ASPECTS OF SELECTION, JUSTIFICATION AND IMPLEMENTATION OF CNC MACHINE TOOLS IN MANUFACTURING AND TOOLROOM ENVIRONMENTS

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SUMMARY

The Thesis reviews the literature relevant to the selection, justification, and implementation of Computer Numerical Control (CNC) machine tools.

A general framework is proposed which covers both technical and managerial aspects. The ten phases are detailed in such a way that they may be practically applied.

The Thesis describes the use of the framework with reference to two contrasting cases within a single Company where a number of CNC machine tools were installed. The first case was a Production Machine Shop, the second a Service Toolroom.

The two cases are compared to show that the framework can be used, even when the applications are markedly different.

The usefulness of the literature reviewed is then discussed; it is shown that much is outdated and does not assist the potential user of CNC technology in justifying and purchasing the most suitable equipment.

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1. INTRODUCTION

Manufacturing industry in the U.K. is going through a major period of change. The economic climate has forced companies to review the way they go about their businesses, and to take action accordingly. The changes are widespread: product design, marketing strategy, financial control, reporting and personnel management have all been critically examined and changes implemented.

One of the most important aspects has been the role of manufacturing technology: that is the method of converting a design into a marketable product. The range of technology involved is enormous, and depends on the processes involved.

Fundamental to all manufacturing is the ability to take a raw material and to convert it into a product which can be sold. Within the engineering trade, this concept may be more precisely defined as making a product by a series of material forming and removal processes.

The development of cheap and reliable electronic systems has led to a great deal of activity in applying a measure of control to manual procedures. Examples would be robot welding, automatic inspection, guided vehicles for materials handling, and the computerisation of production control.

A major area is in the field of metal removal, where a cutting tool is moved in relation to the component in a defined way to produce a desired shape. Electronic systems can eliminate the need for a person to control these movements. This is known as Numerical Control (NC), where the machine actions are controlled by a system which interpet previously defined numerical data in a repeatable way. Computer Numerical Control (CNC) allows more sophisticated interpretation of the data and has become widespread as the cost of information storage and processing has fallen. Such technology is not new. The first NC machine tool was demonstrated in 1951 and CNC machine tools now form the bulk of plant on show at Trade Fairs, both at home and abroad. However, their implementation is difficult and not automatically successful.

This Thesis reviews some aspects of the relevant literature and then presents a general framework which can be used to ensure that implementation is successful.The phases outlined are as follows:

. Definition of terms of reference
. Assessment of existing situation
. Option review
. Target specification definition
. Machine tool selection
. Financial Justification
. Ordering
. Personnel selection and training
. Plant installation
. Aftercare and post-audit

The framework is then applied to a real Company case where a number of CNC machine tools were installed in two contrasting environments.

The cases are then compared and discussed with reference to the literature, to allow some useful conclusions to be drawn on

. How useful is the literature

. How the framework can be a useful tool to aid implemention.

A more detailed technical background of the development of CNC machine tools is given in Appendix 1. Appendix 2 contains a summary of the Company in which the cases were carried out.

The Thesis was written following a project carried out under the auspices of the Science and Engineering Research Council through a Teaching Company Programme arranged between the University of Aston in Birmingham and Mansill Booth & Company Limited.

2. THE LITERATURE REVIEWED

2.1 OVERVIEW

The chapter reviews the literature which is relevant to the Thesis. There is a wide range of possible sources, although Cookson [1] feels that none is necessarily entirely satisfactory on its own. Indeed he notes that:

> "Disappointingly, many of the general, descriptive text books are written at an introductory, elementary level and are not particularly up-to date either".

It is convenient to split the literature into categories to aid this review, as shown in Figure 1. It will be seen that the categories can only be loosely applied. However they do serve to allow a methodical study to be carried out.

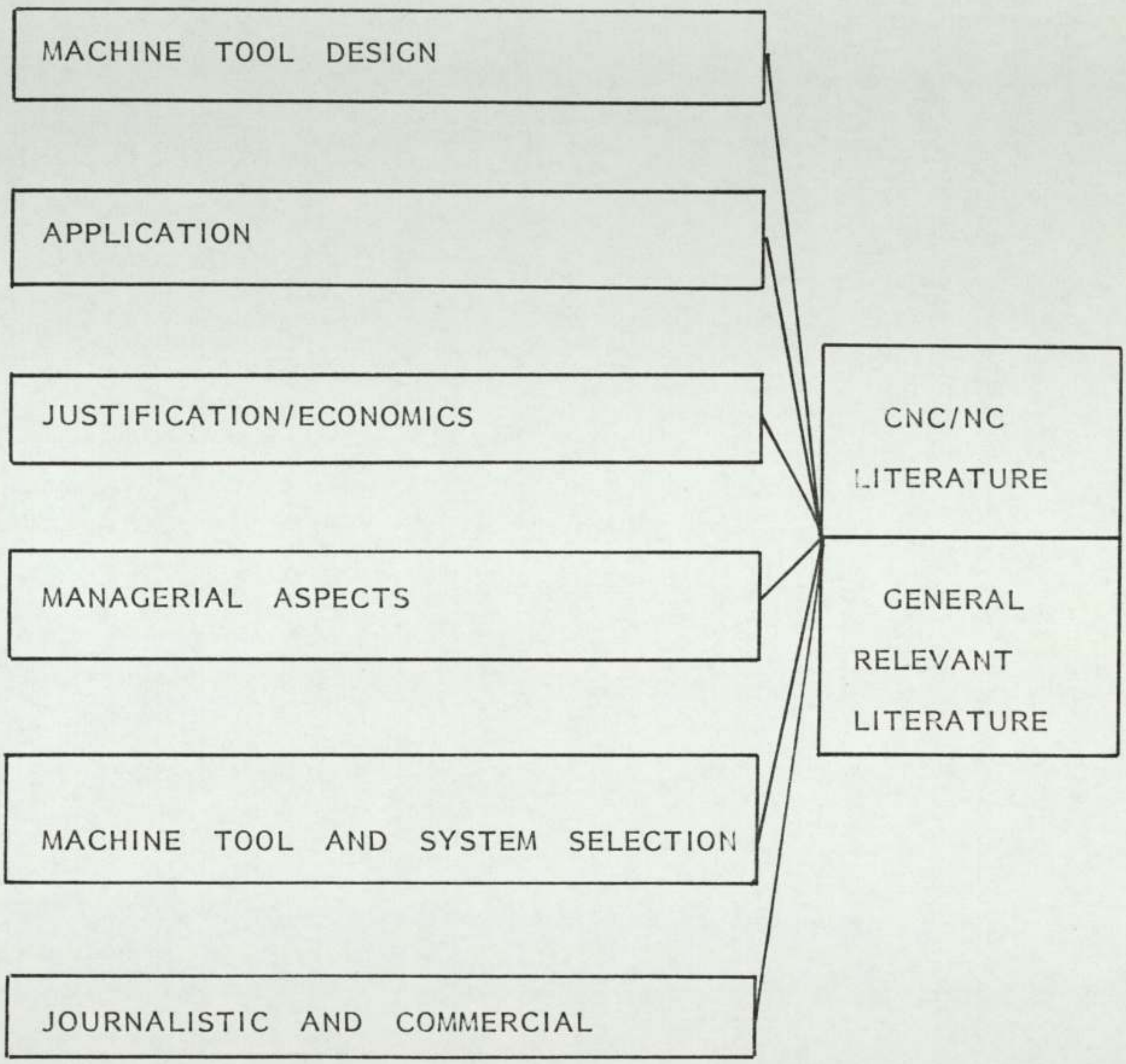


FIG 1 LITERATURE SUBJECT CATEGORIES

2.2. MACHINE TOOL DESIGN

Machine tools are varied in their design, both in terms of basic function, and in terms of achieving that function. This includes the mechanical, electro mechanical and electronic units which go together to form a complete machine tool. There are many standard texts; for example, Koenigsberger [1] discusses the general mechanical principles used, such as stiffness and rigidity, and the design of elements such as slideways and spindles. Ertel [2] and Martin [3] lay out the theory behind servo control.

The present Thesis does not address itself to the design of the equipment, except where the design affects the operation of the machine tool. Thus it is the final specification which is of interest. The pertinent question is:

> "Does the machine tool have this feature?"
>
> and not
>
> "How is this feature achieved?".

This is echoed by I.Prod.E [5], discussing the type of desirable features which should be specified:

> "Purchasers are...recommended to consider accuracy and repeatability...rather than be unduly concerned about detail features which are mainly the concern of the designers".

2.3. APPLICATION

This category includes all aspects relating to the use of CNC machine tools. Whilst the standard production engineering texts were referenced,they are not reviewed. In the application of advanced manufacturing methods, it must be assumed that basic techniques are understood.

The literature includes several sub-sections.

- Tooling & Fixturing
- Methods
- Programming Techniques
- Systems Management

The latter two often blend into each other [4,6], but here the systems management will be kept separate, and treated in a later category.

2.3.1. Tooling & Fixturing

The use of CNC & NC machining techniques places special requirements on tooling and work holding [7]. Although it appears to be specialised, the actual components and principles involved have much in common with what could be considered proper practice for conventional machine tools [5,7].

Two aspects are considered to be important:

- Machining speed
- Change-over time

Here, the literature often has a dichotomy of views.

Standard production engineering texts emphasise the correct use of speeds and feeds and cutting tool materials. Ashley [8] and Turvey [9] discuss how feeds and speeds are often applied by 'rule of thumb', rather than through the use of standard data. In the same way modern cutting materials are not fully understood. This may be because the users have not been trained correctly.

However Astrop, in a short article titled "Don't Worry About Speeds and Feeds" [10], argues that there are more important aspects. Assuming a single shift working pattern, only 15% of the total machine available hours are actually used for "adding value to raw materials". The rest of the time is spent on un-used shifts, week-ends, holidays, idle time and inefficiencies, which should be addressed. Tool management to minimise set-up time is the key [7,11].

It is evident that a balanced approach should be adopted [5] to maximise the potential benefit on using CNC machining, and to ensure that the plant is well utilised. It will be in a later chapter how the emphasis should vary, depending on the specific application.

2.3.2 Methods

The earliest NC machines were milling machines [6], with lathes following together with other applications such as grinding [12]. Olsten [13] describes flame cutting, knitting, rivetting, tube bending, welding, wire processing and filament winding. Other applications include electronic component insertion and automatic testing [36]. Milling machines became machining centres which allowed several operations to be achieved by adding an automatic tool changers. This reduces component handling and setting times, and allows for the automatic substitution of worn cutting tools. Turning machines may now be equipped in the same way [14].

However, the control systems are now being used to extend the machine beyond its original process.

Milling, drilling and tapping have been the domain of the machining centre with the rotating cutter moving around a linearly moving component. The addition of a controlled dividing head allows the profiling of complex rotary parts such as impellors. In the same way, CNC lathes can now be equipped with "2nd Operation" facilities, to allow milling, drilling and tapping [15,16]. This development leads to shorter delivery times reduced W.I.P. and avoids the need for multi-stage first off inspection.

This approach will be tested in later chapters - it will be seen that such benefits may not always accrue.

An alternative approach to increase the productivity of a machine tool is to allow simultaneous cutting by two or more tools. This has recently been possible on lathes to improve the machining time/idle time ratios [17]. However, the increased complexity is not without cost. The benefits and drawbacks of this style of unit are discussed in Appendix 1.

2.3.3. Programming Techniques

Early texts on NC programming [4,6,7,13,18] discuss the methods used to translate component drawing into code to which the system would respond in a given manner. There is much emphasis given to the medium of data transfer (usually paper tape or cards) and the detail of codesets. This literature is now of little interest.

Major steps forwards, as predicted by Vlahos [6], have occurred in the performance of the machine tool control system. This has allowed, in certain cases, the machine tool to be programmed directly by the operator [19]. Colour graphics, conversational programming and tool libraries are now available [20,21,22], though Wilding [23] notes that Graphics was seen as a development nobody needed, even though virtually every control Supplier now offers this feature.

The early machines were often cumbersome to program, which brought about the need for computer-aided part programming (CAPP). This was probably because the components to be processed were complex (precisely the reason why they were selected for NC machining). There are many examples of these early C.A.P. systems [4,6,13]. Today they are powerful and sophisticated [24]. Willer [25] and Sims [26] both look forward and discuss how components can be designed on a computer, and how the NC program can then be created from this data, ready for direct input into the machine tool. No on-machine programming would be necessary, it is argued.

Thus there is a split of views, falling into four categories:

- Computer Aided Part Programming Off Line
- Computer Prompted Conversational On Line
- Manual Off Line
- Manual On Line

It is noted that "manual programming" may be a misnomer, since most manual programmers routinely tap the computer power available in micro-processor based tape-preparation systems and CNC's. At the other end of the spectrum dwell the programmers using mini-computers. It is more usual to discuss the degrees of computer involvement rather than whether or not one is used.

Coleman & Lunn [27] describe a series of tests to compare manual with Computer Assisted Programming. It was concluded that for

> "simple to medium difficulty jobs, contemporary manual programming is very competitive ..... but Computer Assist starts to shine as parts become more complex".

These tests were limited - No general conclusion can be realistically formed. The test was purely on time and not of real cost.

There is little reference in the literature to the problem of comparing methods. It seems that there is an element of commercialism: machine tool manufacturers can sell their machine to a wider range of users if it can stand alone.

Mini-computer and software producers see Computer Aided Manufacturing as a lucrative market. Meanwhile the potential user is faced with a dilemma. This will be developed further in a later chapter.

2.4. JUSTIFICATION AND ECONOMICS

This category of literature includes the general areas of savings which are to be found when installing CNC equipments, as well as case studies and in depth analyses of investment appraisal methods.

Justification forms one element in decision making, which may be expresses as:

- Why do this at all?
- Why do it Now?
- Why do it this way? [28]

More fully, it is generally accepted that any decision has the following elements [29]:

- A set of choice alternatives.
- A set of outcomes associated with each alternative .
- Environmental states which will determine which outcome will prevail given a particular decision.
- Objectives or goals which the decision maker seeks to achieve.

- Criteria derived from these general objectives which allow the choices to be ranked in terms of how far the outcomes lead to achievement of the goals.

- External constraints which are imposed on the decision maker.

- The decision-maker himself.

> "The successful manager does not make a decision simply because it is shown to be mathematically economical to do so. He makes his decision because he sees the consequences of his decision as propelling him along his short and long range objectives. The objective is not to replace an existing machine, to buy a new machine, or even when to make a product, but to carry out the reasons for being in business" [5].

Although profit is the most important reason for being in business, alternative (or supplementary) objectives may be to offer a better product or service, to expand a market share, to gain a reputation or even be an industry leader. Some might argue that to offer people gainful employment is a worthy objective.

Bromwich [29] states:

> ".... that there is little agreement in the academic literature about what the objectives are or what they ought to be. Although central to economics is the assumption that firms should seek to maximise profits, there is growing disenchantment with the idea that the Firm's aim should be the maximisation of the equity holders' wealth".

However, after considering the alternatives Bromwich falls back to the basic assumption that firms seek to maximise profits.

This is echoed by standard texts on NC, which often devote a chapter entitled "Economics of NC", and by papers which concentrate on the financial benefits which can accrue from the installation of NC equipment. Indeed, every attempt is made to quantify benefits which are not easily quantifiable.

It is worth pausing to consider what other justification routes are conceivable.

> "No trials and tribulations of mankind such as strikes or depressions can so completely destroy an established business or its profits as new and better methods, equipment and materials in the hands of an enlightened competitor" [5,7].

One approach to justification is to review what the competitor is doing, and copy [30]. The objection is that the competitor will always be one step ahead, and be in a better position to maximise profits. However, there is something to be said for not being a trailblazer. Childs [31] claims that there is little difference between the procurement of NC equipment and any other capital expenditure:

> "If NC is considered to be somewhat unique, it is probably due to the fact that many of its advantages are not yet readily discernible".

An alternative view may be that one has to search for all of the marginal benefits in order to make the case attractive.
Wilson [7] and PERA [32] make the point that first NC installations should not necessarily have to meet the same rigid justification requirements that are laid down for conventional equipment. Some authorities feel that the purchase should be considered as expenditure in manufacturing research since the benefits are impossible to predict.

It is unlikely that many Company Managements would be prepared to invest in this way. The Thesis will demonstrate how first time installations can be justified. However, it is true that subsequent justifications should draw from the first in a continual development of methodology.

Finisston [33] has reviewed the human aspects of automation (of which NC is a major part) to justify its implementation.

> "People have been used in industry...... in the most uninteresting fashion. They have been used as machines rather than as human beings because the intellectual demand on them have been in many cases nil".

An interesting angle on this is the effort being made by employers to improve the attractiveness of manufacturing industry to slow down the general drift into the service industries. [McKeown 33].

It will be seen later how NC justifications will reduce direct labour costs. Thus people will indeed be freed of boring, repetitive work, and the working environment will improve as a result. However, manpower freed is likely not to be redeployed, but to be shed.

It is not within the scope of this Thesis to develop this argument but it is important to recognise it and its ramifications on the Management of Change. Further reference will be made in a later category.

The literature, it is found, seeks justification in economic terms. This is true for both general investment, and for works which treat NC machine tools as a special case.

The current Thesis reviews NC investment literature and places it in the context of general investment theory.

There are two types of benefits which are seen to result from the use of NC and CNC equipment:

- Direct
- Indirect [5,6,7,32]

There appear to be two ways of assessing these savings, to translate them into a financial justification.

Martin [4] and Shah [34,35] use a comparison method to determine break-even points for NC and conventional machining processes. Before this can be done, a machine hour rate for each process must be established.

This must contain certain assumptions about overhead recovery ratios which are open to question. A more realistic and usual way is to calculate the actual benefits which will accrue, set these against capital and extra running costs, and perform the investment analysis.

Although the two types of benefits would seem to be self explanatory, there is dispute over how they should be organised. For example tooling costs, floor space, and scrap may be classed as direct [6], or indirect [5,7].

An alternative classification might be

- Easy to quantify in financial terms
- Difficult to quantify in financial terms

or

- Obvious (tangible) - any new plant savings
- Non-obvious (Intangible) - specifically NC [7]

or even

- Easy to prove/disprove
- Difficult to prove/disprove

It will be discussed later how the benefits should be classified, if at all. Below, the benefits cited in the literature will be noted with no attempt at classification.

- Floor to Floor Times - can be reduced by virtue of a fully automatic cycle (It will be seen later that this does not always happen). [5,6]

. Tooling Costs	-	Jigs and fixtures (design,manufacture storage maintenance) costs reduced [5,6,7,36].
. Cutting tools		Optimum tool lives achieved because speed and feeds can be optimised [5,6,7,36].
. Floor Space		N/C machines can do the work of a group of previous machines and so minimise the need for plant expansion. Tooling and inventors storage space can also be reduced [4,5,6,32,36].
. Machine Operators		Fewer operators and lower operator skills required. Multi-machine manning is also possible [6].
. Scrap and Rework		Operator errors, tool damage, scrap and rework can be minimised [4,6,7,32].

