In some cases an AGV, on which is mounted a robot arm, carries fresh cutting tools for machining parts scheduled next on the machine.

Tool cartridge can be supplied to a machine in several ways. Most commonly, an AGV delivers five cartridges, to the machines tool load station. Each index brings one of the load station slots in horizontal alignment with a slot in the tool storage wheel. With slots thus aligned, tool cartridges are transferred in or out of the machine's storage matrix by computer control.

6.8 Overall Benefits of a Tool Management System

Through the correct implementation of a basic and competent tool control system, following benefits can be obtained[29].

1. Manpower is conserved and training requirements minimized.
2. Number of tools lost or misplaced is reduced.
3. Timely and up to date information on tool usage is produced.
4. Tool inventory shortages are identified and prevented.
5. The accuracy of the inventory is improved.
6. Space requirements and overheads are reduced.
7. Inventory levels and excess purchasing are reduced.
8. Time spent on re-ordering is reduced.
9. The record keeping functions are consolidated.
10. Tooling can be tracked and its availability within the shop monitored.
11. Tools in rework can be tracked.
12. A record of scrapped tools can be tracked.
13. The value of the total tool inventory and of tools in use can be assessed.
14. Machine set up, tool return and withdrawal times are reduced.
15. The gauges and fixtures are identified and tracked.
16. Obsolete tooling is identified and eliminated.
17. It is possible to take advantage of tool kitting, presetting, storage techniques and other FMS concepts.
18. It is possible to incorporate existing tool numbers and the current mode of operation into an automated system without making radical changes.

6.9 Workholding Considerations

Parts made on a CNC machine are only as good as the work-holding and positioning equipment allow[22]. Workpiece must be held securely with some kind of holding device. And because in most cases multiple operations will be done on the workpiece in the same setting, greater care and ingenuity will often be required in the fixture design for a machining center than for a single purpose machine.

As a general rule, the workpiece should not be clamped directly onto the machine table. To avoid wear and tear on the table, a fixture is needed that can be mounted and registered on the table just once for the machining of all pieces in that particular job lot. By using fixtures assembled off line, setup time at the machine is held to a minimum. In some cases, a universal shoe plate fixture can be designed for a family of parts, with interchangeable and quickly changed subfixtures or details for the different part making up a family.

The horizontal machining center with rotary index tables has become increasingly popular. This is not only for cubic or prismatic parts which can be indexed automatically to present four or more sides to the cutting tool, but also for smaller, flatter parts. Especially on higher volume work, there is renewed interest in clamping automatically, pneumatically or hydraulically, in order to further speed up loading or unloading.

6.9.1 Modular Fixturing

With flexible manufacturing system becoming widely popular, automatic work changer(AWC) module is used with in line and swing around rotary pallet shuttle units and palletizing of fixtured work for transfer into and out of machining stations became popular.

Modular systems employ standard interchangeable base plates, subplates, mounting or riser blocks, clamping elements and so on. In some systems, each element can be used with any other component to build a fixture. Each system employs a particular method to locate and mount the various attachments and accessories: a matrix of precision positioned holes, tee-slot arrangement, or slotted grid. The latter two are very adaptable in positioning components but do not lend themselves to precision repeatability when redundant fixtures are required, or a fixture is rebuild for a second run. A system that features the precision holes scheme favour high repeatability but may not be as flexible when it comes to clamping. The precision positioned hole matrix method may use dowel holes, a combination of tapped and dowel holes, or just tapped holes. The advantage of modular fixturing include the shorter fixture design and assembly time for a new product's entrance into production. When a fixture has completed its mission, it can be disassembled and the components are returned to inventory and are ready for use in another fixture.

The justification for modular fixture and conventional dedicated fixturing may be difficult, considering the usual accounting practice. With conventional fixturing there tend to be hidden costs: storage, maintenance, modification, retrieval and transport.