. Assembly	Handwork and fitting problems during assembly can be eliminated by the improved accuracy [4,6,36].
. Inspection	Accuracy of NC machines can reduce the number of measurements required [4,5,6,7].
. Quality	NC machines can achieve high levels of accuracy and uniformity of parts which will increase reliability in the field [6,7].
. WIP	NC machines quicken production through high speed production and short change over times. Thus it becomes economic to have shorter batches, which, together with higher utilisation, leads to a reduction in WIP [4,37].
. Inventory	Smaller inventories can be sustained because parts can be produced at short notice. Whilst this can reduce costs, it can also allow better inventory control and lessens the risk of obsolescence [5,6,7].

- Prototypes/New Models - Can be put into production quickly without the need to make jigs [4,6,7].

- Design freedom - The designer can consider optimum performance and cost without depending upon the limitation of conventional manufacturing methods [6].

- Customer Service - Reduction in lead times and the ability to accurately duplicate any NC programmed part at any time makes it possible to deliver repair parts on short notice [6].

- Sales - NC-equipped companies are able to serve customers faster with better quality often at a lower price, and commonly report that customers have more confidence in automated NC machining [6].

- Lead Times - Reduction in lead time can provide flexibility to meet changing design of marketing requirements [5,6,32,36].

- Flexibility - Multi-purpose NC machines can meet a broad range of future work requirements [6].

- Added revenue - Increased production with NC means added revenue - the added increments of production that carry the highest level of profitability [6].

- Management Control - Dependence upon operator skills, attitudes and fatigue levels is replaced by programmed production. Scheduling is simplified, and since production rates are more predictable, cost estimating is more accurate [5,6,32].

- Maintenance/Downtime - Replacement of old, worn out machinery with new will lead to a reduction in downtime for maintenance [5].

- Eliminating secondary operations - NC machining can perform operations that previously required several processes [5,15,16].

- Operator Training - The automatic cycle requires less operator skill, and reduction in man power leads to a reduction in training [5].

- Materials handling - The elimination of secondary operation allows a saving in material handling costs [4,5,7,36].

- Department efficiency- When a more productive machine is installed, it can have a stimulating effect on the workers not assigned to the new machine [5].

- Machine deterioration- The performance of a machine tool can fall as it ages. Replacement with new equipment redresses this deterioration [7].

- Increase machine utilisation - Less time is spent on set-up, tool change and inspection, forcing the utilisation up [36]. However, it can be argued that this is an assumption based on "we will make sure that past inefficiencies do not happen on this machine" [38].

It is therefore possible to see how the literature itemises the apparent benefits which result from the introduction of NC equipment. In a later chapter the realism and practicality of them will be discussed. However before moving on to review the methods of analysing the benefits it is a worth nothing some cautionary points.

Kilmartin [39] cites an in-company study where the global assumptions suggested in the literature were found not to be true, especially on utilisation, and the expected benefits did not appear. Kellock [40] discusses a Company case history which found that technology did not solve problems and that machine tools where not as productive as predicted.

It has also been found that quality assurance expectations for NC machines are often beyond their capabilities. This may be because the users have equated the machine tools reported accuracy with the accuracy of the components they produce [41].

Once the benefits have been established they must be analysed to assess whether indeed the expenditure will prove a worthwhile investment. The assessment of the capital projects can be measured in at least one of four ways [42]:

- Payback Method
- Rate of Return Method (or return on investment or return on capital employed
- MAPI Method
- Discounting Method.

Standard NC texts tend to assume the Payback Method which is generally understood to be the ratio between project investment and average net incremental cash flows. This can be used as a simple rough screening device for eliminating very poor projects but can be criticised because it does not take specific account of the earning life of a project, and does not allow for the time value of money [43]. Although Payback may be a useful appraisal devise for the firm that is expecting liquidity problems [29], the method is regarded as unsatisfactory for projects where benefits will accrue over a period of time.

The Rate of Return is the ratio of profit to capital invested. This method generally does take account of a project's earnings over its lifetime and therefore represents an improvement over the payback technique [29]. However, it suffers from the difficulty of putting a figure to expected profits in cases where the profit may not be constant over the years [43]. In addition, it incorporates the distorting effects of the arbitrary allocation of depreciation [29,43], and, like the Payback Method, it fails to take account of the time value of money [42].

Merret and Sykes [45] conclude both Payback and Rate of Return Methods are:

> "..... seriously inadequate for the task of optimising investments decisions"

Although then, the economic literature condemns these approaches, it was found shown in a 1981 survey that Payback and Rate of Return Methods were used 64% of the time [38].

It is not the purpose of the this Thesis to examine the underlying reasons. It may be because the more sophisticated methods are not easily applied of understood.

Childs [31] offers the MAPI Method as an approach to justification. This technique was developed by G. Terbourgh [45] at the Machinery and Allied Products Institute in the United States. Although Childs states that it is probably the most popular method of justification, it does not seem to be widely used in the literature in the UK. It is mentioned by Hitomi [46], though it seems to concentrate on the economics of retirement and replacement [28]. The MAPI formula compares the first year's cost to produce parts by the existing method with that of a proposed method. The savings which would accrue from the first year's operation of the new method are then compared with the first year apportioned cost of the new plant. The approach is similar to the Payback Method, except that MAPI weighs the first year's savings against the apportioned first year's cost. Depreciation is treated not on a straight line basis, but by doubling the percentage rate and depreciating the declining balance. This method never writes-off the item, but this is not important because it is only the first year which is considered.

Childs's [31] opinion that it is not unreasonable to limit the assessment to only the first year is based on the fact that predictions beyond the first year incorporate a good deal of speculation. However, this does not agree with the economists' and accountants' view when DCF calculations are made.

The MAPI formula is simple to understand and easy to use, but does not allow easy comparison of projects where the emphasis on timing may be important. It is for this reason that Discounting Methods may be preferred.

Major offers a justification method which uses discounting techniques but specifically for the installation of NC equipment. He reported difficulties in putting believable numbers to the many variables involved in the Discounting Methods. His analysis appears to be useful when comparing options, but it is doubtful whether it can give an absolute indication on the viability of a project. In addition it is difficult to translate this method into a general format because of the idiosyncrasies of taxes in the Author's country (Canada).

Discounting Method philosophies can be approached either to give a Net Present Value (NPV) or a Discounted Cash Flow Yield. Merret and Sykes [44] describe both. The NPV is calculated by discounting future cash flows at some fixed, annual rate (to account for the cost of capital) to end up with a surplus or deficit present value. The DCF Yield Method adjusts the discounting rate until the future cash flows have the same present value as the original investments. In other words, the DCF Yield (or Internal Rate of Return) is the rate at which the NPV (surplus cash earned) equals zero.

It will be appreciated that both approaches are equally sound technically though Merrett prefers the DCF Yield. However, this is not unanimous [29]. Leslie [47] is unusual in being a specialist NC Handbook which realises the significance of DCF and demonstrates its application.

Thus the literature, whilst agreeing on the philosophy of discounting, is not united on which method should be used.

It has been seen that there is a split in the literature between what might be called "The engineer's stand point" and "The Accountant's stand point" in terms of the justification models used. The difference may be seen to go further [37] in that engineers, having determined a value, will indicate that that value determination is not perfect and place a tolerance on the value. Other engineers using the results in other fields may further amend the value by a factor of safety. However, accountants generally quantify values in precise terms; values which cannot be determined precisely are not qualified by tolerance indications but by riding statements such as "Fair and Reasonable Views". It will be shown in later chapters now this can affect the methodology of NC justification.

2.5 MANAGERIAL

The managerial aspects of the use of NC machine tools may be split into economics, justification, introduction and running. The economics of NC machine tools and their potential benefits have been reviewed in a previous section. Here, the literature covering the introduction and running of the plant is discussed.

The introduction of any new plant into a factory should be treated in the same way. The literature covering this general topic is not reviewed but the introduction of NC machine tools is treated as a specific case. Many of the points raised would be applicable to the general case.

The degree of success achieved by an NC installation depends on the understanding and commitment by senior management [48].

However, Shah [34,35] argues that NC machine tools should not be treated as conventional machines because they differ in many ways including maintenance, tooling, scheduling and operation planning and require extensive supporting services such as programming and tape preparation groups. Although the points raised are valid, the conclusion drawn that NC is a special case is not. The general concept of a methodical, well planned campaign should be identical. Like all projects, NC has its own particular problems which should be tackled.

This commitment should manifest itself by the appointment of a high level person to co-ordinate the introduction and who can influence (if not make) policy [49]. He should have a mandate from top management delegating the task and vesting the necessary authority. He should have the ability to organise, to question and rethink techniques and procedures and have a knowledge of Production Engineering and Machine Tools.

It is not apparent from the literature whether the cost of this man should be absorbed as a general overhead or by the first year NC project costs.

This leader will have around him a team with representation from manufacturing, tooling, programming, quality assurance, maintenance and other involved functions. The team's job begins with justification of the initial NC machine. It never ends [48].

Terbourgh [45] develops the concept of project character, classifying them as either "Shop" (or minor) and "Front Office" (or major) projects. The division is a useful one, though it will be seen later that there is some benefit in presenting all on a "Shop" basis.

Fig. 2 [from 34,35] shows a CPM chart for the introduction of NC machines which provides one with a comprehensive checklist. Ferris [49] shows a simplified version of this. It will be seen that the project is complex, with a great deal of interaction.

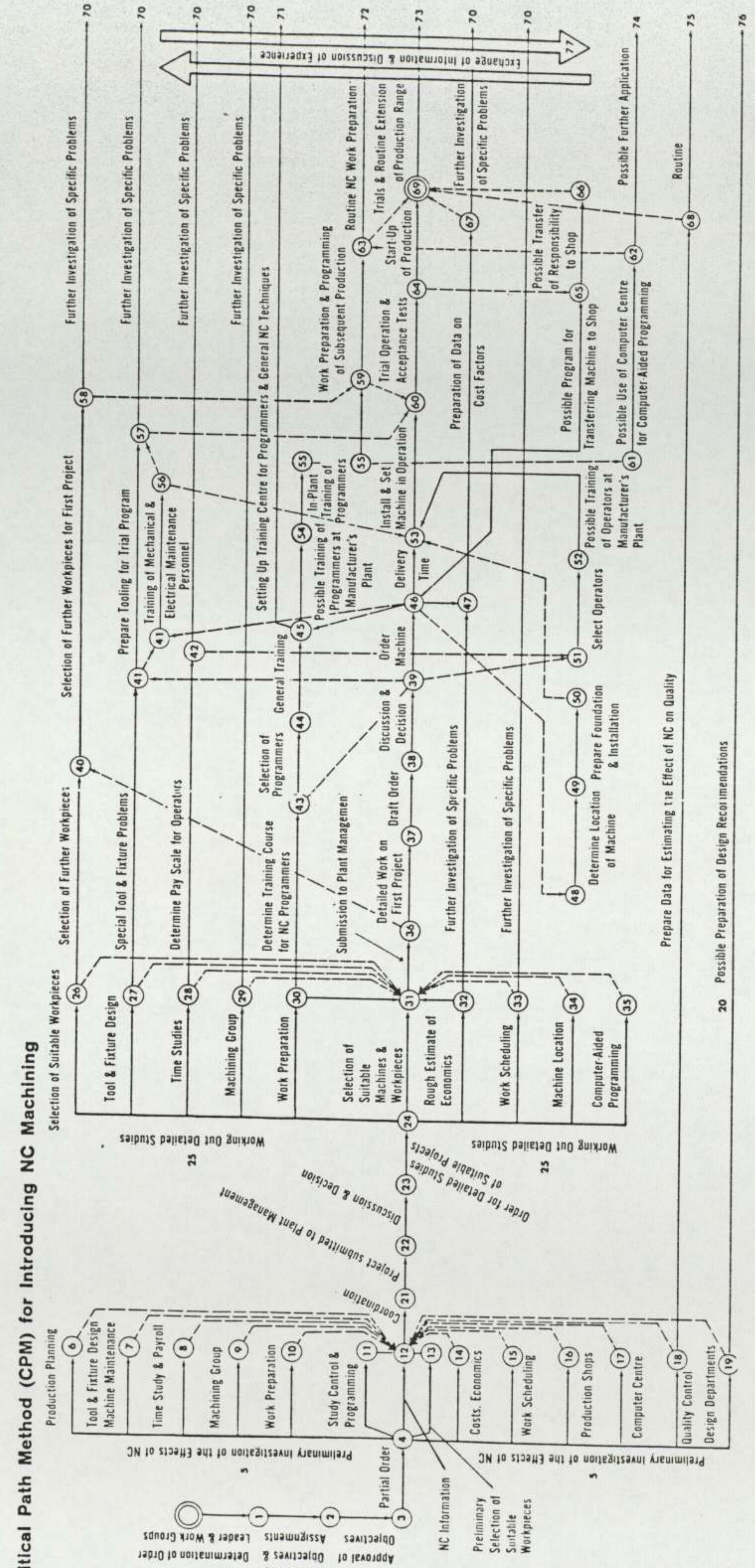


FIG 2: CPM FOR INTRODUCING CNC MACHINES

These charts are self explanatory, but fail to discuss the Industrial Relations aspects which must be considered. It is here that one must draw upon the philosophies incorporated in the general management of change, the key concept being employee involvement [33].

NC specialist literature is weak because it tends to concentrate on the engineering change rather than the total change. I.Prod.E [5] devotes only a small section to IR and touches upon machine location, job responsibilities, shift operation and payment methods. However, there must be an overall philosophy of how the change is going to be effected.

The main thrust of Rooney [33] is how to persuade people to change.

> "When a man is his own master, he is an innovative creature but when he is not (which is true of the vast majority of people in industry), then if change is in the air he is at best anxious and at worse deeply threatened."

He goes on to suggest that people who are going to be affected by the change should be involved in the change. The management approach based on "Like it or lump it " or "We will do it now because the manager says so", is a recipe for disaster. The rules to a smooth plan of change are laid down, including timing, participation and behaviour. It will be seen in later chapter how important this aspect is in the introduction of NC equipment, despite the literature being weak. It will be shown that however comprehensive the justification and search for the best machine tools, no matter how sophisticated then tooling, if the will of the people is absent the machine will not achieve expectations.

2.6 MACHINE TOOL AND SYSTEM SELECTION

This is a key area in the introduction of all new manufacturing equipment: NC is no exception. The selector is faced with a wide variety of options and sub-options. It will be seen later how large and overwhelming this jungle can be for the uninitiated.

The potential NC machine tool user must not only financially justify his purchase and install it with sound management practices, but also correctly select the plant most suited to his application. He may want to read about recent developments.

The literature cited so far in this survey has for the most part consisted of texts and technical papers presented to pass on objective comments, experience and knowledge. However, the rapid technological development which has taken place has caused certain of these works to be outdated. This is especially true of case studies and technical background.

The prime source of technical data on machines will come from the suppliers (Agents or Manufacturers). The quality of the information may vary from a simple list of specifications and characteristics through to a sophisticated piece of technical advertising claiming specific benefits. It is unusual to find comparisons made with competitors though some suppliers do produce these as an aid to salesmen.

The potential purchaser does need to make unbiased comparisons: the Machine Tool Industry Research Association (MTIRA) run a machine tool selection service which is run on a card index. The data contained is very basic, but can be useful as a starting point. The most recent published comparisons [50] give a brief specification summary for a wide selection of turning centres and lathes. It is not comprehensive enough for machine tool selection purposes and contains no price data.

Shah [35] provides a far more comprehensive series of specification charts covering most major machine classifications. It is a little dated (1980), has no price details and is international: not all machinery listed may be available locally.

Thus the selector should collate his own data by contacting suppliers himself. This will ensure that the information obtained is current and accurate, and that pricing details are on a comparable basis (exchange rate fluctuations)

This is not a task to be undertaken lightly - Shah's International Directory of Machines and List of Suppliers [35] offer a range of over 460 different lathes.

Suppliers available in the UK (manufacturers/agents) may be found through Buyers' Guides [51,52], advertisements in trade/professional journals and exhibitions. The latter can be very useful in obtaining realistic target specifications but can be time consuming. The value of exhibitions will be discussed in a later chapter. Cookson [1] believes that they are more useful than conferences.

Once the potential user has decided to collect data to aid his selection process, he must then decide what parameters are relevant, and what weight must be applied to each. There is no standard specification layout from machine tool suppliers and some information may not readily be obtainable.

There are a number of frameworks available to aid the collation and comparison of information [1,35].The most comprehensive is produced by MTIRA [53], which comes in the form of blank charts, and includes space for machine tool, system, supplier's reputation, maintenance and spares facilities. This systematic way of presenting the raw data allows the use of value selection by applying a weighting factor. This can be useful in aiding a decision where two or more machines are similar, or where they differ widely but meet the requirements in different respects. The usefulness of value selection will be discussed in a later chapter.

The literature is poor in discussing the commercial aspects of machine tool purchasing. Contractural requirements are well understood, but the relationship between the vendor and purchaser prior to formal contract are not covered. The importance of the relationship between the representatives of the two parties is probably underestimated and will be discussed later.

2.7 JOURNALISTIC AND COMMERCIAL.

Editorial articles in both Trade and Professional journals are often in the form of potted case studies. They should be treated with caution however, because invariably their objective is publicity for a particular make of machine tool rather than the dissemination of information. killock [54] outlines the financial and technical problems of one small subcontractor which was convinced that the only way to survive was by using CNC machine tools. This article does not develop the ideas involved. It merely acts as an advertising vehicle for two machine tool agencies.

An unattributed article [55] illustrates one particular machine and follows on with a survey of three companies which used it. Again, the discussion is shallow, concluding with the statement:

> " With the right management attitude and involvement, with the right operator and in the right area, one machine can more than justify the investment."

There are numerous similar articles [56-69] which retread the same theme.

Occasionally, an article will attempt to go a little further. Atkey [70] describes the Westland Helicopter project which decided to use conversational control systems so that the existing manpower skills could be used to advantage. A follow-up note [71] gave the final results of this development. However, there is still the underlying element of publicity for the Supplier (and of course the User).

These articles can often be given an air of respectability. "Numerical Control" [76] is a two volume compilation of articles drawn from a wide variety of sources: some are papers; the majority are reprints of commercial/journalistic articles which happen to mention machine names.

In conclusion, the use of commercially based "journo-technical" papers are of little hard value, though they can provide some general food for thought.

3. THE GENERAL FRAMEWORK

3.1. OVERVIEW

This chapter lays down a systematic methodology for the introduction of CNC machine tools into a company.

This framework starts with project definition and ends with the installation, commissioning, running and post audit. It also covers machine tool assessment and selection, financial justification, personnel selection, and systems management. It is specific to CNC machine tools, though with modification it could be applied to introducing other manufacturing facilities. The methodology will be tested in a later chapter by a real Company case where machines were installed in two cost centres on a single site. This will allow a useful comparison to be made.

The two cases will be seen to be fundamentally different in their environment, products and systems. It will be shown how the framework should be applied so that these differences will be highlighted.

The first stage to consider is the general framework.

The framework for the introduction of CNC machine tools falls into ten activity phases. Although they are treated in a modular form here, it will be seen that none can be treated separately. The phases feedback on each other with the results of one phase being affected by, and effecting the results of another. The splits between phases might be said to be arbitrary, but can be defended by the type of activity within each.

In addition the phases are in chronological order, though one may (and often must) start one before completion of the previous phase. It may be that each phase is completed by a different person, though it will be seen that this is inadvisable.

3.2. PHASE ONE - DEFINITION OF TERMS OF REFERENCE

This phase should include problem definition, timescale projection and a project team structure, as well as aims and objectives.

The decision to investigate the viability of CNC machine tools can come about in several ways. It can be Front-Office initiated, or Shop initiated. It is most likely to be a combination of both. In other words, Shop personnel realise that there is a "better" way of performing a function and the Front-Office is continuously attempting to improve its profitability.

However, it is important to highlight the fact that a mainly Front-Office initiated project may have different objectives and judgement criteria and that this can affect the go/no-go decision. A Shop driven project is more likely to succeed because it will not be seen as being the latest management "fad".

Thus a project which is conceived by management must be turned with subtlty into a shop driven project in its embryonic stage. On the other hand, a Shop idea will get nowhere without management backing, and this must be obtained and maintained.

It is imperative to nominate an individual to co-ordinate, guide and, if necessary, force the project through its programme. There may be an existing member of the production engineering team, or he may need to be recruited. In either case, he should be recognised by all as "Mr. CNC," with full responsibility and total accountability. He will need to be able to blend technical and financial requirements, and to be prepared to nurse men and machines as the introduction takes place.

Upon his appointment he should be presented with his terms of reference, a sample of which is shown in Fig. 3. This might be accompanied by a summary of the framework phases as a check list, though he should be motivated to think and act in a logical, structured manner. The terms of reference should be sufficient as a guideline document.

PROJECT LEADER - TERMS OF REFERENCE

PROJECT TYPE	.	Manufacturing facilities improvement.
AIMS	.	To study the feasibility and viabilities of installing CNC equipment within the Machine Shop.
OBJECTIVES	.	Cost reduction.
	.	Quality improvement.
	.	Improved Customer Service.
	.	Increased Flexibility.
METHOD	.	Detailed parts analysis to determine target specification.
	.	Search and find most suitable machine tool.
	.	Justify Financially.
JUSTIFICATION	.	Use of savings analysis to allow DCF computation.
BUDGET/TIMESCALE	.	To be agreed after preliminary study.
RESPONSIBILITIES TO INCLUDE	.	To take project from conception through to installation and to provide aftercare once in production.
	.	Appointment of project team.
	.	Technical and financial justification of most suitable machines and ancillary equipment.
	.	Personnel selection and training.
	.	Information dissemination.
	.	Obtaining of grants if available.
	.	Machine installation and commissioning.
	.	Aftercare.
REPORT TO	.	Manufacturing Director on a continuous basis.
LIAISE WITH	.	Shop supervisors, superintendent, managers.
	.	Engineering services/maintenance department.
	.	Industrial engineering department.
	.	Quality department.
	.	Cost and management accountants
	.	Commercial/Sales department.
	.	Data processing department.
	.	Personnel department.

FIG 3 SAMPLE CNC TERMS OF REFERENCE

This philosophy of "management by involvement" should be adopted throughout the project. The leader should generate interest through the use of both formal seminars and informal conversation, notice boards, handouts and Company briefing notes. Once generated, the interest must be sustained. The information flow should be bi-directional, with the team leader noting all comments arising from the project. Questions must be answered, worries and fears allayed and curiosity satisfied.

It is certain that a major worry will be security of jobs. CNC machine tools, like robots and other "high-tech" plant, have a reputation for cutting manpower. There is no simple solution, since justification will often be dependent on the reduction in direct hours. The benefit will only be achieved if those direct hours actually disappear from the payroll, unless the volume of work changes.

Possible approaches are as follows:

- Commence project with a declining order book so that the shedding of labour can be combined.

- Commence project with a growing order book so that the direct hours can be redeployed.

- Commence project at a time when there are retirements due, so that direct hours are shed through natural wastage.

- Shed labour directly attributable to the project with no attempt to conceal the cause.

- Find the alternative benefits to allow justification with no requirement on labour shedding.

The project leader should agree upon the strategy with the senior management. Once adopted, there should be consistency of policy: no promises should be made which cannot be kept.

A NOTE ON DATA COLLECTION

It may be found that the raw historical data does not exist to allow the project to proceed as described. At best, it is likely to be incomplete or inaccurate. The collection of new data may be necessary and it is worth noting the following points.

1. Data collection is time consuming, enough time must be laid aside to allow for this activity.

2. Data collection is unpopular, especially where it is seen to encroach on personal freedom. The decision to collect data must be carefully considered and discussed with all concerned.

3. Data collection is not always passive. The very act of measuring a parameter can have an affect on the parameter itself. Examples are setting times and reject rates.

3.3. PHASE 2 - ASSESS EXISTING SITUATION

This phase is designed to allow the reviewing of the existing situation, and to collect the data which will be necessary in later phases. It presupposes that the terms of reference have been agreed.

This assessment should include the following items :

- Product mix analysis
- Factory data
- Plant survey
- Manufacturing systems
- Personnel

i) Product Mix Analysis.

The products manufactured within the target area must be surveyed. These may be limited in number, but more usually the quantity will be too large for every item to be analysed in detail.

The first stage should be to review the total production of the target area over a given time. A year is a suitable period. The breakdown should give batch quantity and frequency for each component. Armed with this data, a representative sample may be selected. A check should be made to ensure that it is representative.

- Are (or will) any components be discontinued?

- Are there any technical/commercial changes due which will make the sample unrepresentative?

Having established a suitable sample range the analysis may proceed, by categorising according to the following parameters:

- By raw material composition and condition
- By size
- By shape
- By accuracy required
- By complexity of operations
- By batch size
- By batch frequency

The result will be a series of profiles which can be used to develop a "Typical" component. It may be found that the profiles suggest two or more differing "Typical" components which suggest a multi-pronged attack, the outcome being that a number of varying styles of machine tools are required.

ii) <u>Factory data</u>

The following data should be collected for use at the justification stage:

- Production and set up times
- Value of components
- Jig and tooling costs
- Inspection costs
- Reject rates

iii) <u>Plant Survey</u>

The existing manufacturing plant used should be surveyed with the following parameters in mind:

- Age and condition
- Make and type
- Book value
- Machine specification and feature
  - spindle speeds
  - capacity
  - Traverse
- Maintenance costs.

The survey will result in a series of machine profiles which should be corrected, maintained and reviewed on a regular basis. These can be used for developing a machine replacement policy and as an aid to production engineering and maintenance programmes.

iv) Assessment of Manufacturing Systems.

It is necessary to understand how the production system operates. This allows weaknesses and deficiencies to be corrected so that new plant introduction will be smooth and trouble free.

The most important system is the programming system. If there is no existing NC or CNC plant then a new system is required. If there is one already operating, its appropriateness should be tested and action taken accordingly. In either case, program generation, data storage and documentation procedures must be considered. The requirement for a new system will be detailed later. The present stage is designed to highlight where the weaknesses lie.

Quality control is also important. In volume production, work may require pre-production pass-off, followed by regular gauging.

In this case, the procedures should be tested:

- Will the facility be able to cope with the increased level of work without holding up the machines?

- Will the machine tools reduce the requirements for pass-off and subsequent gauging?

- How are the gauging periods determined and will the parameters continue to be appropriate?

- Is the equipment used of suitable style and quality?

Low volume (or one off) production may not have formal quality control procedures, in which case the following should be noted:

- Where does quality accountability lie?

- Is the equipment used of suitable style and quality?

- How is the quality level determined?.

Vital to the economic operation of all machine tools is the planning of manufacture. This is no less true for CNC equipment, and in fact is possibly more important. The CNC machines will probably replace an assortment of conventional plant where there is little emphasis on utilisation.

Thus raw materials and tooling shortages take on a new importance, for without these ingredients the machines will fail to deliver. The following questions should be asked:

- How is work loaded on to the cost centre?
- What is the procedure for raw materials requisitioning?
- How are tooling requirements determined and corrected where necessary?

Related to the planning of manufacture is the production of management reports. These gives an indication of how well the function is performing either against a predetermined budget or against historical records.

- Will these measures continue to be appropriate?

If not, then more suitable parameters must be found and methods of measuring them determined.

It is important to note that this aspect should be tackled carefully. Performance ratios can be used to determine the sign and size effect of a particular manufacturering system change.

This will only be valid if the ratios:

- Are not affected by other factors.
- Are the most appropriate.

Thus any reporting weaknesses should rectified well before plant installation to allow the building of a valid historical data base which can be used for "Before" and "After" post audits. It will be seen later how difficult this can be in practice.

v) Personnel Assessment.

No matter how sophisticated the economic justification, how thorough the product mix analysis, and how expensive the plant, the project will fall short of expectations without the proper consideration of personnel. This point will be expanded upon in a later chapter. Suffice it to note at this stage, that it can be argued that the more automated a manufacturing system becomes, so the human influence becomes vested in fewer people. In the limit one person could have control of a very large system. Thus the suitability of this one person for the job must be very carefully explored.

CNC manufacturing takes much of the operator influence away and places it in the hands of programmers. If the necessary skills are not available, then there are a number of options available:

Either

- Recruit ready trained personnel

or

- Train existing personnel who show the required aptitude and attitude

or

- Recruit good raw material for subsequent training.

This stage is designed assess the level of expertise available in-house (latent or otherwise). A later phase deals with personnel selection and training.

In addition, an assessment should be made of the supervisory, maintenance and other supporting staff for their ability to take on the new equipment. This may well require a quantum leap in concepts, skills, understanding and knowledge and will extend right up to senior management. In other cases cases the new plant may be purely a natural development. The same thorough audit of personnel should nonetheless take place.

3.4 PHASE 3: REVIEW OPTIONS

This phase runs alongside the entire study and is more a method of thinking than an activity phase in its own right. However, it is treated as a discrete phase here, so that the nature of option reviewing can be highlighted. Properly initiated, it will ensure that all avenues are considered.

The review takes place at a number of levels, each more detailed than the previous level. The example in Fig. 4 shows how the review looks rather like a decision tree. The legs may be of unequal length depending on the nature of the option.

The first attempt to produce a review tree will leave many unanswered questions, but will serve to clarify thinking.

As the rest of the study continues, options will be considered in more detail and benefits will be added. The decision which shows the best benefits should be passed up the tree for comparison at the next level. In this way, the most beneficial decision route will appear.

The primary function of the reviewing task is to ensure that minds are not closed prematurely. The present Thesis does not consider the non-CNC routes.

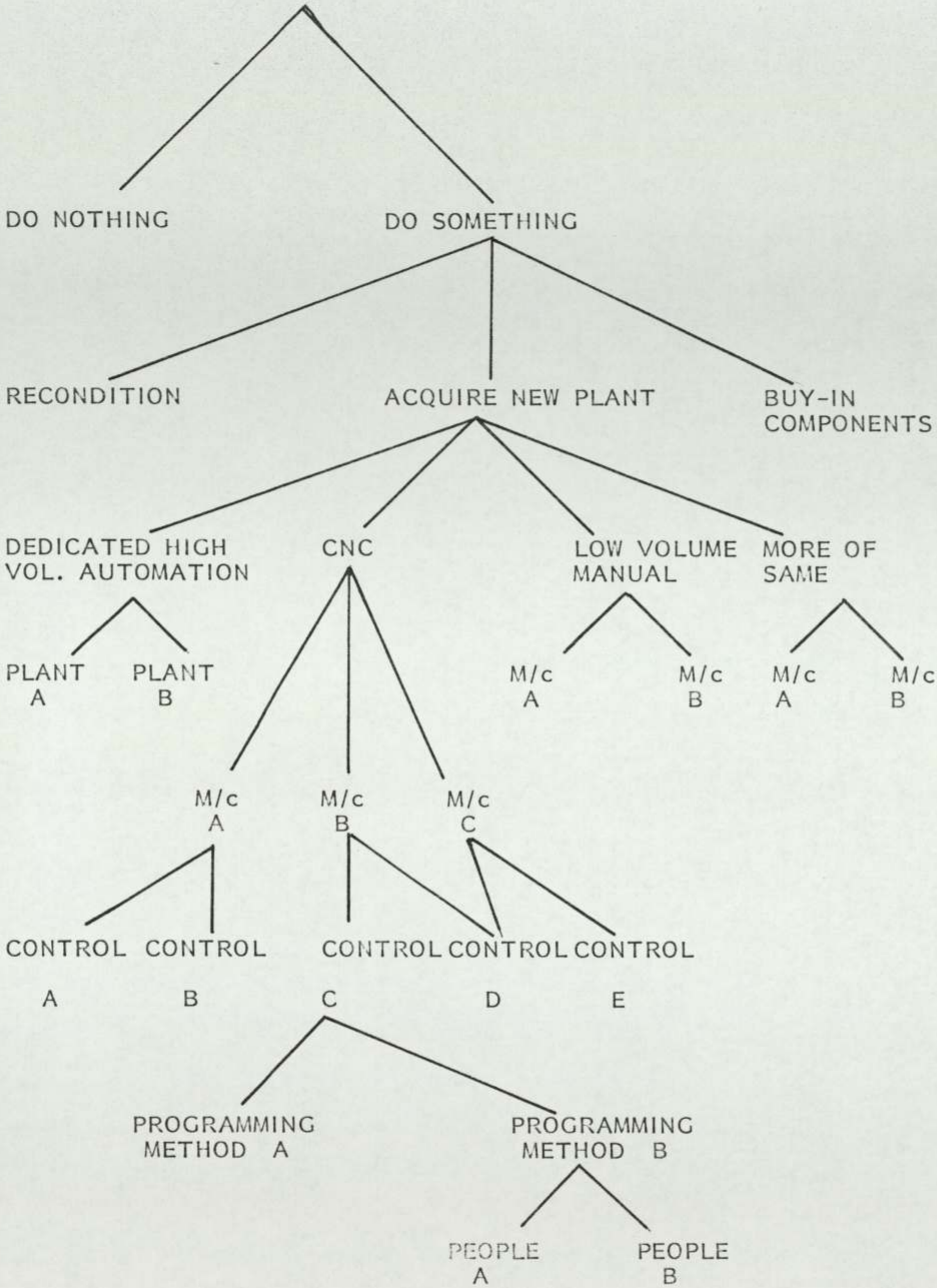


FIG.4 CNC OPTION REVIEW TREE

3.5. PHASE 4: DESIGN TARGET SPECIFICATION

If the option review determines that CNC machines are the best option then the target specification can begin. This should commence with a rough-cut target for use as a course filter when contacting suppliers. The second target will be more detailed: the third will be even more so.

The multi-stage process limits the unnecessary collation of data for unsuitable machines, making it easier to quickly isolate those worthy of detailed study.

Figure 5 shows a sample rough cut target specification.

The characteristics included in the specification are determined by the data collated during the assessment of the existing situation. The rough cut need not be exhaustive: it should merely act as a guideline to suppliers. As information arrives, the specification can be expanded and amended.

It is not the purpose of the Thesis to lay down what characteristics are important or what they should be in numerical or other terms. It will be seen from the Cases discussed in a later chapter that each application will have different emphases. It is stressed that it is the principle which is important.

MACHINE TYPE:	CNC Lathe
APPLICATION:	Production Machine Shop
PRIMARY OBJECTIVE:	To economically replace capstan lathes.
MACHINING ENVELOPE:	6" Dia x 4" Long
MAXIMUM HORSEPOWER:	10 HP
SPINDLE SPEED RANGE:	0-5000 RPM steplessly variable
TOOLING POSITIONS:	6 maximum
CONTROL SYSTEM:	Contouring canned cycles
	Paper tape input/output
	Tool nose radius compensation
	On-machine conversational programming
	Graphic representation of cutter paths
	Full screen edit functions
	16K permanent RAM
OPTIONS:	Swarf Conveyor
	3 Jaw / 2 Jaw chucks
	Bar feed
BUDGET:	£40.000 installed and tooled up.

FIG. 5 SAMPLE ROUGH CUT TARGET SPECIFICATION

3.6. PHASE 5: STUDY MACHINE TOOL MARKET AND SELECT MACHINE

This is a very important phase, but should only begin when the target specification has been agreed.

It is vital to ensure that the market is adequately covered. If this is not done then there is a risk that a suitable machine is rejected by default. Trade directories, buyers' guides, exhibitions (with their manuals) and the trade press should all be used to find suppliers.

The best method to ensure that information is correct and current, is to present each Supplier with the rough cut target specification and a number of drawings of representative parts. In this way he will understand the overall requirements and be in a position to select the most suitable plant from his range. However, care should be taken to ensure that he does not reject a suitable machine. The Supplier should be asked for a quote and for the technical specifications.

At this stage it is likely that the suppliers will change from passive to active marketing. In other words they will start a positive sales campaign.

It is worth making a few salient points on this subject if the machine tool selection is to be successful.

The Supplier will wish to establish an immediate presence, usually by personal contact through a sales representative who may or may not be an Engineer. He may be a "Professional Salesman", through it is generally found that the market is so specialised that the representative will have an production engineering background.

His first objective will be to establish the reason for the enquiry:

- The client has not yet decided anything
- The client has decided to do something
- The client has decided to purchase CNC plant, but has not yet selected the unit(s)

If he finds the client to be in either of the first two categories then he will either:

- Commence a program of education on benefits and advantages to get the client to the third stage.

or

- Leave the enquiry until the client reaches the third stage, either by learning, or through another representative carrying out the education for him.

For these reasons the potential buyer must present himself as a third stage client; that is, he has decided what he wants to do and has clear objectives.

The representative looks for the "Three M's:

- Man
- Method
- Money

The individual (usually the project team leader) must present himself as being the man with the authority and ability to make the decisions and that the budget is available to carry out the project. The representative will satisfy himself that his CNC machine tools are likely to be a competitive method for manufacturing the components.

It is said that the UK machine tool industry is like a village. The suppliers know each others' strengths and weaknesses; the representatives know each other. In addition clients get a reputation. It will be found that suppliers responds in a positive fashion, if the client presents himself as a knowledgeable professional man who does not waste time (His own or other peoples) and who has clear objectives. This image should be complemented by courtesy calls or letters to suppliers who have quoted but been unsuccessful in their bids. The approach to be adopted when closing a deal will be discovered in a later phase.

Once the information from the suppliers has been collected, it must be collated into a suitable form to allow comparison. This is most easily done by assembling the data on a comparison chart.

The medium cut specification should allow a short-list to be drawn up. It may be found that the nature of the rough cut filtering allows one to proceed directly to the short-listing and final selection stage. This will happen when the rough cut target contains a feature which is in some way unusual.

Examples would be two turrets on a lathe, or a very large quill on a machining centre.

Having reached a shortlist of machines which are capable of performing the desired functions, a final comparison must be made against the detailed target specification. It is likely that there will be a need to request further details from the Supplier, who may not be able to furnish the information. Such gaps in data should be noted. In addition, the suppliers themselves should be audited to test their ability to supply and maintain the equipment. The financial affairs of the Company might also be investigated, especially if the project is multi-machine or multi-staged. Spares holding, training facilities and the quality and quantity of service engineers warrant special attention.

The suppliers on the shortlist should be requested to requote if there has been any significant time lapse since the original enquiry. Price increases, currency fluctuations, specification changes and delivery lead time variations will all affect the attractiveness of a particular machine tool. Quotes should be stripped down to a basic machine price, with additional equipment noted separately, to allow true price comparisons to be made. Where units are imported, prices should always be set on exchange rates ruling on a particular date.