6.10 Fixture Offsets

Among the features available on the various MCUs to facilitate setup and workholding, the newer fixture offsets feature is of outstanding importance-especially for critical work. They allow the operator to compensate for a dimensional error in the fixture or its location, or in the part. It permits the operator to enter a separate error value in each of the axes involved. The offset can prevail for the entire part program, or they can be assignable to just certain operations. This feature is invaluable when work is located on a rotary index table.

Also, a part may have some feature like a boss or a cored hole that may vary in position from lot to lot, but not piece to piece within the lot. The part programmer can put the fixture offset code on the machining of that feature. When a first piece of a new lot comes through, the operator determines the error in position of that part feature and enters the appropriate value or values throughout the MCU keyboard. On all subsequent pieces of that job lot, the machine will automatically zero shift for those operations.

6.11 Locating Fixtures

Normally the fixture, at least for critical work, should be fitted with precisely located tram button at the parts reference point to which operator can touch up in precisely locating the fixture for alignment purpose. The machine table may have the tram button or plug to assist in aligning with machine zero.

The fixture must be designed for use on a certain machine or machines, because of different provisions for locating. Some permit fast fixture interchange. Some use edge locators or blocks permanently mounted to the table, usually at right angle to each other. The fixture is placed on the table and pulled back into the corner formed by the two blocks and then clamped down. But such blocks tend to become displaced because of excessive forces, or dirt interface with snugging the fixtures, or poor clamping pulls the fixture away from the positive seating. A rotary indexed table is frequently fitted with a plug precisely located at the center of index. When mounting the fixture, a button or pin built into the center of fixture is dropped into a precision keyway in the table to provide a precise angular orientation.

CHAPTER 7

NC SHOP MANAGEMENT

7.1 Management Role in NC Shop

Use of NC automatically does not means success. For NC to contribute to successful plant operation, NC must be managed well.

NC involves many people. NC crosses departmental lines. NC should be everyone's concern in the shop, including top management. NC needs some direction from top management. Heavy management involvement is needed to assure success when moving into NC machining (and migrating to CIM). The plant may be small, a 20 man contract shop, or it may be a much larger 250 man plant making 50 or 500 varieties of products. The plant may still not have its first NC machine or it may have been using NC for 15 years, but is now wondering if it couldn't be used more effectively or more extensively. This needs constant management involvement.

NC technology is running very fast. New developments appear at high frequency. The typical numerically controlled machine is now computer controlled; there's a computer in that NC console. With microprocessors, all the electronics in the console are starting to divide, separate and multiply, and take residence on the machine to control specific nearby functions. The total machine control, whether a single package or distributed, is acquiring constantly more capacity and more power to provide more output with less input. The machine's CNC is starting to talk back to the operator, to question him, to prompt him. The machine's CNC is starting to talk to other computers in the plant to supply information and to receive other information. The plant's NC activities and its computer activities are moving together, and the lines separating them are very fuzzy. Figure 7.1 shows various