Visits to a number of previous installations for each Supplier should be carried out to assess the plant performance in the field. Due note should be taken of adverse comments. There should be an attempt to discuss the machines independently with the actual users, rather than the people who were responsible for implementing the machines, who may not be totally objective. Selection of the sites to be visited should not be left to the Supplier: it is preferable to select from a complete list of installations.

Before final selection, the machine tools should be put to the test through the use of cutting trials. The components should be representative, but if possible they should be difficult. Cutting trials fulfil several needs, in that they:

- Allow real life tests agains suppliers' claims
- Test the suppliers' ability to provide customer support
- Allow other members to the team (including machine operators) to see the machine manufacturing components with which they are familiar and to note ease of access, guarding etc.

The components should be tested for quality, and floor-to-floor times compared with those claimed by the Supplier at the quotation stage. Variances should be investigated and noted.

The selector now has enough facts to select the most suitable machine tool. Weighting of features to allow value analysis may be necessary to aid selection. In other cases, the machine tool will select itself. Thus the final choice will have been made taking into account not only the technical performance of the machine tool, but also other factors such as ergonomics and Supplier's standing.

3.7. PHASE 6: FINANCIAL JUSTIFICATION

The financial justification of a CNC machine tool takes the data collected in Phases 2 (Assess Existing Situation) and 5 (Select Machine Tool), and manipulates it to form a realistic projection of the financial benefits.

Here the definition of realistic, is that all items should have objective existence. Benefits which can not be shown to exist should not be included. The result of the justification phase will be a report produced as a tool to decision-making. This report should have credibility or it will run the risk of rejection because the assessor cannot, will not or should not believe in its contents.

The components with in the sample load from Phase 2 should be analysed in turn to assess the change in:

- Direct times to produce components
- Indirect times to produce components (setting, inspection, programming etc.)
- Reject rates and costs
- Tooling costs
- Any other specific cost (material, power etc.)

The result from this sample load analysis should then be scaled up to give a full year's representation. This can be used either to calculate the total number of machines required (given unlimited budget), or more usually, the benefits obtainable through the introduction of a fixed number of machines.

The data for the existing situation has been collected during Phase 2; the CNC case must now be discussed.

Production times may be estimated with a reasonable degree of accuracy by the use of synthetics. A cycle can be split into:

- Component load/unload time
- Cutting time
- Tool change time
- Tool positioning time

The load/unload time, which is significant for short cycle time components, can be determined through the use of Standard Times. Tool change and positioning times are machine-dependent, and can be determined from the technical specification of the machine tool selected in Phase 5.

Cutting times can be assessed by using standard cutting data and matching this with surface length. Thus the cycle time can be calculated and compared with the existing method.

CNC setting times will vary from component to component. They will probably represent a major element in the build-up of benefits. Where a user has previous experience with CNC equipment, determining setting times will not prove to be a problem. The difficulty arises for the first time user. This is where the cutting trials will be of great use. The sample that can be collected in this way will be very small. It is therefore important that a true like-for-like comparison is made: ie., "empty machine" to "1st component satisfactory", plus "end of batch run" to "empty machine". An empty machine is a misnomer for a CNC machine tool, because its very principle of operation is to use standard tools. Therefore an empty CNC machine should be defined as one with all non-standard tools and work- holding equipment removed.

The results from the cutting trials should be scaled (with an uncertainty factor if appropriate) to the full annual load to give a setting time benefit.

Reject work can be classified in two ways:

- Setting Scrap
- Production Scrap

Setting scrap consists of components scrapped beyond the point of reworking during the setting of tools. CNC machine tools can be set with no rejects whatsoever, although certain conditions may cause scrap to occur, such as forgings or castings not matching the work holding equipment, material problems or programming errors.

The production reject rate under ideal conditions can also be eliminated with CNC machine tools, because the cycle is fixed and the machine rigid. Again, certain situations can cause rejects. Examples might be uncorrected tool wear, allowing a dimension to go out of tolerance, or an incorrectly loaded component. These rejects are Operater induced. On the other hand, a reject caused by the premature catastrophic failure of a cutting insert is a purely random effect which may be the result of a material fault in either component or cutter.

Savings in reject rates are difficult to assess. The cutting trials can usefully be used to assess the most likely levels of reject work of both varieties. The value of these rejects should not only include the raw material cost but also the cost of previous manufacturing operations. It is a matter of judgement as to whether data collected in this way will be acceptable. It is likely that the first-time user will have to ignore reject savings, although subsequent justifications can make use of data from the primary installation.

It will be seen in a later chapter how the significance of reject costs can vary with application. In certain circumstances, the existing scrap level will already be near zero, with no potential for improvement.

The same is true for tooling costs, which will be significant where CNC machining can eliminate the requirement for special tools or costly tooling systems, such as diehead chasers.

The original and maintenance costs of existing methods can be established through study with a reasonable degree of accuracy, and compared with the cost of tooling, using CNC machining techniques. The extra cost of cutter inserts should be deducted from the annual savings, to arrive at a net cost saving.

The cost savings described can be expressed a as total annual benefit. This must be offset by the cost of program preparation, which can be assessed by predicting the number of programs to be written. This is likely to be high in the first year and lower in subsequent years. The time taken to produce a program can be assessed at the cutting trials.

The alternative to purchasing CNC equipment may be the reconditioning of existing plant. When this is the case, such savings should be itemised as a first year benefit.

The capital cost of the project must include not only the purchase price of the machine tool, tooling and ancillary equipment, but also the cost of installation, training and run up expenses. The disposal value of existing plant should be included, if significant.

Some installations will qualify for grants, either through a Government "High-Technology Programme" or through Regional Aid. Application for such grants must be made in the early stage of the project, so that any grants forthcoming can be included at the justification stage.

The annual and first year savings along with the capital cost can be assembled and presented as a series of cash flows.

The use of discounting techniques to judge the benefits is recommended. However, it will often be found that the investment will realise such significant savings that the pay-back period is short enough not to require DCF calculations, which are more suitable for long term projects with varying cash flows. Nonetheless, DCF is recognised as the most reliable and should be used in most cases.

3.8. PHASE 7: ORDER

If the justification analysis reveals that a project is worthwhile, then the project can move to the ordering phase.

The machine tool market, like most capital goods and services, is open to a measure of bargaining. The results of such bargaining, it will be noted, have not been included in the justification, though the analysis can be used as an effective bargaining tool.

Multi-machine installations warrant significant discounts because the Suppliers' training and commissioning costs will be lower. The suggestion of future business may cause the Supplier to consider lowering the purchase price, which he will almost certainly do if the selected machine is new into the field. Such installations are fraught with danger, and the buyer should seek significant discounts, extended payment facilities and a non-satisfaction return clause before following this route.

The purchaser should attempt to cover currency fluctuations if appropriate, either by agreeing a fixed price contract, or by obtaining a quote in the currency of the country of manufacture and buying currency forward himself. The latter option can cause problems if the delivery date is not achieved. The use of penalty clauses for late delivery is attractive, although suppliers will be unwilling to accept them.

Once the bargaining has been completed, the purchase order should be placed. Ancillary items, tooling and services should be itemised with care.

The progress of the order should be monitored, especially when the delivery lead time is long. The Supplier should be continuously pressurised to ensure he achieves his promises.

Preparation for the receipt of the plant can now commence.

3.9. PHASE 8: PERSONNEL SELECTION AND TRAINING

This phase is designed to ensure that the right people are trained in the right way. The personnel assessment stage covered in Phase 2 will have revealed what route should be adopted to obtain the personnel.

The first-time user will probably decide to recruit in-house, for external recruitment can cause shop floor friction and discontentment.

If the 'management by involvement' philosophy has been successfully adopted, it is likely that a number of people will be interested in running and supporting the new plant. Their aptitude and attitude should be formally tested, but before this can be done the job descriptions must be constructed. In turn, this calls for a careful examination of the functions to be carried out.

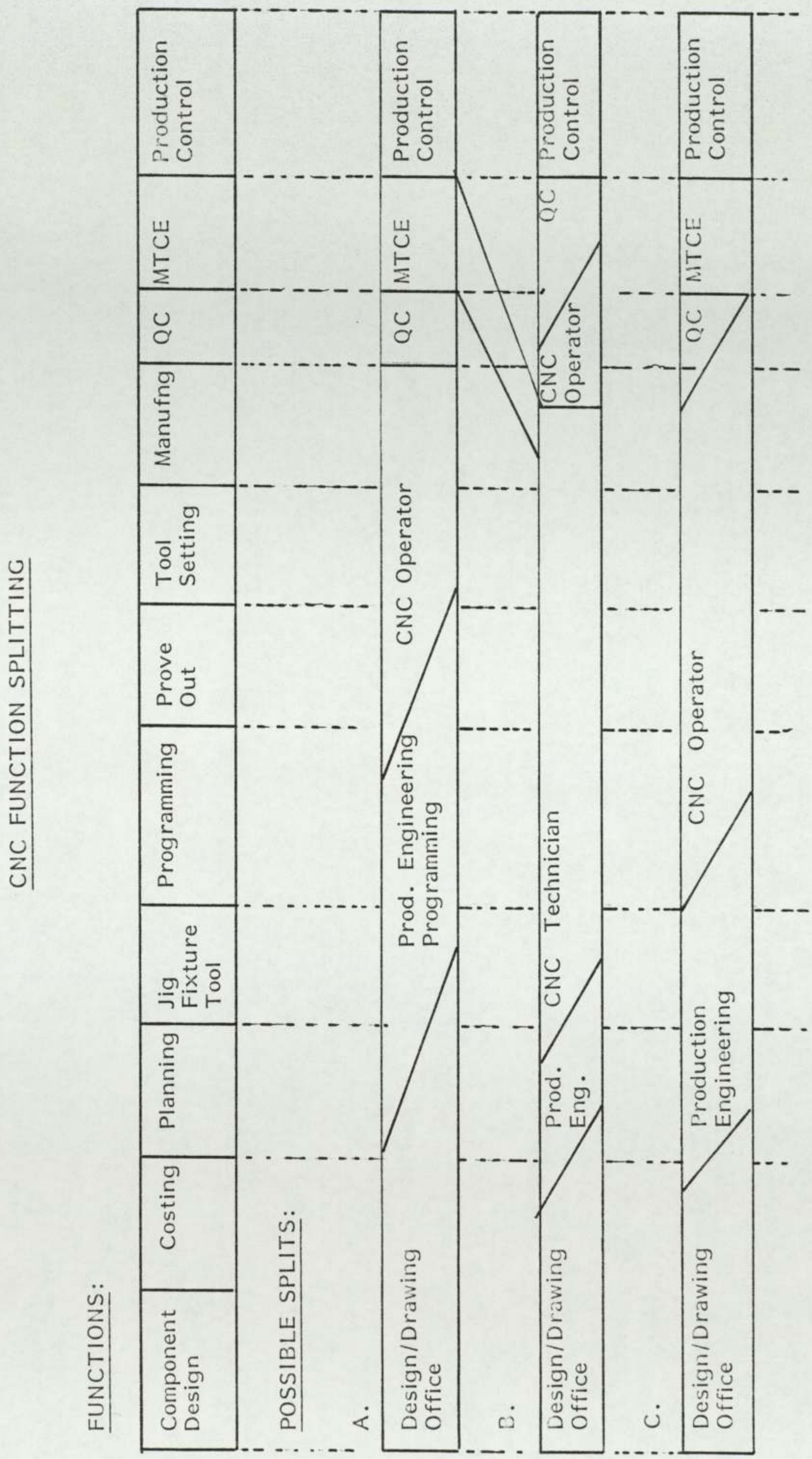


FIG 6: CNC FUNCTION SPLITTING

Fig. 6 shows the main and peripheral function involved in running CNC equipment, and how the functions may be split up to form discrete jobs. It should be noted that the length of each function represented does not indicate volume or technical difficulty. The selection of the most suitable split will depend on the nature of the work to be carried out, and on any existing technical structure.

Option A is the "traditional" split for low volume, complex work with the Production Engineering function producing programmes, possibly using a computer aid. The CNC operator sets the tools up and stays with the machine as it performs its function, loading in raw material and checking quality as necessary.

A development of this is option C, where the advent of machine tool control systems with conversational on-machine programming facilities allows the operator to "write" the program himself.

Option B is more suitable for higher volume work, with an operator taking over responsibility of manufacture when the technician has written and perfected the program and set up the tools. The technician may also take responsibility for part of the Maintenance and Production Control functions.

The function split should be carefully considered and agreed with all interested parties. The job descriptions can then be constructed.

JOB DESCRIPTION

JOB TITLE: CNC PROGRAMMER

GENERAL PURPOSE OF JOB	. To produce accurate CNC programs for parts from a schedule which will allow components to be correctly machined at the minimum cost.
MAIN DUTIES	. Plan method of machining component. . Write CNC program so that it can safely be used with the minimum of modification. . Layout tools required to produce component . Provide user with complete documentation for each program.
OTHER DUTIES	. Ensure full protection of data by backing-up computer files. . Ensure that tooling is available. . Satisfy delivery requirements and amend work schedule when requested.
LIAISE WITH	. CNC Operators and shop foremen . Jig and tool designers . Production controllers . Inspection/Quality Control
RESPONSIBLE TO	. Technical Manager
SKILL/KNOWLEDGE	. Full understanding of machining technology. . Skill in selecting correct tooling and appropriate cutting conditions. . Ability to fully understand and assimilate the contents of an engineering drawing. . Numeracy. . Logical thought, tidiness and precision.

FIG 7: SAMPLE JOB DESCRIPTION - CNC PROGRAMMER

The setting of remuneration levels also needs careful consideration. The piecemeal creation of additional payment categories should be avoided and the "New Technology Award" syndrome resisted. On the other hand, the long term wages strategy will need to take account of the fact that higher technology requires skills which may be in short supply and command a premium.

A Sample Job Description for a CNC Programmer is shown in Fig. 7.

Once the job descriptions have been set, personnel selection can take place. Aptitude, attitude and skills (actual and potential) should be assessed by interviews and, if appropriate, by short tests.

The training of those selected will vary according to the jobs they fill. For operators in a high volume production shop, a day "on the job" may suffice. For technicians, tool setters and programmers, a more complete programme will be necessary, including a period spent at the Suppliers' premises, prior to machine installation. Initial components should be programmed at this stage, both to serve as a training vehicle, and to allow a smooth start following installation. A formal Training Manual is useful as a guideline document.

The training should include aspects of tooling which may be new, and the use of services, equipment and systems. The need for discipline, logic, and housekeeping should be stressed.

3.10. PHASE 9: PLANT INSTALLATION

Once the necessary off-site training has been completed, the machinery can be installed. Site preparation may be necessary, such as floor strengthening, as well as the laying-on of new power and air services.

The contractural agreement determined in Phase 7 should have noted where installation/commissioning responsibilities lie. It is usual for the purchaser to site the plant with the vendor connecting and commissioning prior to hand-over.

Dimensional machining checks should be carried out prior to acceptance.

A period of settling-in should be allowed, although it should be expected that a measure of production should be achieved within a few days of hand-over.

A multi-machine installation may warrant a staged introduction.

3.11. PHASE 10: AFTERCARE AND POSTAUDIT

Aftercare is a continuous phase which follows plant installation. It is designed to ensure that the standards layed down during training and installation are maintained and to allow the post- auditing of the entire project.

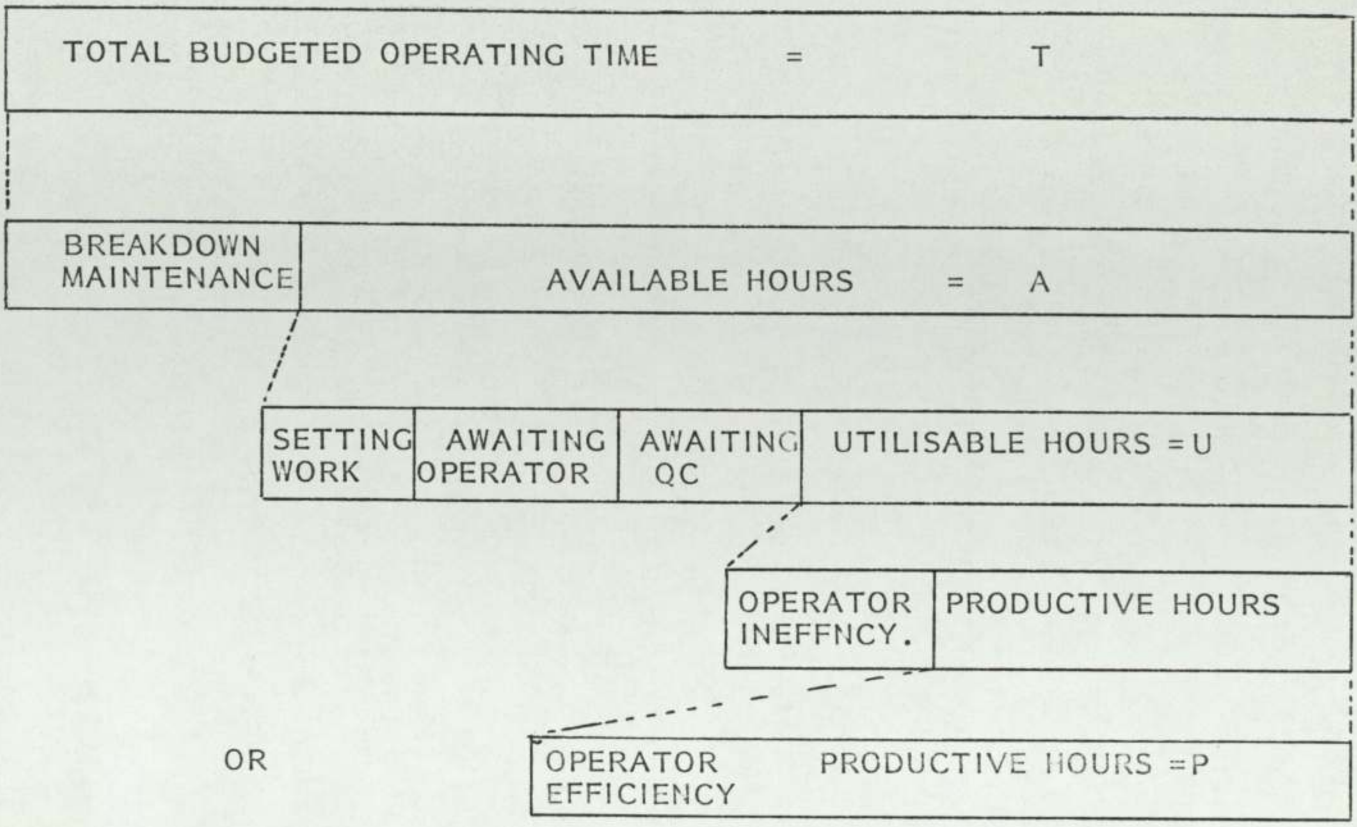
A performance analysis should be carried out to assess efficiency, utilisation and availability.

Efficiency is a measure useful in higher volume applications to assess the performance of an operator compared with a standard. This may be linked with a productivity-based incentive scheme. Reasons for an efficiency less than 100% will be discussed later.