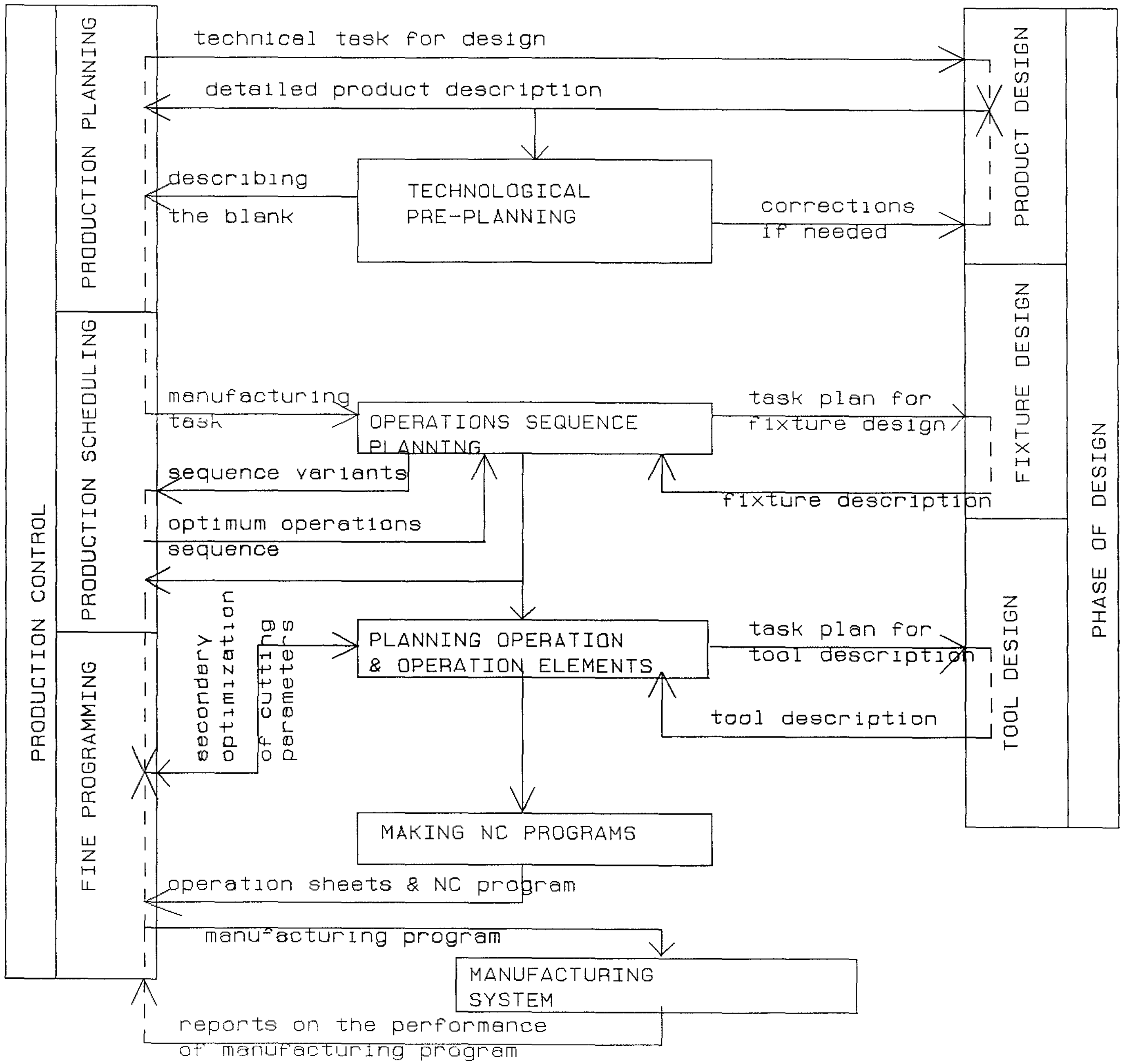


Fig. 7.1 TECHNICAL PREPARATION AND CONTROL IN NC SHOP

technical activities carried out in NC Shop. Many successful NC plants are now actually a successful NC/CIM plant.

Management must be conscious of these changes. They must be alert to what's coming. They must act in the present, but plan for the future. NC is a big part of the present, it has attained a maturity that has paid off for many but it is being infused with new ideas that will help reshape the future.

7.2 Planning to Implement NC

Some NC installations have been failure. Such experiences may had resulted in expensive and unpleasant experience. Usually, a technical reason is blamed for failure when, actually it could be traced to inadequate planning and/or to improper administration. The key to good NC management lies in prior planning so that an installation becomes productive in a minimum amount of time and with as few disturbances as possible. It is imperative that planning start long before the equipment order it signed. Implementing the following major steps[30] to getting started in NC can help ensure success. Similar principles apply also to later NC acquisitions.

1. Organize for NC. Determine how NC will be handled within the existing organization, and who will be affected. Set objectives.
2. Designate an NC coordinator. Give him full management support.
3. Establish a plan, identifying all tasks to be done, and establish checklists, critical path network, and schedule it. Allow for major update of plan after initial machine selections.
4. Select the candidate parts for early processing.
5. Select and order the machine or machines for initial installation.

6. Decide how parts will be programmed, whether manual or with computer assist, whether to access existing inplant or service bureau computer or to purchase dedicated computer.
7. Select and train key personnel-part programmers, machine operators, and maintenance people.
8. Take actions necessary to assure that site is ready for machine installation, that parts have been programmed, that tooling is on hand, that affected departments and people are ready.

7.3 Organization for NC Environment

The traditional activities carried out by planning, methods, scheduling, tooling, production, inspection and maintenance requires to work more closely in NC environment. Here, there will be new concepts, new skills. This can be handled by establishing a new NC department or assigning NC coordinator in each of the current department. This new department or coordinator may have to deal with resistance to bring any change in previous activity.

Many organization has introduced NC by creating new department assigning well defined group of parts, which functions same like other departments. The rest of the organization remains intact and functions much as it did before without any beneficial influence of NC. For shops which introduce NC coordinator, the integration of NC into the existing organization may initially be little slower and more difficult, but as NC proves itself, it can expand more rapidly. Many of the procedural change for NC can be beneficial for the remaining conventional production. Once management has decided to go for NC, it is essential to communicate this decision to all people who will be affected with new machine purchase. They should be involved in the decision making process. They should be informed as to what changes are taking place, what will be expected, what opportunities will be created and what changes will have to be met.

Failure to involve people and to adequately inform them can bring about resentments, frustration, lack of cooperation and antagonism.

7.3.1 Designating NC Coordinator

The NC coordinator has a direct line of accountability to the highest possible rung in management, and this be known throughout the organization. Top management support and continued involvement are very essential.

If NC has existed in the plant for some time, but its growth has stagnated, management should again review the start-up principles against its own experience and determine what must be reinstated or initiated so as to reap still further benefits from NC. Whether it's a start-up operation or expansion, the NC coordinator's selection and/or endorsement by top management are of paramount importance. He should be a generalist who has a good working knowledge of operations and is respected at all levels. If he doesn't already have the specific knowledge, he should become thoroughly indoctrinated in NC management as quickly as possible-through visits to other NC user plants, seminars, NC machine and control vendors, and so on.

7.3.2 Selecting Candidate Parts

NC coordinator should determine where to apply NC most effectively or most profitable. The starting point is an analysis of the parts currently in production. The acquisition of a new NC machine tool demands that the focus should be on the parts to be machined and the processing of them rather than on what some existing machine does. If it's a new facility being planned or a new product being introduced, the selection of parts for the new machine should be underway from design stage.

Detailed analysis of all parts running in the shop would be too time-consuming and wasteful. They can be loosely categorized by configuration; for example, flat plate-like or beam-like parts, cubic or prismatic parts, and parts of rotation. Each of these groups can be divided by general size, then by work material characteristics. Next step is to decide which group offers maximum benefits of lowering production cost and shop floor problems. Once group has been selected, it can be further divided until a specific target group of part candidates are selected. Some generally considered group of parts is given below.

1. The smaller the job or batch lot, the more NC is favored. However very small batch size may require special evaluation.
2. Parts that are subject to intermittent or cyclic demand.
3. Parts having a high work content, a high value added by manufacture, a multiplicity of operations, that would conventionally visit several machine tools and require as many different setups resulting in high associated tooling costs and lengthy total setup time.
4. Parts of complex configuration and difficult to machine conventionally.
5. Parts requiring very close tolerance relationship of machined features in several planes or on multiple surfaces.
6. Parts that are subjected to frequent design change.

7.3.3 Selecting NC Machine Tools

NC coordinator should consider machine control compatibility for given part before selecting CNC. Machine compatibility at the shop floor level simplifies operation and maintenance, and reduces investment in toolholders and spare parts. Before selecting the CNC machine, it is required to study general part configuration and types of operations involved to machine that part. The general part size will help to decide required work envelop and table travel range. The work material and hardness, hole diameters, and depth of cut will help determine required horse power, and spindle thrust capacity. The types of operations to be performed will help determine different types of cutting tools needed in tool turrets and tool storage matrix.