Utilisation reflects the ability of Management and Supervision to use the plant to its best advantage by minimising machine waiting time. Lack of tooling, materials and manpower will affect the utilisation.

Availability measures the quality of a machine by reflecting the time lost through breakdowns and maintenance.

The three measures should be represented separately to highlight the problems areas which then may be attacked. Fig. 8 shows how the three parameters are calculated.



RATIOS

- AVAILABILITY = $\left(\frac{A}{T} \times 100\right)$ %

- UTILISATION = $\left(\frac{U}{A} \times 100\right)$ %

- EFFICIENCY = $\left(\frac{P}{U} \times 100\right)$ %

- TOTAL PRODUCTIVITY = $\left(\frac{P}{T} \times 100\right)$ %

FIG. 8: PERFORMANCE PARAMETERS

3.12. CONCLUDING REMARKS

This chapter has outlined the general framework for selecting, justifying and implementing CNC Machine Tools within a manufacturing environment. The next chapter reviews the framework in a real case where a number of CNC Machine Tools were installed.

4. THE PRAGMATIC TEST: THE FRAMEWORK APPLIED

This chapter takes the framework and demonstrates its application with 2 examples within a Company (Appendix 1: Company Background).

The first case considered will be a multi-machine implementation into a production Machine Shop producing components from forgings in non-ferrous materials, with medium to high batch quantities. It will be seen how the product mix analysis led to two target specifications which resulted in purchase of a mixture of machines and control systems.

The second case will be a single unit installation in a service Toolroom producing components in small quantities out of tool steels. It will be shown how the use of advanced tooling techniques placed severe requirements on the target specification.

A later chapter will compare and contrast the two cases and discuss particular aspects with reference to the literature cited in Chapter Two.

4.1. CASE 1 - THE PRODUCTION MACHINE SHOP

4.1 .1. Background

The Machine Shop within the Company had developed over the years to machine forgings produced by the hot non-ferrous stamping shop which traditionally formed the mainstay of the business. The machining of components formed a linear integration of processes which became increasingly important to gross margins, and to allow a change in emphasis away from ornamental towards engineering markets. It was necessary to enhance both the flexibility and the sophistication of the facilities, to increase productivity, and to improve quality.

The equipment in the Machine Shop was split functionally into high speed chucking automatics for high volume work, and into a range of capstan lathes for shorter quantities. In addition, a range of drillers, millers and tappers provided 2nd operation facilities.

The project spanned 3 years, and resulted in the introduction of a total of 6 machine tools, installed in pairs after 8 months, 20 months and 30 months. The third pair were identical to the first, and are not considered in the present Thesis.

The first 4 machine tools will be treated as a single installation, except for justification where the two cases are treated separately.

4.1.2. Definition of Terms of Reference

The decision to investigate the use of CNC machining techniques arose as a joint desire of both "Shop" and "Front Office" to improve the facilities in the Machine Shop. The senior management decision was made following an independent consultant's report which highlighted some of the deficiencies, such as poor quality and delivery achievements, and low availability.

A project leader was appointed to head up and implement the plan, but the emphasis was a "Shop" driven one, with the "Front Office" waiting in the wings to give go/no go decisions when appropriate.

The objectives laid down were:

- To reduce production costs.
- To improve quality.
- To improve customer service.

However, it was required that the justification be based of tangible evidence with the minimum of global assumptions. Any benefits which could not be backed-up with acceptable quantitative data were to be omitted. In other words, the justification would under-estimate, rather than be unduly optimistic.

This requirement was laid down by senior management. It might be argued that this was a conservative stance and that a good case might have been rejected because insufficient note had been taken of, for example, the resultant reduction in work-in-progress.

However there was a general suspicion of the apparent benefits of CNC claimed by its advocates in the literature. This disagreement will be discussed in greater depth in the next chapter.

The Company had had trading difficulties, requiring the consolidation of facilities and resulting in the closure of one of its two sites and a reduction in the size of the workforce. It was anticipated that a further reduction in manpower would be necessary, and that any net labour shedding arising from the implementation of the project would be projected to be part of this restructuring programme.

From the commencement of the project, the active participation of Company personnel was sought and found. A series of seminars and discussion sessions, together with notice boards and handouts, allowed a two way flow of ideas and information. Once the machine tools were finally selected, line supervisors, toolsetters and quality control personnel were taken to see the machine tools in action. The generation of interest was not limited to the shopfloor. Sales, personnel, estimating and production control departments were also included. The aim was not to say definitively:

- "This is going to happen"

But rather:

- "The technology is available - how can we best use it?"

The result was a continuous flow of ideas, thoughts, worries and objections which could be considered or answered as they arose.

4.1.3. Assessment of Existing Systems

i) Product Mix Analysis

The product mix analysis used a large sample of the work carried out within the capstan area of the Machine Shop. From this sample, representative parts were selected for collection of more detailed factory data for justification purposes.

The Company held historical production information covering a period of 18 months. The data set held included:

- Part Number.
- Operation Number.
- Work Centre.
- Works Order Number.
- Batch Quantity.
- Delivery Date.

Approximately 330 components were represented: 125 components were studied in detail and information collected to cover:

- Component Shape
- Component Size
- Component material
- Type and number of tools used in turning operations
- Breakdown of all machining operations
- Accuracy of machining required

This information had to be collected from a wide variety of sources including work study records, drawings, operation layouts and job routing charts. Where possible, the recorded information was verified by study of actual custom-and-practice on the shopfloor. The study revealed that there were two distinct types of component, classified by the machining operations required:

- "Simple" parts requiring one or more simple turning operations only.

- "Complex" parts requiring one or more turning operations followed by a number of "second operations" such as milling, drilling and tapping. The turning operations were in themselves complex, generally requiring more tools than the simple parts.

JOB ROUTING

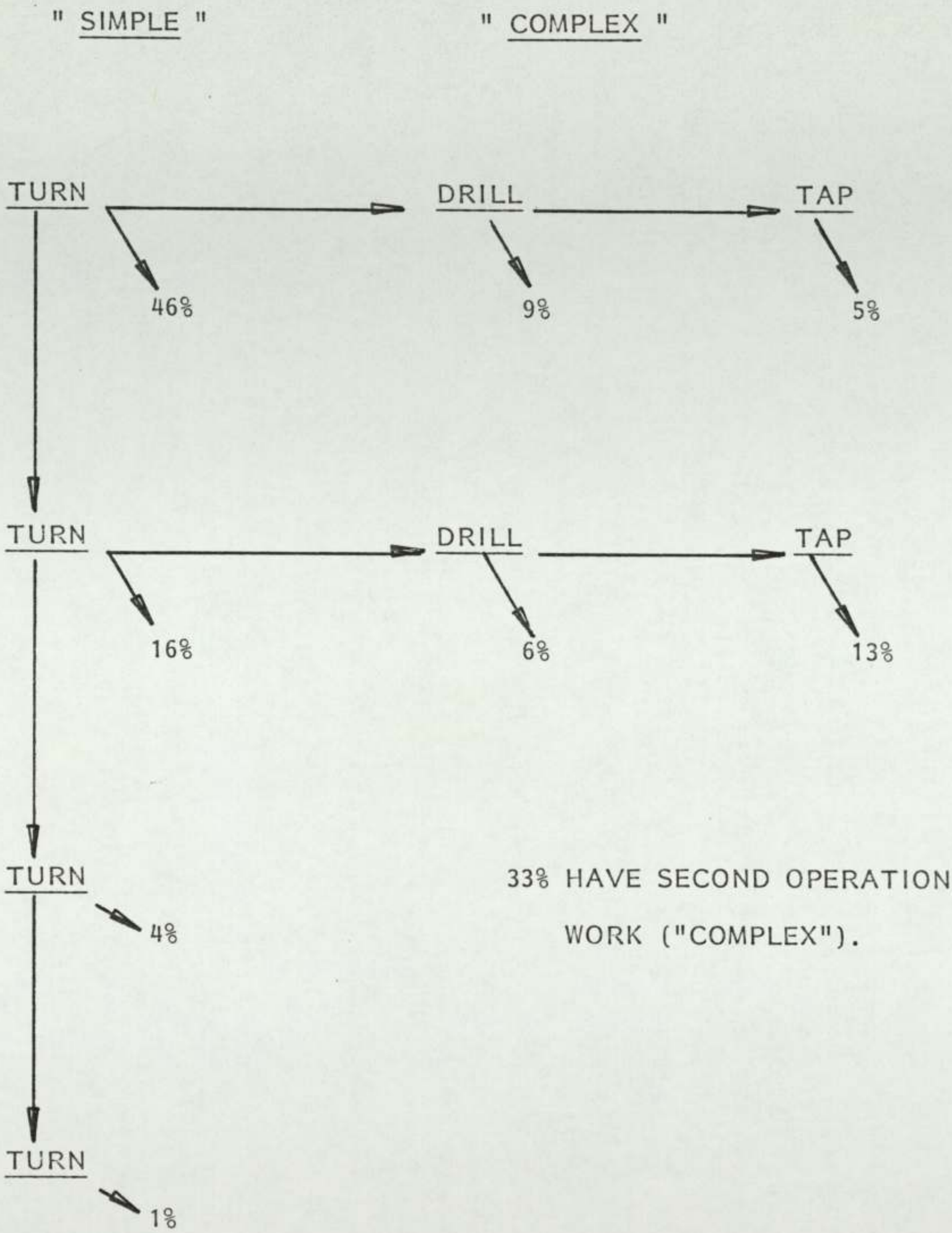


FIG 9: MACHINE SHOP MACHINING OPERATIONS

The split between the two categories is shown in Fig. 9

In both cases, the raw materials were non-ferrous forgings, principally of brass and other copper-based alloys. The forgings were varied in shape, but a a general split in both categories was round (cylindrical) and irregular. This had no bearing on the machining itself, but was of paramount importance in terms of external work holding. Round components could be held by a conventional three jaw chuck, but externally irregular parts required a self-centring two jaw chucking method with special purpose jaws designed to accommodate the irregularities. The Company had some experience in this respect, and had equipped some of its capstan lathes with this type of work holding unit. Components which were turned in two or more operations were held on a previously machined datum surface; expanding mandrel arrangement were not widely used.

Component size was reviewed by considering the total envelope dimensions, expressed as a diameter and length combination. Fig. 10 expresses this graphically. It will be seen that all components fitted inside a 150mm total machining envelope with over 85% having envelope dimensions not exceeding 100mm diameter and 75mm length.

The turning operations themselves varied in terms of their complexity, expressed in terms of the number of tools required. The tools themselves were also varied, ranging from a simple standard drill to a multi-diameter external or internal form tool designed specifically for the component.

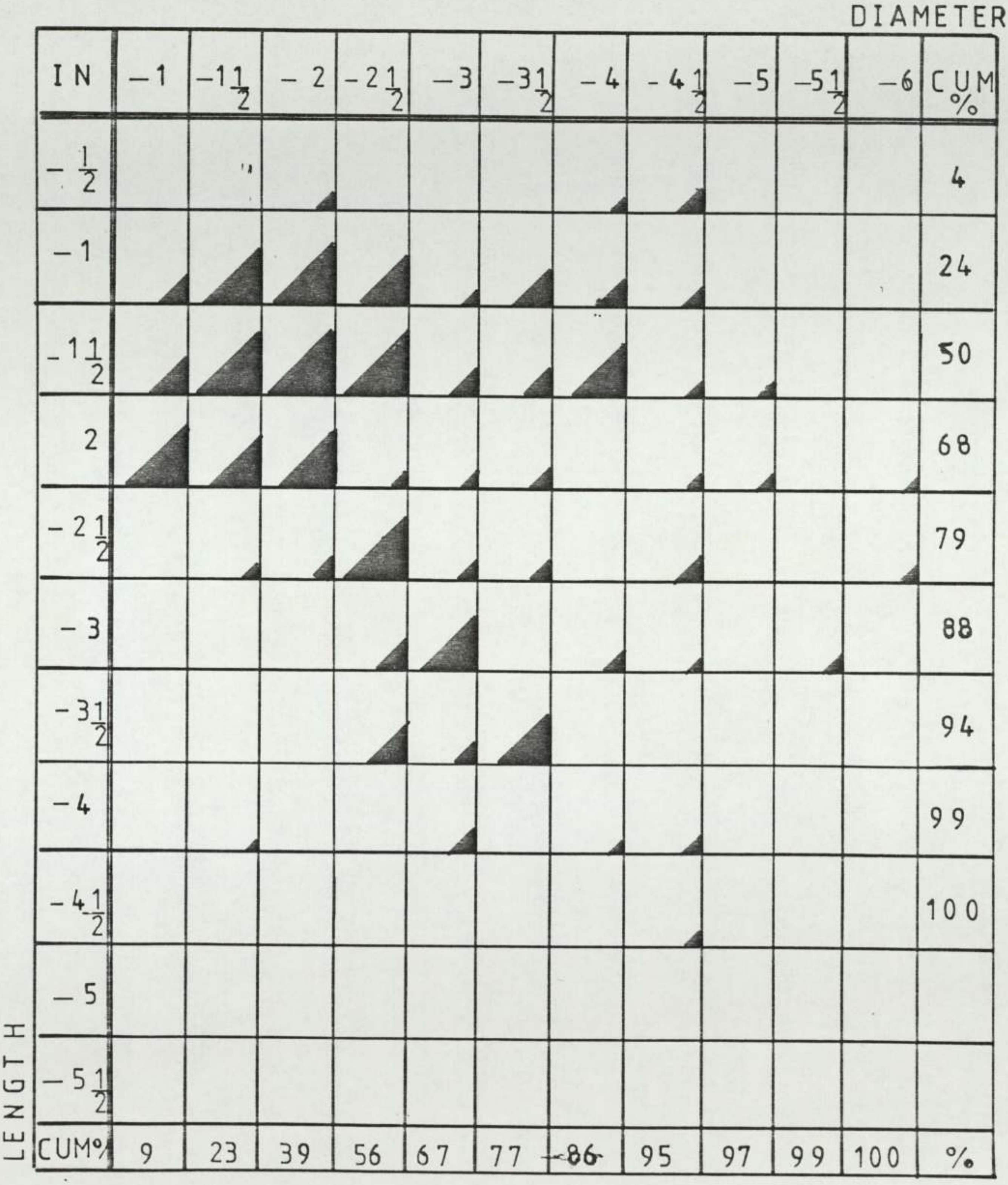


FIG 10 MACHINING ENVELOPE PROFILE

Fig. 11 shows how 34% of the operations considered required only one tool, and that 42% required three or more tools. The average was 2.6 tools per operation.

Another route to assessing the complexity was to assess the spread of production rates. Production rate is proportional to the inverse of the total cycle time, and is based on an operator working at "100 Performance" (B.S) with all relaxation and other job related allowances included. Fig. 12 shows the frequency of batches against production rate; frequency of all components against production rate was also compared. Across the board, the average production rate by batch was 114 per-hour, representing a total turning cycle time of 0.52 minutes. By CNC turning standards, this was very short. It will be seen later how this affected the justification.

The batch production rates were split into the four lathe groupings within the Machine Shop, and demonstrated that the larger capstans were working on longer cycle times. This was significant in that potentially greater cycle time reductions would be achieved on larger work.

The analysis so far has considered the sample selected from the total output of the capstan section over an 18 month period. The number of batches per component for the full range is shown in Fig. 13, together with the sample profile, which shows how the multi-batched components were well represented in the sample.

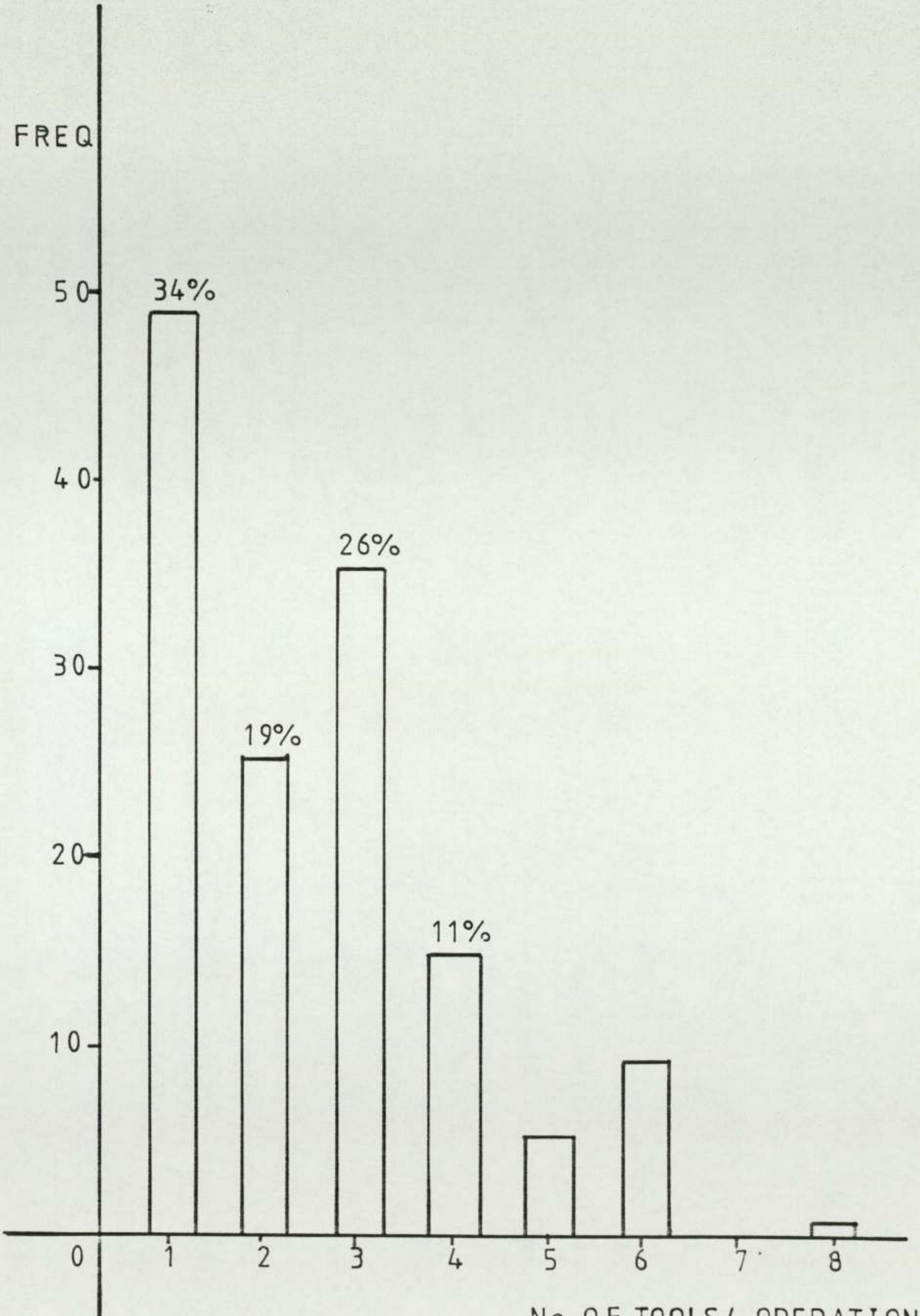


FIG 11 COMPLEXITY : TOOLING USED

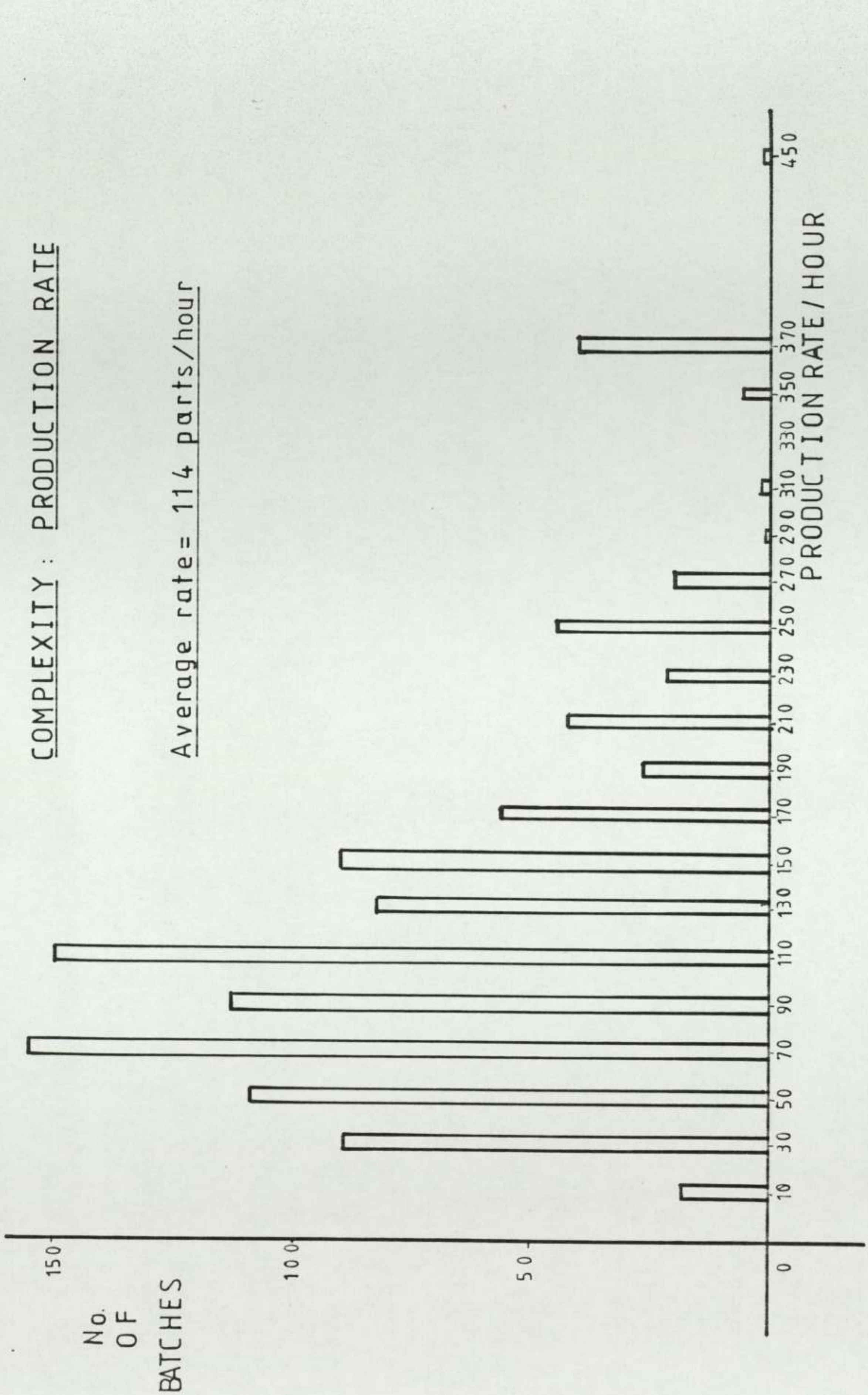


FIG 12 COMPLEXITY: PRODUCTION RATE

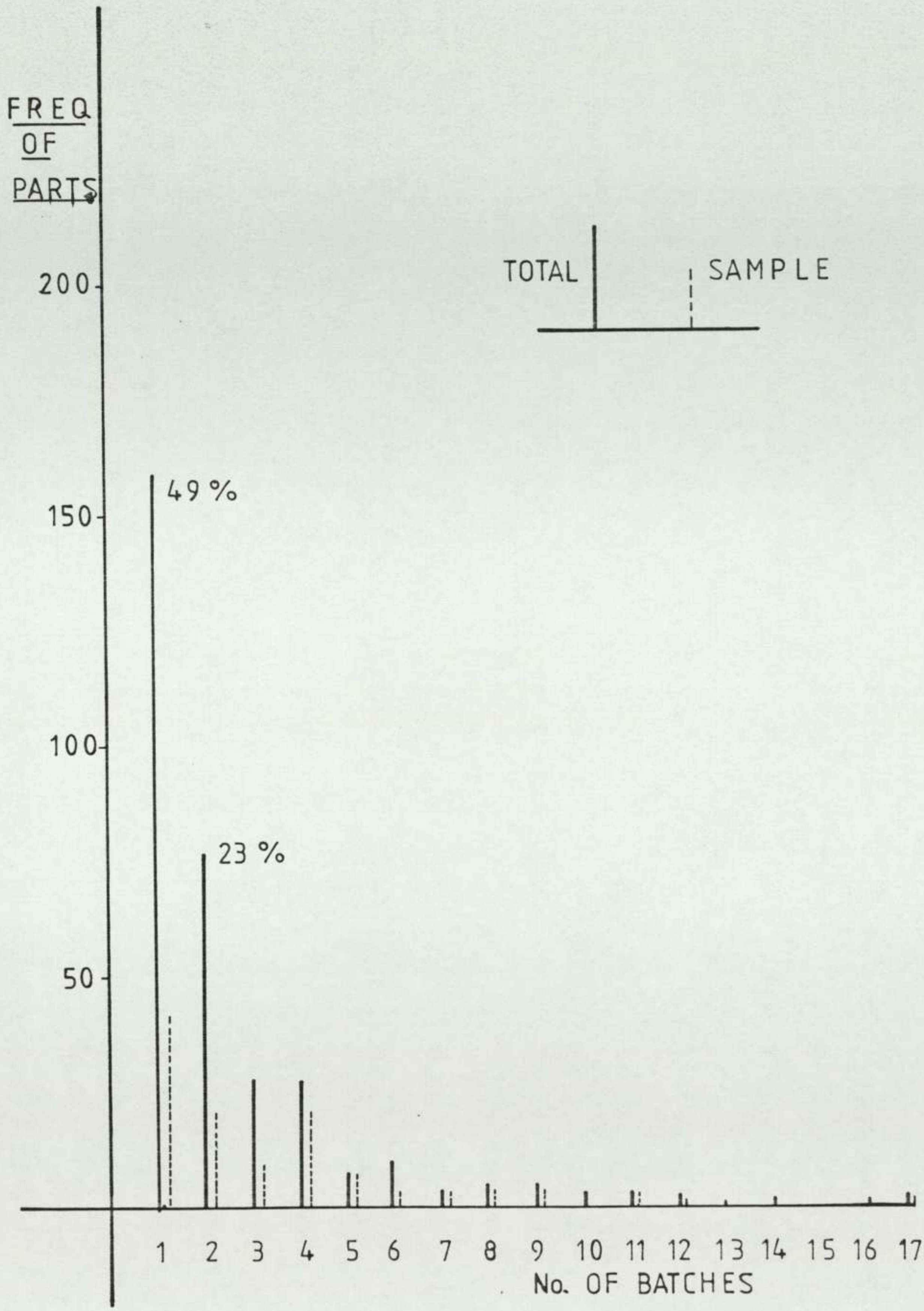


FIG 13 BATCH FREQUENCIES

The graph shows that there was an equal split between one-off batches and those which were repeated. The information was not available to allow a longer time span to be considered. It is probably true that some of the components, produced only once during the study period, would have had a repeat cycle of greater than 18 months but less than two years. A proportion of components would be produced once only in a single batch.

An analysis of precision required was difficult to perform because of poor drawings and notations thereon. However, general machining tolerances were of the order of ±.125mm with specific tolerances tied to ±.025 in some cases. It was the tighter tolerances which gave the current equipment the most difficulties. It was generally found that the complex components were the most stringent in their tolerance requirement.

ii) Plant Survey

The Company plant register was insufficient to give a complete picture of the age and specification of the plant within the Machine Shop. A survey was carried out for the Machine Shop in its entirety. The capstan and second operation section are presented in this section.

A specification chart for each machine type was used to collate the information. A sample is shown in Fig. 14. This allowed several profiles to be drawn up.

MANSILL BOOTH & CO. LTD.

LATHE SPECIFICATION CHART

TYPE: CAPSTAN MAKE: WARD VERSION: 2DS VARIANT:

CHUCK/COLLET:

ADAPTATIONS:

PNEUMATIC XSLIDE

MOTOR H.P.: 3

SPEED RANGES:

60	95	120	175	215	320
400	605	740	1110	1366	2040

TURRET FEED: rev/in

63	116	130	214	242	440

SADDLE FEED:

62	115	213			

SWING OVER CROSS SLIDE: 6 1/2"

TURNING LENGTH: 6"

CROSS SLIDE TRAVEL: 8 3/4"

SADDLE TRAVEL:

HISTORY

RECORD	Nasmo	1964
PURCHASED	Elks	7/64
PLANT NO.		1021

COMMENTS

POSITION IN SHOP 4D

DATE: 1/9/83

BY: PJS

WORK CENTRE: M2A CHU

FIG. 14: LATHE SPECIFICATION CHART

Fig. 15 shows the age of the capstan lathes as a cumulative sum graph. Plant age ranged from 2-30 years with an average age of 16 years. Although some of the capstans had been reconditioned, it was found that the plant was generally labour intensive, technologically obsolescent and in poor condition mechanically. Examination of the machine tools in this area suggested that the plant had been purchased on an ad-hoc basis rather than as part of a structured investment programme. It was also reasonable to assume that when additional capacity had been required, the policy applied had been to purchase more of the same, rather than assess what improved productivity could be obtained by investing in more modern technology. In principle, the equipment was capable of producing the components required, but in practice both quality and output were affected by the condition of the plant.

Drilling machines comprised a range of single spindle drills (some of which were equipped with multi-drilling heads), turret drills, tapping machine and bench drills. The age range of equipment was from 1½ years up to 35 years, the average age being 18 years. The age distribution is shown in Fig. 16, in the form of a cumulative sum graph. Apart from some of the machines being in poor condition, due to normal wear and tear and to age, the drills were functionally adequate for the work carried out.

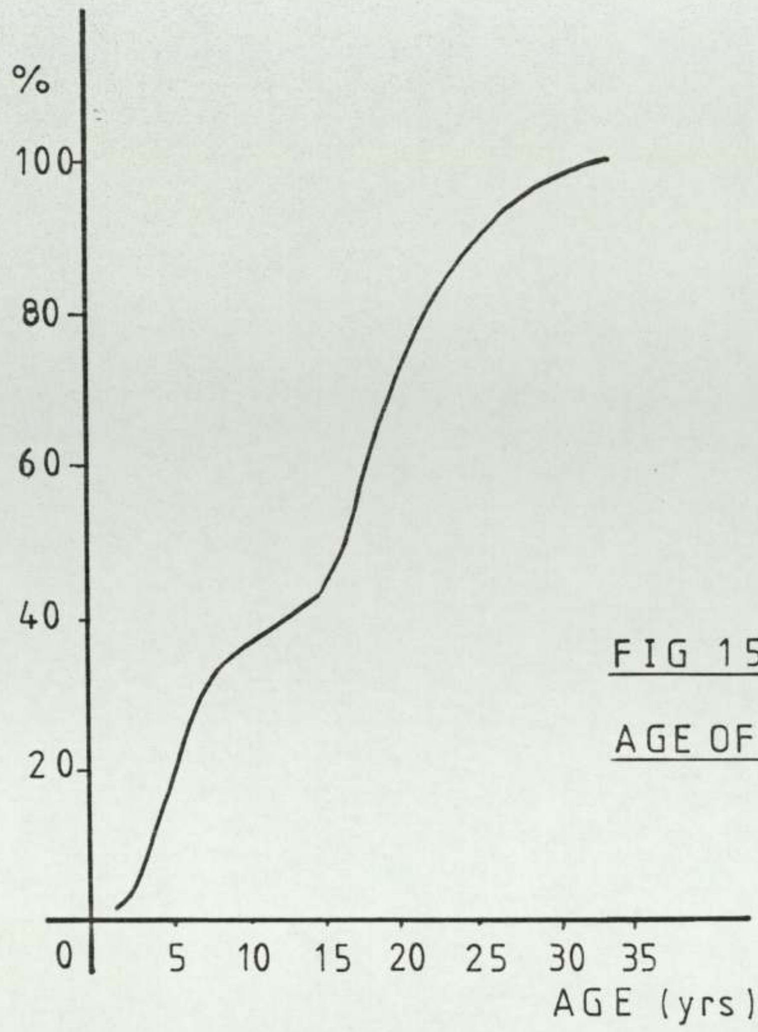


FIG 15

AGE OF CAPSTANS

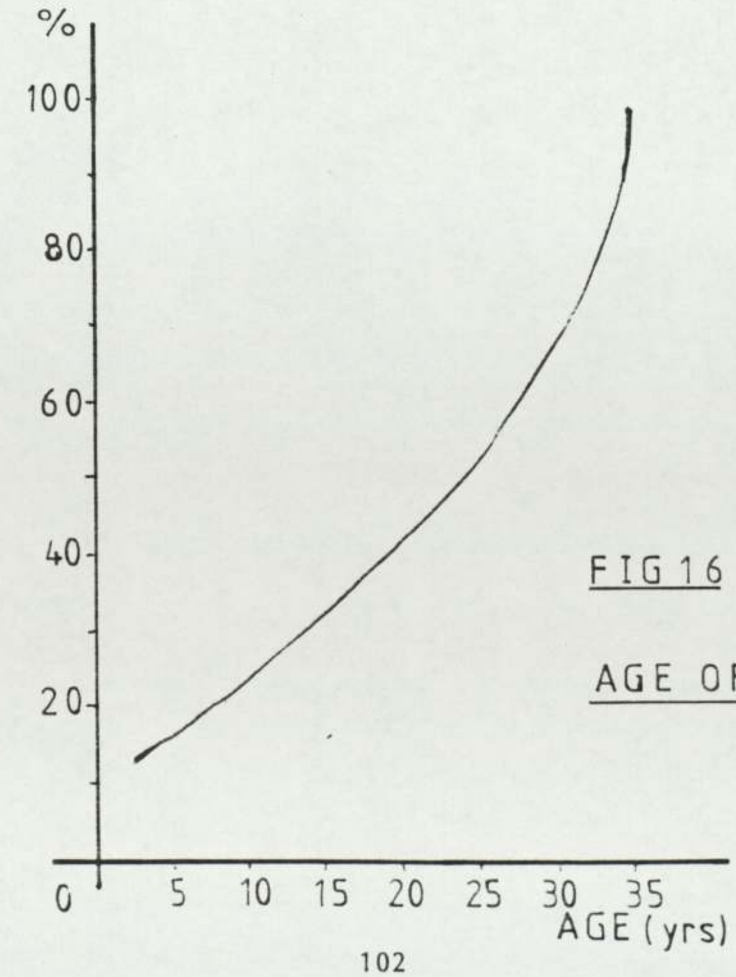


FIG 16

AGE OF DRILLS

Although the plant may have been capable of doing the work, this did not imply that they were highly productive, even when they were actually in operation. The graph shown in Fig. 17 plots the recommended surface speeds [72] for machining brass over a range of diameters. It will be seen that the capstan lathes were marginally acceptable for use with high speed steel (HSS) tooling, but lacked speed for effective use of carbide. A 5,000 RPM CNC lathe is also shown.

The 2nd operation machines, such as drilling and tapping were often less will equipped to cope with smaller diameters. There were some notable exceptions. A few drilling machines were capable of running at high speeds. The majority (by type and quantity) did not fall into this category.

The plant survey demonstrated that the machinery was generally old and unable to take advantage of the modern range of cutting materials.

It is worthwhile to consider how capstan lathe tooling are designed, manufactured and used. Standard tools, such as drills and facing tools present no particular problem. Forms, such as internal multi-diameter bores or external profiles, are achieved in production by grinding the shape onto a piece of braized carbide or a H.S.S. tool. The grinding shape is drawn onto a "skin" which can be back-illuminated and followed on an Optical Profile Grinder. Once the tool is correctly on the lathe, the operator merely has to feed the tool until a dead stop is reached, and the profile, which may be quite complex, is formed in the material rotating in the chuck.

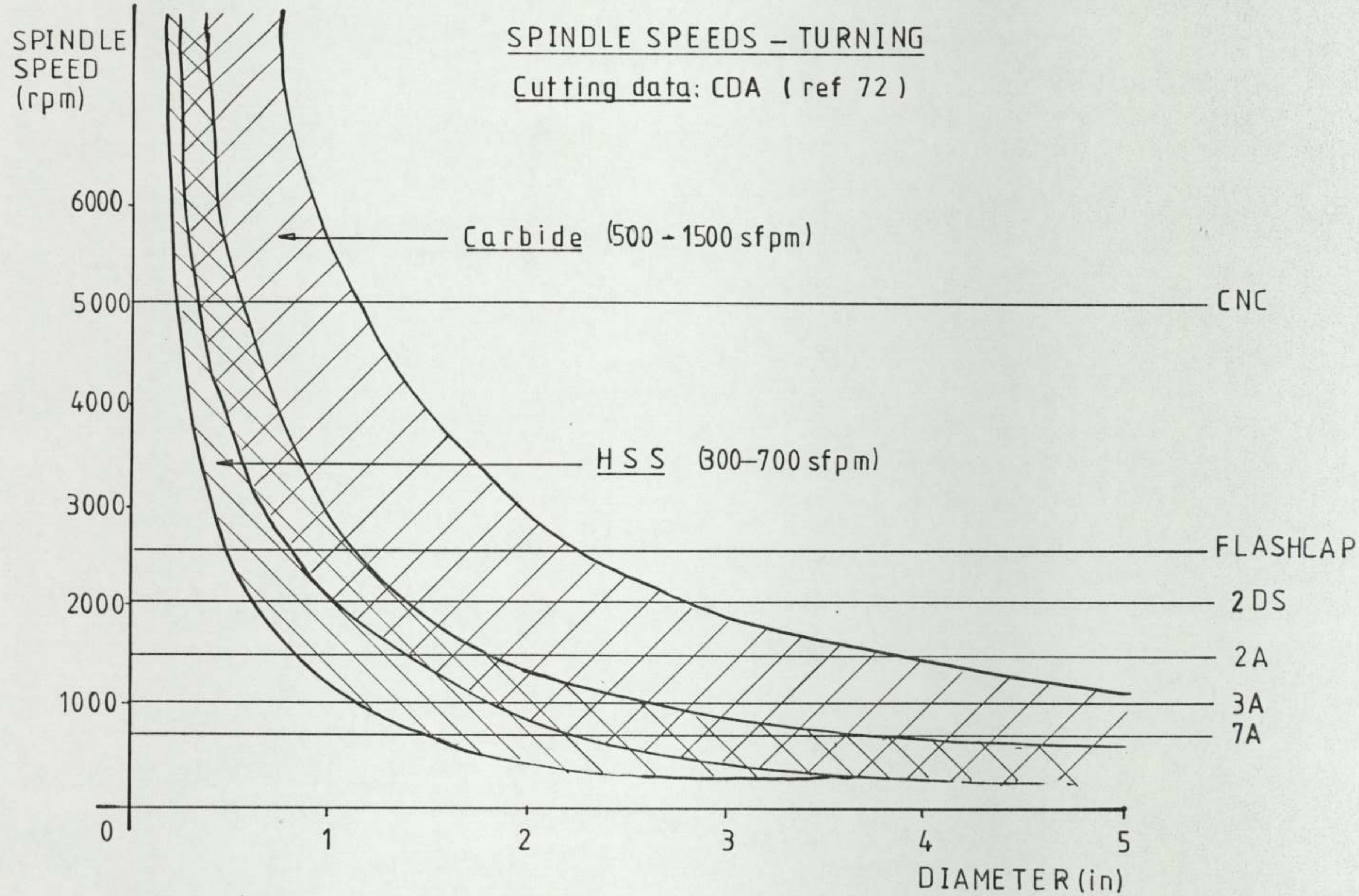


FIG 17 SPINDLE SPEED COMPARISONS

If the form tool is incorrect, damaged or worn, a new tool must be manufactured. The turret holding an internal form tool must present the tool precisely on centre line, otherwise the bore will cut oversize and give a poor finish. Thus the machine must be in good condition with no play in the capstan slide, and the operator must take care not to over-work the tool.