While selecting adequate standard and optional machine and control unit features, special attention should be given to those features that tend to reduce the machine's nonproductive time. The machine tool itself should have drives, ways, and features that can stand up under sustained use. The control unit should have the features necessary to keep the machine functioning. Any of them, tool offsets, assignable tool trims, cutter diameter compensation, diagnostics, fixture offsets and many others may be one of the wisest investment made. Another point that needs attention is to make sure that machine can deliver required accuracy and finish at acceptable metal removal rates. A control unit manufacturer may claim .00005 or .0001 inch. resolution. Although this may be true, it does not assure that the machine tool can produce to this accuracy. A combination of very accurate control with very inaccurate machine can result in inaccurate finished part. The various machine and tooling components are subject to individual tolerances. These all factors play a role in determining the final machining capability.

NC coordinator should also consider for environment and utilities that the NC machine and control will need. Because of their electronics, they tend to be sensitive to certain shop conditions. Temperature, humidity and electrical interference are factors to consider. Some control units may malfunction if there are wide electrical voltage variations. There may be special requirements covering spacings, foundations, air and other support utilities. The wise way is to check these all with machine tool supplier. Especially while installing large machines, the machine tool builder's field service people should be called to supervise the actual physical installation and instruct operator in getting started.

7.3.4 Key Personnel Training

NC coordinator should follow up on upper management's early communication of project objectives and scope with more detailed disclosure to all affected departments and personnel. Depending upon scope of program and number of machines proposed, it may be required to set up in-house seminars or otherwise undertake some formal education of people who will be directly involved. NC coordinator should counsel department heads on the selection and training of key personnel-the part programmer, machine operators and maintenance men. The training of both mechanical and electronics maintenance personnel should be done on the particular type of equipment being purchased, and should include how to utilize any built in diagnostic capability of the control.

The attributes most important for the selection of programmer are: communicative skill, machining background, analytical mind, trigonometry, spatial conception. Management should also decide as to how much intelligence to leave (in control) at the machine and how much operator input to require or how much decisions programmer should leave on operator. This will help to govern selection of the operator. Operator will be responsible for the well-being and behavior of costly machine and (partly) for its productivity. Basically he has to be capable of making a deep commitment to that machine, and he must be conscientious. In many cases he will set up his own work, make alignment checks, set tool offsets or tool trims, inspect his own work, watch for alert messages on the CRT, decide reasonable speed and feed overrides, and so on. A good operator will be valuable in spotting and reacting to broken and worn tools, programming errors, unexpected differences in castings or forgings, and other unplanned situations that could result in costly downtime.

A strong mechanical maintenance capability include the knowledge of sophisticated hydraulic and pneumatic systems of the machine. The electronics maintenance capability include the skills necessary to maintain the machine wiring, machine magnetics, electric drives and the NC control unit. The electronic technician should be able to make decisions whether the machine problem is essentially mechanical, hydraulic, pneumatic or electrical.

7.4 Selecting the NC Programming Language

Selecting the most appropriate NC language is of great importance. There is a wide variety of NC languages available in the market. Some requires much more computer capacity than others. Some covers a wide range of applications. Some are for specific application. Management has to choose that is best for their plant. If the plant has potential for a considerable number of NC machines of various types, a general purpose NC language should be considered of which subsets are available for more efficient programming of certain classes of parts for certain types of machines. Some suppliers offer purely a software system designed to run on certain personal or larger computers. Others offer a complete software/hardware system-of both the stand-alone and parametric types. All deserve attention, but demands caution and aggressive evaluation. In general, they provide lower cost solutions to programming, but not without tradeoffs which may influence the prospective user one way or another.

Deep study of how restrictive or how flexible is the software in the initial system package is required. Some of the most important factors management should concern are listed below.

1. Is it limited to just simpler parts?
2. How much skill and time is required for more complex work?
3. How dedicated must the computer be?
4. Will there be enough parts programming volume to keep it busy?
5. Can it be used for other purposes than part programming? A few systems feature a DNC capability. A few multi-tasking CAD/CAM systems exist, including parts programming. For the system in consideration, are other compatible modules available for other classes of machining work or other shop management functions.