The form tool was widely used in the Machine Shop for volume production of components. It was often expensive to design and manufacture, time consuming to set up and difficult to maintain accuracy, especially on machine tools which were past their prime. It was worth striving for the elimination of form tools.

iii) <u>Assessment of Manufacturing Systems</u>

The Machine Shop possessed no CNC or NC machine tools at the commencement of the project. The manufacturing system, therefore, would need modification to allow the smooth implementation of the new plant.

The core of the manufacturing system was the computerised control of production. This held production information in files covering:

- Order Bank
- Component Routing File
- Component Item Master
- Machine Work Centre File

Orders from the customer Order Bank were broken down into appropriate batches, with each identified by a unique batch number. From the Component Routing File, a batch file was created which listed all the operations to be carried out together with production times. The Item Master was used to determine material requirements. The Work Centre File contained capacity data so that production load profiles could be calculated. In addition, it also contained machine hour rates, allowing component costs to be determined for each batch.

The production load profiles were presented to the shop floor in the form of work-to lists. At each operation, progress was monitored by logging the quantities produced by a particular operator against the batch routing file Thus the state of each batch could be seen quickly. In addition, the data was also used to monitor the performance of each operator against the Standard, to allow calculation of the incentive payment. In a slightly different form, cost variances could also be reported.

Components which were new to the Company started life as an estimate, calculated manually by estimators and production engineers. If the enquirer was satisfied with the quotation, an order would be placed, usually subject to the production of samples. The necessary tooling would be designed and manufactured and a mini-batch manually processed through the works. If satisfactory, the order would be used to create a batch file and work would continue in the normal way.

However, estimated production times would be altered as necessary if they differed from what was actually achieved.

It is not the purpose of the current Thesis to note in detail all of the deficiencies of the system. Over the period of the project, much work was done to improve its effectiveness. Suffice it to note, at this point, the major areas of weakness.

Raw routing information was found often to be unreliable: either a Routing was unworkable, or it did not correspond to activity on the shop floor. As a result, operations were occasionally carried out in the wrong order, or in the worst case (which occurred on an unhappily frequent basis), omitted completely. Missed operations arose on the more complex work where the sales value was highest, and were a cause for major concern. Production times (and hence costs) were also found to be questionable.

This unreliability of product information led to unworkable schedules and improbable load profiles. Needless to say, the result was that shop floor Supervision did not believe the work-to lists, and often ignored them. Delivery dates were passed, and potential future orders lost.

Thus there appeared to be a lack of discipline in maintaining data integrity. This integrity is central to the concept of CNC manufacturing, because without it, the machine tools will not do what is required, or do nothing whatsoever. Any new system had to work within the existing system, and operate notwithstanding the deficiencies of that system. It will be seen later how the necessary discipline was achieved.

There were other manual systems running alongside Production Control.

Components were not designed by the Company but by the Customer. The product data usually came in the form of a Customer drawing, but sometimes a sample would be received which was then drawn up. Occasionally, minor modifications were suggested to the Customer to aid manufacture.

Forging dies, jigs, fixtures, gauges and tooling were then designed from this master drawing, which would later follow the job on its production route through the works. Briefly then, there was no numerical database: all physical data regarding a component was held on paper. Thus the CNC programming system would have to use drawing data, rather than a numerical database. The part number merely identified the component. There was no structured part numbering system.

Tooling was stored by component, so that cross-referencing was virtually impossible. Inventory control was inadequate, resulting in lost or mislaid tools, and no attempt was made to ensure that tooling was complete at the end of a batch. Thus any CNC equipment had to have a new tooling control system which would lead the way to improved discipline shop-wide.

Quality control was achieved in two ways. A pre-production component had to be passed off prior to bulk production of a batch. This "first-off" inspection checked the component dimensionally against the drawing and noted any special comments such as previous customer complaints, held on a component record file. At the same time, the quality and quantity of gauges would be checked. Once signed off, the batch could proceed into production, during which time the operator would be responsible for ensuring quality by the use of gauges at predetermined intervals.

A major weakness in the system was the time required to achieve "first-off" approval, during which time the machine tool would be idle. A new co-ordinate measuring machine had recently been installed. It was later found that this did indeed help matters. Combined with adequate tool and gauge control, first off approval times would be improved. Gauging intervals were somewhat arbitrarily set on a time basis, rather than by assessing the process capability of a particular machine and the tolerances required on the drawing. Process capability data did not exist, nor were there facilities available to collect and analyse such data.

The assessment of the production systems suggested that there were major areas of weakness. The Thesis will not describe in detail the efforts made to improve the overall performance. A later section will note the changes made as a direct result of the implementation of CNC machine tools.

iv) Assessment of Personnel

It has already been noted that the Machine Shop possessed no CNC or NC machine tools at the commencement of the project.

On the shop floor itself, the level of technology was low, indicating that either:

- a sustained phase of intensive training of existing staff would be required

or:

- personnel capable of handling the tasks would have to be externally recruited.

A later section will show how the former option was achieved. The choice was determined by the Company's desire to minimise the necessity to shed labour, and to maximise the motivation benefits personnel development and training can bring. In the same way, Supervisory and Production Engineering staff were found to require further training.

The Maintenance function gave particular cause for concern because of the conventional nature of the plant currently on site. CNC machine tools, stripped of their guards and panels, are remarkably simple mechanically. Their sophistication is purely electrical and electronic and it was in this discipline that the Company possessed few in-house skills. It was decided that, given the high reliability of the control systems and the availability of external (albeit expensive) services, no attempt would be made to train in-house nor recruit the skills necessary.

Management knowledge in CNC machining techniques was limited. However, there was full commitment to the implementation and open minds were maintained throughout.

4.1.4 The Options Reviewed

The two major options are usually to do something and to do nothing. The assessment of the existing systems suggest that much could be done to raise productivity and quality standards within the Machine Shop, regardless of the introduction Of CNC machine tools. Tooling management and data integrity are two examples.

However, the state of the existing machine tools was such that drastic action was required. Reconditioning has been used in the past but was found to give only temporary relief. The purchase of new replacements was considered but difficult to justify because, in themselves, they would not yield substantial batch time savings. In addition, the suppliers of conventional capstan lathes were disappearing from the market place.

These factors, combined with an overall desire to move the Company to a new level of flexibility, indicated that the purchase of new CNC machine tools to be the best option, if it could be justified financially.

The Company's "raison d'etre" was to provide customers with a complete component manufacturing facility. The vertical integration of machining parts produced in the forging shop was central to the business, with a great deal of the overhead contribution coming from the Machine Shop. The buy-out option was, therefore, considered unsatisfactory.

The product mix analysis indicated that there were two distinct styles of component:

- "Simple"
- "Complex"

The Simple components required a high speed machine capable of competing directly with a capstan.

The Complex components required not only turning operations, but also second operations such as milling, drilling and tapping, which were found to be difficult to manage, and were the cause of major concern. Although these complex components could be turned on the style of machine suitable for the Simple type, benefits could be improved if they could be completed on a single machine style. Thus the complex components required a machine tool capable of secondary operations as well as high speed turning.

The review of options, which was continuous, indicated that two markedly different machine tool styles should be specified.

Fig. 18 shows the option review tree.

4.1.5 Target Specifications

The Option Review indicated that two target specifications were required: one for simple parts, another for complex parts. The component profiles, determined from the product analysis, were used to design the rough cut target specifications. As information was received from suppliers, a medium cut and finally a finalised target specification was agreed for each of the two machine types.

The target specifications are shown in Figs. 19 and 20.

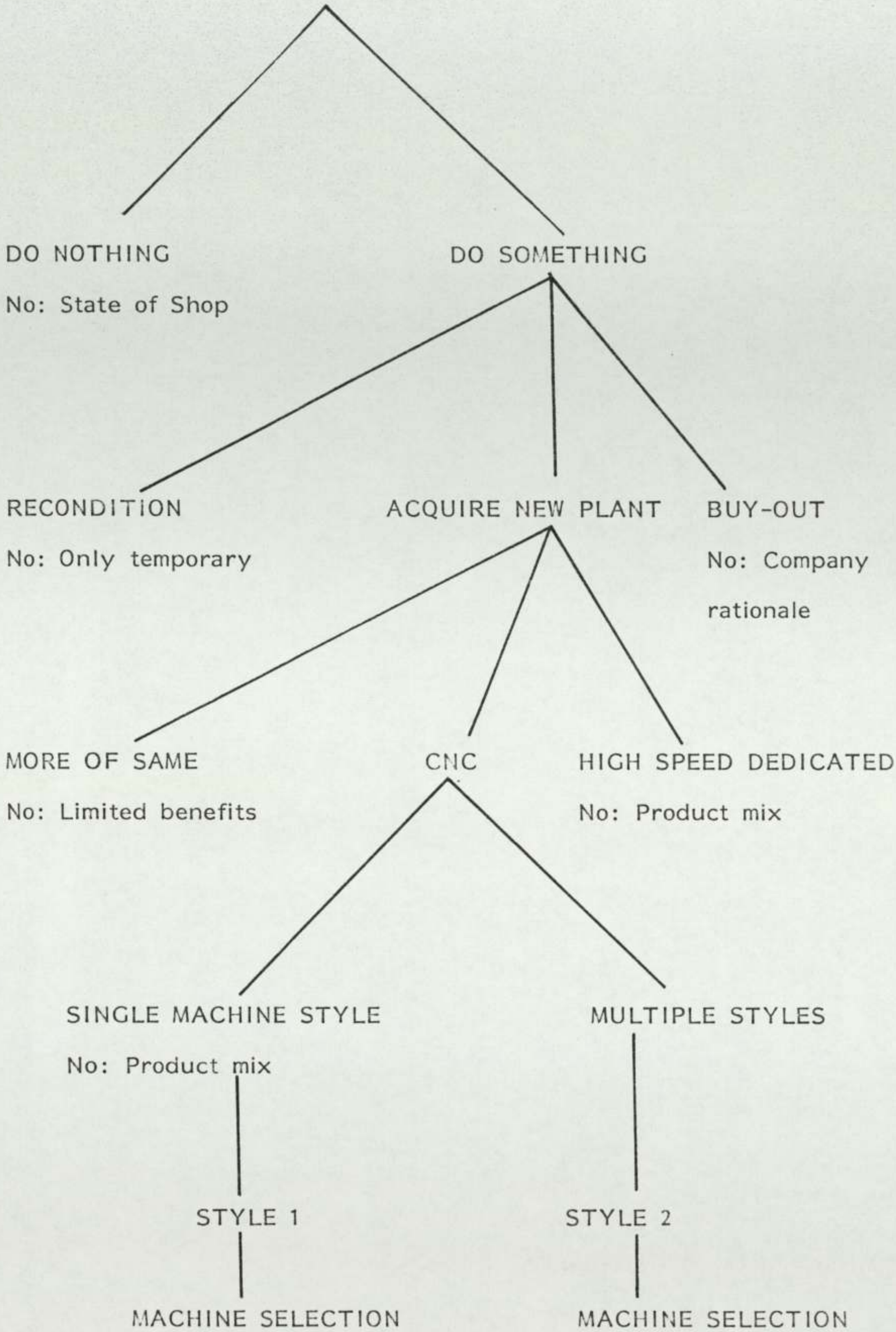


FIG 18: OPTION REVIEW TREE: MACHINE SHOP

MACHINE TARGET SPECIFICATION

Machine Type :	CNC Lathe
Application :	Production Machine Shop, non ferrous
Primary Objective:	To economically replace capstan lathes

Machining envelope:	150mm dia x 100mm long
Spindle power:	5hp (3.7 kw)
Swing over bed:	300mm
Speed range:	100 - 5000 rpm steplessly variable.
Tooling positions:	8 maximum
Rapid rate X & Z:	10m/min & 10m/min

Control System:

- Full 2 axis contouring
- Automatic tool nose radius compensation
- Canned cycles for threading, profile roughing and finishing
- Tape and remote computer data input/output
- Full screen edit facilities
- Sub-program facility

Special Requirements:

- Two and three jaw chucking systems
- Full Supplier technical support

FIG 19: - ROUGH CUT TARGET SPECIFICATION - "SIMPLE" PRODUCT RANGE

MACHINE TARGET SPECIFICATION

Machine type:	CNC Turning Centre
Application objective:	Production Machine Shop
Primary Objective:	To economically replace capstan lathes and secondary machines (drillers, millers & tappers)
Machining envelope:	150mm dia x 150mm long
Spindle power:	10hp (7.5 kw)
Swing over bed:	400mm
Speed range:	100 - 5000 rpm steeplessly variable.
Tooling positions:	12
Rapid rate X & Z:	10m/min & 10m/min
Control System:	. Full 3 axis contouring . Automatic tool nose radius compensation . Canned cycles for threading, profile roughing and finishing, drilling, tapping . Sub programming and macro (parametric) facilities with conditional testing . Full screen edit facilities . Tape and remote computer data input/output
Special Requirements:	. Two and three jaw chucking systems together with mandrel option . Programmable tailstock . Full Supplier technical support

FIG 20: ROUGH CUT TARGET SPECIFICATION: "COMPLEX" PRODUCT RANGE

4.1.6. Machine Tool Selection

Potential suppliers of CNC lathes were able to supply details of machine tools which were suitable to a greater or lesser extent. A total of over 50 machines were reviewed, of both UK and overseas origin.

The majority of the lathes fell into the "standard" category. This category is those machines which have a single multi-tool turret which moves in two axis in relation to a component rotating around its own centre line. The machine may or may not have a tail stock.

However, this majority did not satisfy the first target specification, because a turret style lathe is inherently slower than capstan lathes. The gang type lathe, losing no in-cycle time for turret indexing is more competitive. It can be limited in its flexibility, because the maximum number of tools is not only fixed by the machine itself, but also depends on the size of the component and the operations to be performed. Thus a major factor in the final selection is the size of the platten and the x-axis stroke over which it can travel.

This limitation was investigated in more detail by laying out the tools for each of the most complex parts in the "Simple" category. It was found that a minimum stroke of 400mm would be required, with a maximum chuck size of 125mm to avoid collision. The final shortlisting, shown in Fig. 21 included representatives from all the Suppliers of gang type CNC lathes in the U.K.

MAKE		WASINO	AKEBONO	BOLEY	PPL	TAKAHASHI	TAKAHASHI	TAKAHASHI	TSUGAMI
Country		Japan	Japan	Germany	Italy	Japan	Japan	Japan	Japan
Type		LG7 1		BDN160	ANTARES	10AD	NIX	NIX2	PL3B
Agent		IMTL	WARD	MB M/C's	BEAVER	WMT	WMT	WMT	HEPWORTH
Price	£K	42	38	59	33	43	34	36	39.5
Delivery	Mnths	2/3	Stock	3	1	2/3	2/3	2/3	3
Control		FANUC 6T	FANUC 3TA	SEIMENS 6T	OLIVETTI	FANUC 6T	FANUC 3TA	FANUC 3TC	FANUC 3TA
X-Axis Stroke	mm	480	350	480	250	275	200	200	300
Turning Dia	mm	150		150	150	200	120	200	150
Turning Length	mm	250 Travel	250 Travel	400 Travel	140	150	100	120	300 Travel
Swing	mm	320	220		250	300	200	300	260
Speed Range	RPM	120-6000	35-4500	50-6300	0-5000	50-5000	1500,3000, 6,000	50-5000	1-5000
Rapid Rate X	m/min	8.5	6	10	10	4	5	5	6
Rapid Rate Z	m/min	8	8	10	10	8	10	10	8
Spindle Power	HP	5	5	14	8	5	5	5	10
Spindle Power	KW	3.7	3.7	11	6	3.7	3.7	3.7	7.5
Floor Space w & l	mm	1650 1950	1300 1500	1500 1900	1080 2100	1700 1950	1050 1590	1200 1800	1435 1811
Weight	kg	1500	1600	2300	1500	2267	1000	1800	2000

FIG. 21: GANG TYPE CNC LATHE COMPARISON

The turning centre specification was also satisfied by a minority of the machines reviewed. The full 3-axis machine was a new concept to the market; 2½ axis units were not suitable. The shortlist of 3-axis machines, shown in Fig. 22, included representatives from all the Suppliers of 3-axis CNC turning centres in the U.K.

It will be seen that in both cases, the majority of machines finally considered were Japanese, with none of U.K. origin. Home machine tool manufacturers were unable to offer satisfactory specifications from their current range; nor were they able to predict when such units would be available.

The machines finally selected co-incidentally came from the same Supplier, and carried the same make of control system. Although this can be advantageous in terms of Supplier responsibility and system compatibilty, it can be a drawback in terms of single sourcing. Indeed each machine type was selected on its own merits. User sites were visited and cutting trials were performed. These were attended by members of Quality Control and Production Engineering departments as well as shop floor personnel.

The Wasino LG71 gang type machine offered the largest x-axis stroke within the budget price range. The layout of the machine was compact and preferred by the final users, as was the control system, which was made by a Company holding between 50% and 70% of the World control system market. Not only did the machine stand out on paper specification: it was also preferred in practice.