7.5 Network Management

As the number of network users has increased, vendors have provided an array of tools to oversee network operation. Many companies offer software licensing, which permits only somany network users to check out a particular application at one time. Some leading network software companies are expanding their services by offering number of facilities with softwares. Knowledge of such facilities could help management expanding its activities efficiently. Some important facilities offered by major software and hardware companies are mentioned below[31].

Intergraph Corporation offers one called I/NFM (Intergraph Network File Manager), which can be used as a stand alone data management product or as the underlying network data management tool for Intergraph and user developed applications. It runs on intergraph or other Reduced Instruction Set Computing (RISC) workstations. I/NFM is built on top of the company's Relational Interface

System (RIS) tools that translate calls to different databases such as Informix, Oracle, Ingres, and DB2. Once linked to these databases, users can access and manipulate data through a graphics application without having to learn a database language. This saves system administrators from having to do a lot of retraining. Also I/NFM offers an automated workflow control subsystem and ensures that only users with proper clearance can access files and attribute data. Another type of network management tool tracks network resources such as computers, network devices, communication protocols, and applications and services. Sun Microsystems offer such capabilities in SunNet Manager, which specializes in managing TCP/IP based systems. The Manager portion of the product runs on user's workstions while modules called "agents" run on system throughout the network. Agents act as probes, monitoring objects and sending data back on request. While other management products require users to personally monitor changes on the network, SunNet Manager involves users only when they need to be involved. This frees up administrator's time, enabling them to manage larger networks and reduce overall network management costs.

Another important area of concern in networking is connectivity, the ability to link with other network workstations. DEC, for instance, has a suite of communication software that enables it's computers to IBM computers. Products range from single function, point to point protocol emulation, to multifunction network-to-network connections via an IBM channel. DEC offers similar support for TCP/IP systems, packet switched data networks, and OSI requirements. IBM, offers products that provide connectivity between its many plateforms-mainframes, workstations, and PCs-as well as to another vendor's systems. Sun Microsystems supports connectivity products that link its systems to IBM, Digital and other networks.

DEC has offered several options to add PCs to a network. The company's Pathworks for Macintosh, Pathworks for DOS, and Pathworks for OS/2 are software based products that establish links between DEC computers and these PCs. PCs and Sun Sparc systems can be networked via Sun's PC-NFS software.

7.6 CNC to CIM

Many shops are using stand alone computers and CNC machines to do specific jobs. But that is just a small part of what can be gained when all these computers are linked, sharing information across the manufacturing enterprise. Better of the shop floor can be reached by better, more timely management of information. It can be reached by connecting all machines, peoples and processes within the manufacturing operations. Stand alone CNC machine's are now common as are process planning systems, NC programming systems, statistical process control analyzers, and so on. These computer based manufacturing tools have brought remarkable improvements to their respective areas of functionality. Integration of these requires technological and management strategies. This is called Computer Integrated Manufacturing (CIM).

7.7 Computer Integrated Manufacturing (CIM)

CIM is a business philosophy aimed at achieving a more efficient and effective product design and production process by integrating the control and distribution of information through the entire process[32]. Successful companies whether large, medium or small do recognize that CIM represents changes in management practice as well as changes in technology. CIM can also stand for 'control, information and mechanization' architecture of a company. The control portion of the CIM architecture deals with management (control) technologies, including the concepts of work simplicity, value analysis, and group technology to achieve product and process stabilization and synchronized flow techniques or Just in Time (JIT) strategy to eliminate waste and to increase production. CIM architecture which represents automation technology such as CAD, CAM and CNC as well as information technology such as material requirement planning (MRP) and cost system[33]. In short, CIM is maturing from a little understood, widely interpreted, and fairly educational discipline into a generally accepted code name for employing computers through the manufacturing process to ensure quality, increase throughput and uptime utilization rates, implement continuous flow production, reduce inventory and in process overhead, and make the manufacturing function a more consistent, flexible and responsive tool in the service of overall corporate objectives.

7.7.1 Organizational Strategy for CIM Implementation

The first step in organizing for CIM can be described as analyzing the existing organizational and operational structure. The fundamental building block of the new organization involves setting up a CAD/CAM system, eventually resulting into DNC for CNC machines. This is particularly instrumental in reducing the time taken for information transfer from drawing to finished product. Some problems in manufacturing planning and control can be dealt with, by computerizing the existing paper base data. A similar line of action can be adopted to deal with business function problems. The limitations of forming an isolated database can be overcome by the use of software which is capable to store the manufacturing and business function data and also symbolically linked. Hence change, in data on a module in software correspondingly updates the related modules. This provides an up-to-date database at any given tome.

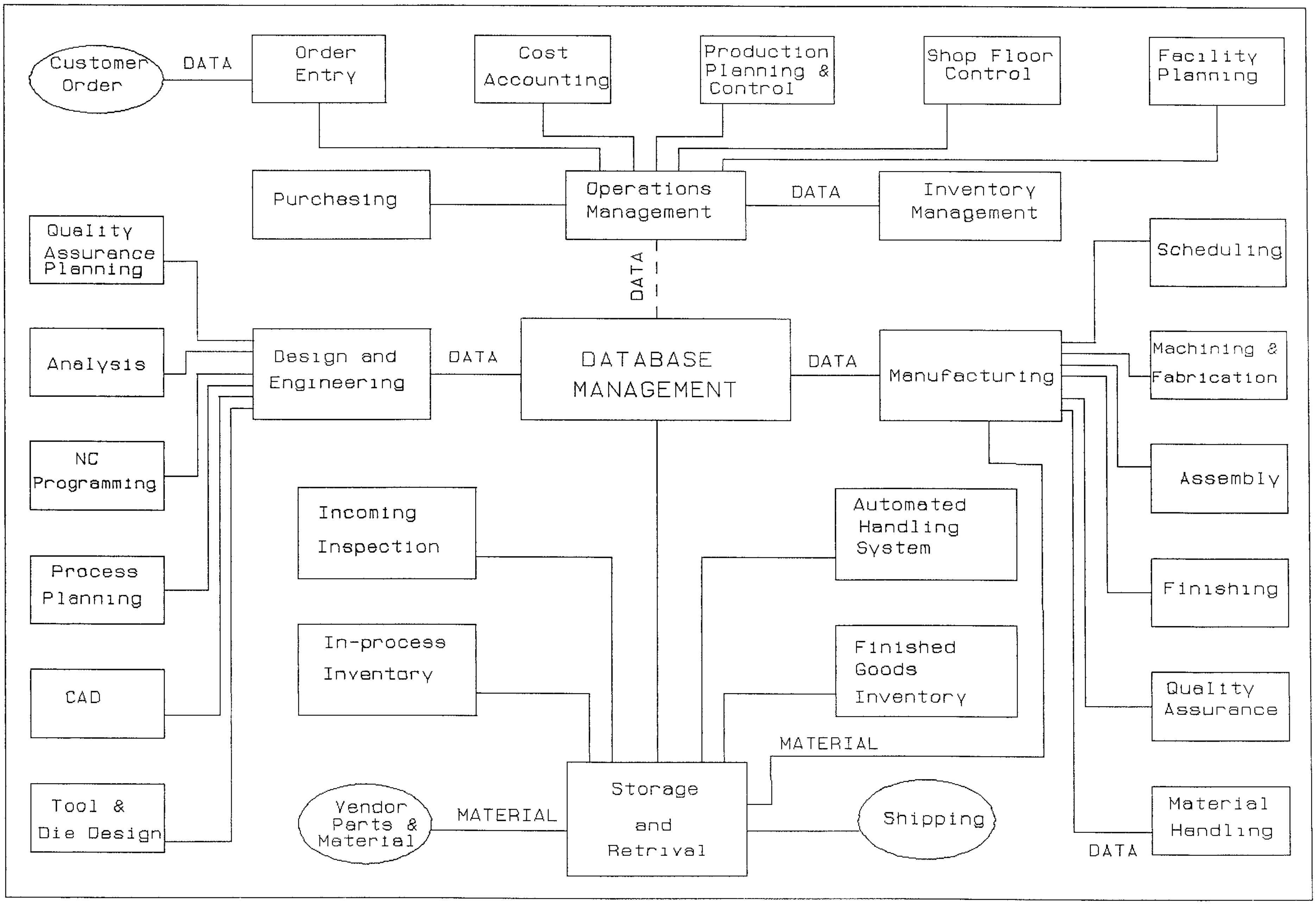


Fig. 7.2 CIM DATABASE MANAGEMENT

In small manufacturing environment complete integration may not be needed. The only data required by the business function activities, from CADD system is the bill of material. Besides, CAM software database has no significant information to be sent to business function activities. In other words, there exists a link which is weak. Hence, there exists two separate islands namely "CAD-CAM" and "Production Planning and Control along with administrative functions". Realizing that there is no significant data required to be transfer between two islands, it is advisable to avoid complete database integration. Many of these improvements can be in stages of installation and implementation with as little disruption to the manufacturing process as possible.

The components of the integrated computer system, and their relationship is illustrated in figure 7.2. This figure shows how the various functions of a factory are effectively linked together. New products are designed on a CAD system by the design engineer. The components that comprise the product are designed, the bill of materials is compiled, and the assembly drawings are prepared on the computer by the draftsman. Partial output of the design department serves as the input to the manufacturing engineering, where process planning and similar activities are accomplished by the respective personnel, to prepare for production. Output from CAD system serves as an input to CAM system wherein machine codes are generated internally to aid the CNC machining, thereby establishing a DNC. Many of these manufacturing engineering activities are supported by the CIM computer system. Process planning is performed using Computer Aided Process Planning (CAPP), NC part programming and NC verification are done on a CAM system by the programmer. The output from manufacturing engineering provides the input to production planning control and the business function. Figure 7.2 illustrates that the functions of design and manufacturing are closely related to one another. However, the business database is not widely dependent on the design and manufacturing database.

CHAPTER 8

CONCLUSIONS

The decision to invest in CNC machine tool must not be taken just on the basis of machining technology alone. Investment in CNC machine must be economically justified. Economic justification should also be done between different CNC machines. For complex part manufacturing in small batch size, CNC machines are more profitable over conventional machines. For complex part manufacturing in large batch size, higher investment in more advanced CNC machines can be more profitable over conventional CNC machines.

Ring type networking is preferred for networking upto plant level (when number of nodes are less than 1000 and distance upto 1 Kilometer between nodes).

For interfacing within 15 meter distance RS-232C is preferred while RS-422C is preferred for interfacing upto 50 meter distance between terminal and serial interface device.

If a plant is buying 2nd CNC machine and if networking (now or in future) is consideration, the user should give complete interface specifications to the machine control builder.

If a plant is planning to involve earlier designed CNC machines which do not provide MAP interface for networking, Network Interface Unit (NIU) should be used to accomplish networking.

Computer assisted offline part programming (using CAM software) is more accurate and time saving for programming complex configuration.

While offline part programming, control of every phase of machining should rest with part programmer. A complete set of rules should be defined deciding duties of the operator and of the programmer.

Shops manufacturing batch size of more than 100, carbide and indexable insert types of tools should be preferred to maintain consistent product quality within the batch.

A minor wrong input of tool length offset value can affect the finished product accuracy and tolerances. Most accurate available method should be adopted to measure tool length offset value. Also tool length offset measurement activity do not add value to the product, so fastest technique should be used to measure tool length offset. In shop with number of CNC machines, investment in offline tool length measurement technique is preferred.

Management should carry out detailed planning about selecting parts for CNC machines and key personnel training well in advance of machine procurement. Management should take people into confidence who will be affected with new machine purchase.

Management should not consider CNC just as a machine tool, but should integrate it with other manufacturing tools like process planning system, CAD/CAM system and statistical process analyzer. The level of benefits gained from CNC machine tool is entirely dependent upon the user. It can range from a minimum where CNC is being used as a machine control to a maximum where CNC is adopted as a management control.

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