MACHINE		TSGAMI NCMU45 160	WASINO L3J3	IKEGAI FT20	OKUMA LC20M	TARGET	TARGET
AGENT		HEPWORTHS	I.M.T.L.	NC.ENG.LTD	NCMT	(2 AXIS)	(3 AXIS)
PRICE	£	£62 K	£66K	£66K	£85K	£30-40K	£50-70K
DELIVERY	MONTHS	2/3	3	EX-STOCK	3	EX-STOCK	EX-STOCK
NO. INSTALLED IN U.K.	MACHINES	5	5	5	0	10+	10+
SYSTEM		FANUC6TB	FANUC6TB	FANUC6TB 2000FT	OSP3000L	?	?
MAX. REC. WORK DIA.	MM	165	250	200	220	200	200
MAX. REC. WORK LENGTH	MM	220	350	250	700	150	150
MAX. X TRAVEL	MM	130	160	200	350	-	-
MAX. Z TRAVEL	MM	190	420	350	700	-	-
MAX. C TRAVEL	DEGREES°	99999.999	99999.999	99999.999	99999.999	-	99999.99
BAR CAPACITY	MM	45	42	63	65	-	-
DRIVE	DC/AC	AC	DC	DC	DC	CONT CONTROL	CONT CONTROL
MAIN MOTOR POWER	KW/CONT	10	11	7.5	11	7.5	7.5
SPEED RANGE	RPM	70-3550	12-1210;40-4000 15-1500;50-5000	125-3150	65-3500	0-6000	0-6000
STD. CHUCK SIZE	MM	165	210	220	220	150MIN	150MIN
TURRET TOOL STATIONS	-	12	12	12	8	8	12
MAX. NO. OF POWER-TOOLS	-	6	4	12	8	-	6
POWER TOOLS SPEED	RPM	59-1200 TAP 800-5000DRILL 700-4200 MILL	40-2400	125-3150	100-1500	-	0-3200
POWER TOOL MOTOR	KW/CONT	1.5	1.8	2.2	2	-	2
TAILSTOCK QUILL DIA.	MM	35	52	N/A	90	-	-
TAILSTOCK QUILL TRAVEL	MM	125	100	N/A	100	-	-
CUTTING FEED RATE X & Z	MM/REV	0.01-200	0.001-500	0.001-500	0.01-100	-	-
CUTTING FEED RATE C	°/MIN	1-6000	0.1-5000	1-2000	0.001-7200	-	-
RAPID TRAVERSE X/Z	M/MIN	6/6	8/10	4/8	5/10	10	10
RAPID INDEX C	RPM	19.4	22.2	13.3	20	-	20
SPINDLE MIN INCREMENT	DEGREES°	.001°	.001°	.001°	.001°	-	.001°
TURRET TIME STN 1-2	SEC	2.5	1.5	1.2	1.5	2	2
TURRET TIME STN 1-7	SEC	5	3	4	3.25	3	3
WEIGHT	KG	3500	3500	3500	-	-	-

FIG. 22: 3-AXIS CNC TURNIG CENTRE COMPARISON

The selection of 3-axis turning centre was less obvious. It was necessary to draw up a pros-cons table for the three major contenders, shown in Fig. 23. The Wasino L3J3 was found to offer the most attractive combination and was selected on that basis.

The Supplier's Audit, shown in Fig. 24, indicated a specialist reasonably established young business with a professional engineering approach, supported by a large manufacturing Company, which was itself a member of a major Japanese machine tool Group.

IKEGAI VS TSUGAMI VS WASINO

IKEGAI	TSUGAMI	WASINO
- DEAREST		+ CHEAPEST
- SLOWEST SPINDLE SPEED		+ FASTEST SPINDLE SPEED
- SLOWEST RAPID X,Z		+ FASTEST RAPID
- SMALLEST TURNING DIAMETER		+ LARGEST TURNING DIAMETER
- SMALLEST SPINDLE MOTOR		+ LARGEST SPINDLE MOTOR
	- SLOWEST INDEX SPEED	+ FASTEST INDEX SPEED
+ MOST POWERED TOOLS		- LEAST POWERED TOOLS
+ LARGEST TOOL MOTOR	- SMALLEST TOOL MOTOR	

* WASINO OFFERS BEST VALUE, ITS FAILING BEING POWERED TOOL QUANTITY LIMITATION.

* ANALYSIS OF PRODUCT MIX INDICATED THAT WASINO WOULD BE CAPABLE OF MACHINING PARTS SATISFACTORILY, IN SPITE OF THE LIMITATION

FIG. 23: PRO's - CON's TABLE: CNC MACHINE SHOP

PLANT SUPPLIER'S AUDIT

NAME:	Integrated Machine Tools Ltd.
OWNED BY:	Johnson, BA (Private)
AGENT:	Yes
MANUFACTURING :	No

MACHINE TYPE:	Wasino L3J3
MANUFACTURER:	Wasino (Japan): Part of Amada Group
OTHER AGENCIES:	2
ESTABLISHED:	1980
HELD AGENCY:	2 Yrs
CNC EXPERIENCE:	2 Yrs (Company); Average 12 years each engineer
TURNOVER:	£3m
SITES:	1
EMPLOYEES:	13
CNC ENGINEERS:	3 Application + 3 Service

INSTALLED THIS MACHINE:	5
INSTALLED ALL CNC:	35
USERS LIST:	Furnished
USERS VISITS:	2: Both favourable

MACHINE SERVICE:	Yes
MACHINE SPARES:	Front-line:UK. Major items:Germany
CONTROL SERVICE:	Fanuc
CONTROL SPARES:	Fanuc
SERVICE CONTRACT:	Yes: £1000 40 hours plus annual inspection
TRAINING PACKAGE:	1 Week flexible
INSTALLATION:	Yes
TOOLING PACKAGE:	Advice given: No Supplier bias

CUTTING TRIALS	Complete: Satisfactory

CONTACTS:	Ainger 8/10 Johnson 9/10 Debenham 7/10 NO REPS!

FIG. 24: SUPPLIER'S AUDIT

4.1.7. Financial Justification: Gang Type Machines

The information drawn from the data collection phase was combined with a projection of the benefits which would be achievable, namely tooling savings, reject cost savings and tool-setting savings. The financial appraisal revealed a NPV of £44,000, equating to 48.9% over the period of the investment. The DCF yield was calculated to be 27.7% with a straight Payback period of 2.4 years.

4.1.8. Financial Justification - 3 Axis Machines

In the 3-axis case, the benefits yielded a NPV of £87,000, equating to 62.6% over the period of the investment. THe DCF yield was calculated to be 31.1%, with a 2.2 year payback.

4.1.9. Order

Once the financial justifications were accepted and the expenditure sanctioned, orders could be placed for the equipment. This included necessary start up tooling, chucking systems and programming aids as well as the machine tools themselves. A training programme was also agreed with the Suppliers. The lead time for delivery was used to begin final personnel selection and background training, and to establish the various management and control systems which would be necessary.

4.1.10 PERSONNEL SELECTION AND TRAINING

The Machine Shop application was found to be rather different from many CNC installations by virtue of the type of work to be carried out, the batch quantities, the cycle time and the condition of the raw material, as well as the customs and practices presently adopted.

It will be recalled that the shop had two skill levels: toolsetters and operators. The toolsetters were responsible for setting up the tools and submitting the first-off sample for pass-off, before handing over the machine to a lower skilled operator for production. It was decided to split the CNC machine tool responsibilities in a similar way: that is, a toolsetter and an operator. However, the job of toolsetter was to be extended to include the creation of CNC programs and the planning of jobs so that the role became "CNC Toolsetter/Programmer" or "CNC Technician". The grade was equivalent to the highest existing skill level in the Machine Shop of "Universal Autosetter".

The selection of operators was less important, for the operators would merely load and unload work from the machine tool and check the quality of finished components: a practice universal within the works. Any adjustments necessary would be carried out by the Technician.

Thus the role of Technician was central to operation of the new installation. A job description was assembled and the position advertised within the Company.

There were over a dozen applicants for the two posts advertised, from all areas of the works. This indicated that the project had initiated a great deal of interest, and that the process of information dissemination had struck home.

The applicants were subjected to a two-phase selection procedure. The first was an informal detailed discussion of the machine tools and the duties of the job. It was designed to give a realistic idea of the challenge that lay ahead. No-one withdrew their application after this somewhat daunting picture had been painted.

The applicants were then invited to attend a formal interview, which consisted of a short aptitude test and some structured questions. The aptitude test contained some trigonometric problems together with questions on metal cutting speeds and feeds. The aim was not to test current knowledge but rather to assess potential ability. It was found that the majority had difficulty in performing simple tasks such as Pythagorous triangle calculations. However, those who were able to apply the equations once they had been demonstrated were the applicants of most interest. Some were not only unfamiliar with the concepts, but also unable to use them after repeated demonstrations.

The structured questions were designed to assess the attitude of the individuals, as well as their motives for applying. The two applicants finally selected came from different sections of the Machine Shop. They both had a measure of practical ability but lacked formal qualifications. They were both under 30 years of age but had been with the Company for at least eight years.

Most of the unsuccessful applicants were disappointed. However, they were able to understand their weaknesses because of the structure of the interviews. A number of them asked for further explanations on the trigonometric tests and requested some informal coaching in this respect.

In conclusion, the selection process was exhaustive but, more importantly, was seen to be fair.

The selected CNC toolsetter/programmers were also given further coaching in basic mathematic skills. They were keen to learn and were soon asking for exercises to take home and study. They learnt how to exploit the power of their newly acquired calculators, so that they were armed with the necessary background skills by the time their full-time training took place.

This was carried out away from distractions on the Suppliers' premises and was followed up with further continuous training once the machines were installed. A number of Production Engineers were given to the same training to ensure adequate technical backup.

The whole training programme was structured with a formal Company training manual, an extract of which is shown in Fig. 25. This allowed each individual to note his progress and also laid down the training procedure for new personnel who were to join the teams when further CNC machine tools were installed at a later date.

TITLE: PROGRAM WRITING AND TAPE PREPARATION

OBJECTIVE: FROM DETAIL ON PLANNING AND CALCULATION SHEETS, TO WRITE A CORRECT PROGRAM AND PREPARE A PAPER TAPE

MAIN TASK	SUB TASK/KNOWLEDGE	COMMENTS
1. COMPILE PROGRAMME	WRITE OPENING BLOCKS	REFER: OPENING BLOCK SHEET
	WRITE PROGRAM FOR EACH TOOL • Correct sequence • Correct use and knowledge of - speeds and feeds - G codes - M codes - other codes	I.M.T.L. PROGRAMMING MANUAL
	USE OF "C" AXIS	
2. TAPE PREPARATION	FAMILIARISATION • Use of keyboard • Use of punch • Tape System (I.S.O.) • Parity check	GENERAL ELECTRIC MANUAL TERMINET 2030
	PUNCH TAPE • Keying in • Back spacing • Deleting	
	CORRECTING TAPE • Read • Edit • Skip	FANUC PROGRAMMING MANUAL

FIG. 25: SAMPLE CNC TRAINING SCHEDULE

Training was viewed to be continuous. The CNC control system purchased was very powerful, and had features which were found to be useful some time after the implementation. From time to time, the toolsetter/programmers continued to be coached in the more subtle and sophisticated techniques.

An example was 3 axis profile milling, where a component is rotated around the c-axis whilst the milling cutter is moved in the x-axis to generate a profile. The toolsetter/programmers were able to produce the cutting data by constructing the geometry and writing a program in a version of Basic to carry out the calculations. They attended night school classes to learn Basic and used this skill to analyse their machines' performances and to manipulate data. In short, they had grown from being pure toolsetters into a role which was far more complex and challenging, and, in their own judgement, more satisfying.

4.1.11. Installation

The training of personnel could not be treated in isolation: this project represented the Machine Shop's first CNC installation. It had been discovered in an earlier phase that the management systems supporting the shop were weak in certain respects.

Central to CNC machines is the programming function. This was to be carried out by the toolsetter/programmers. Given the type of point-to-point work to be carried out, it was deemed necessary to give the Technicians the ability to modify the programs quickly, both during the writing phase and in production. Proprietary computer aids tend not to use the canned cycles and facilities available on the machine system, but rather to expand all machine operations out to raw cutter location data. This makes on-machine program enhancement difficult. In addition, the 3-axis turning centre concept was so new that the computer aids were unable to offer 3-axis (X,Z,C) facilities.

Therefore, it was decided to use a small portable micro-computer with text editing software so that programs could be written to manipulate the machine tool precisely. Once written, the data could be transferred to the machine tool directly, using the communications software. The program could be modified as necessary to improve cycle times, for example before being downloaded to the micro-computer for subsequent archiving on paper tape.

In tandem with this, layout sheets were designed to allow tool layouts to be quickly constructed. This was especially important for the gang type lathes where an incorrectly positioned tool can be disastrous.

Checklists were drawn up to ensure that the necessary duties were carried out. This included tool storage and maintenance, which was to be kept separate, until the overall control of tooling within the Machine Shop could be brought into line. Much of this preparation work was carried out by or with the newly appointed CNC personnel. This ensured they understood the systems and their objectives.

In due course, the site was cleared and services prepared to allow a smooth implementation. The machines were required to go straight into production following installation and commissioning: there was no working-in period. Within two days they were running, and were deemed to be up to budget within several weeks.

4.1.12 Aftercare and Post-Audit

Although the installation was quickly on-stream, a continued level of support was necessary to provide confidence, advice and guidance. This consultative role lay with Production Engineering. It was necessary to measure how well the machine tools were performing. A data collection exercise was carried out to access the efficiency, utilisation and availability of the plant, and to carry out cycle time comparisons to test the justification.

A sample of the results are shown in Figs. 26 and 27. The cycle time analysis shows results that were on target with the proposal, although it will be seen that there was a wide band of cycle time improvements. It should be noted that the Cycle Time Audit was carried out within two months of the implementation: further improvements were obtained as the level of skill and knowledge increased. Most noteworthy was the reduction in the number of operations, which was highly significant in some cases.

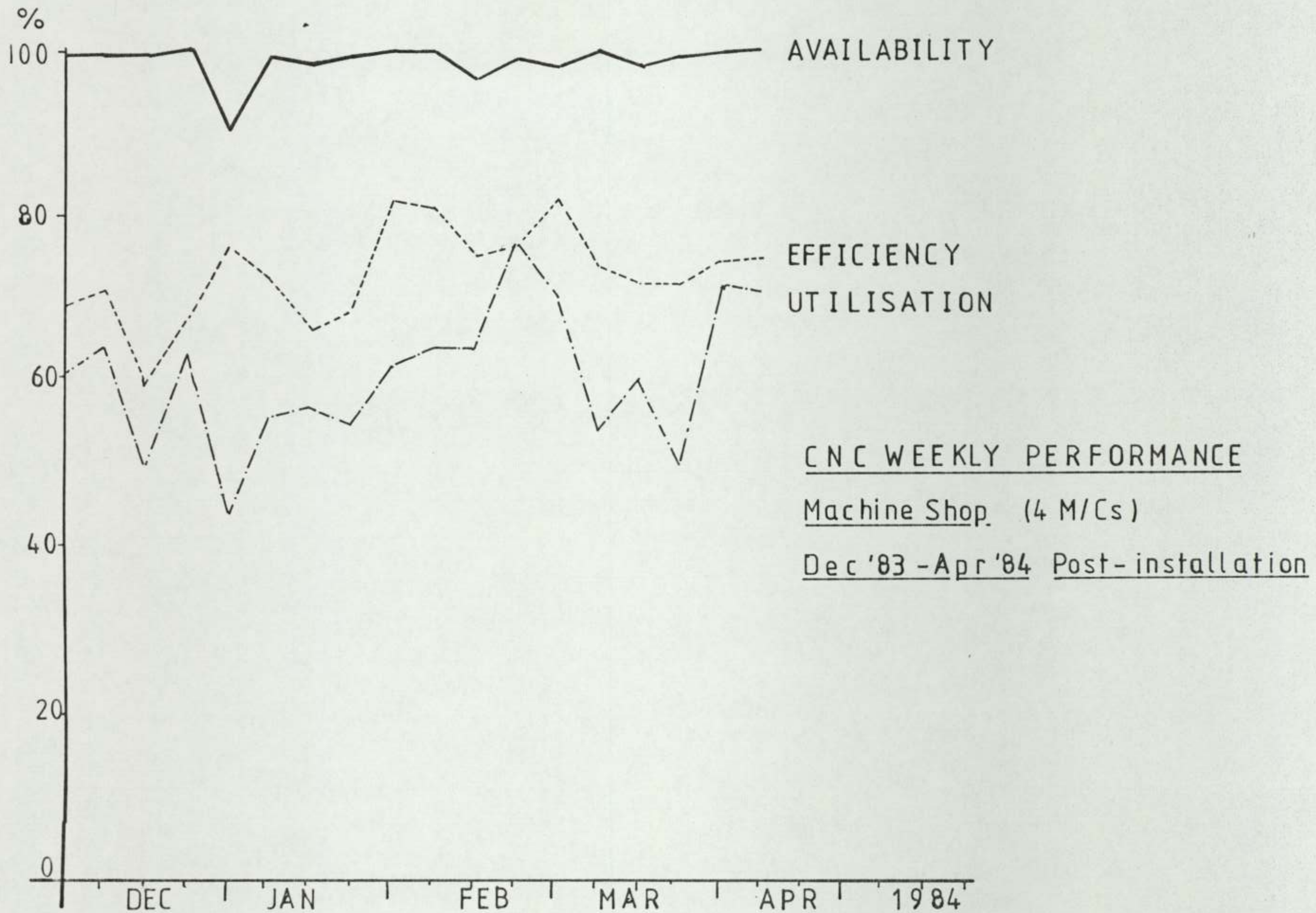
It will be seen from Fig. 27 that Availability was consistently above 90%, and averaged approximately 97%. A single dip was caused by an operator error which resulted in extensive machine tool damage. Utilisation fluctuated between 45% and 77%: poor Utilisation was mainly due to material and operator shortages. Machine Utilisation was a new concept to Shop Supervision, who were accustomed to having a surplus of machine tools, and instead measured Operator Utilisation. Much work remained to be done to improve machine tool Utilisation.

CYCLE TIME ANALYSIS

Part No.	CNC		Traditional		Saving
	Mins	Ops	Mins	Ops	(Time)
M6973	4.80	2	7.13	10	33 %
M6975	4.67	2	5.80	12	20 %
N0603	1.30	1	1.40	5	7 %
P7658	2.27	2	3.06	3	25 %
Q5092	0.55	1	1.17	1	53 %
R4975	3.55	2	4.88	13	27 %
R8614	2.16	1	2.33	5	7 %
V0575	3.00	2	6.00	4	50 %
Z0056	6.60	2	13.20	7	50 %

FIG. 26 POST AUDIT: CYCLE TIME COMPARISON

FIG 27 CNC PERFORMANCE ANALYSIS



Operator Efficiency fluctuated between 60% and 82%. This shortfall warranted further investigation because, in theory, the operator could only affect the load/unload portion of the total cycle time. It was found that the efficiency figures were lower than expected because:

- The operators were not working to an incentive, unlike elsewhere within the works.

- Multi-machine manning was leading to interference.

An incentive scheme therefore was necessary, but it could only be implemented once the interference problem had been solved.

Interference occurred when operator intervention was required simultaneously on both machines. For a given set of cycle and load/unload times, the effect of interference could be predicted. Fig. 28 demonstrates this graphically. The first case shows no interference, because the combination is balanced; the second case gives rise to an interference pattern. Whilst this can be plotted manually using Gandt charts, the method is laborious and time consuming.

A simulation program was written using a "next event" algorithm to predict interference levels. Sample results are shown in Fig. 29. The program allowed poor cycle-time combinations to be avoided in production, and gave adjustment values for Standard Times so that an incentive scheme could be implemented. Operator Efficiency figures rose accordingly to a satisfactory level.

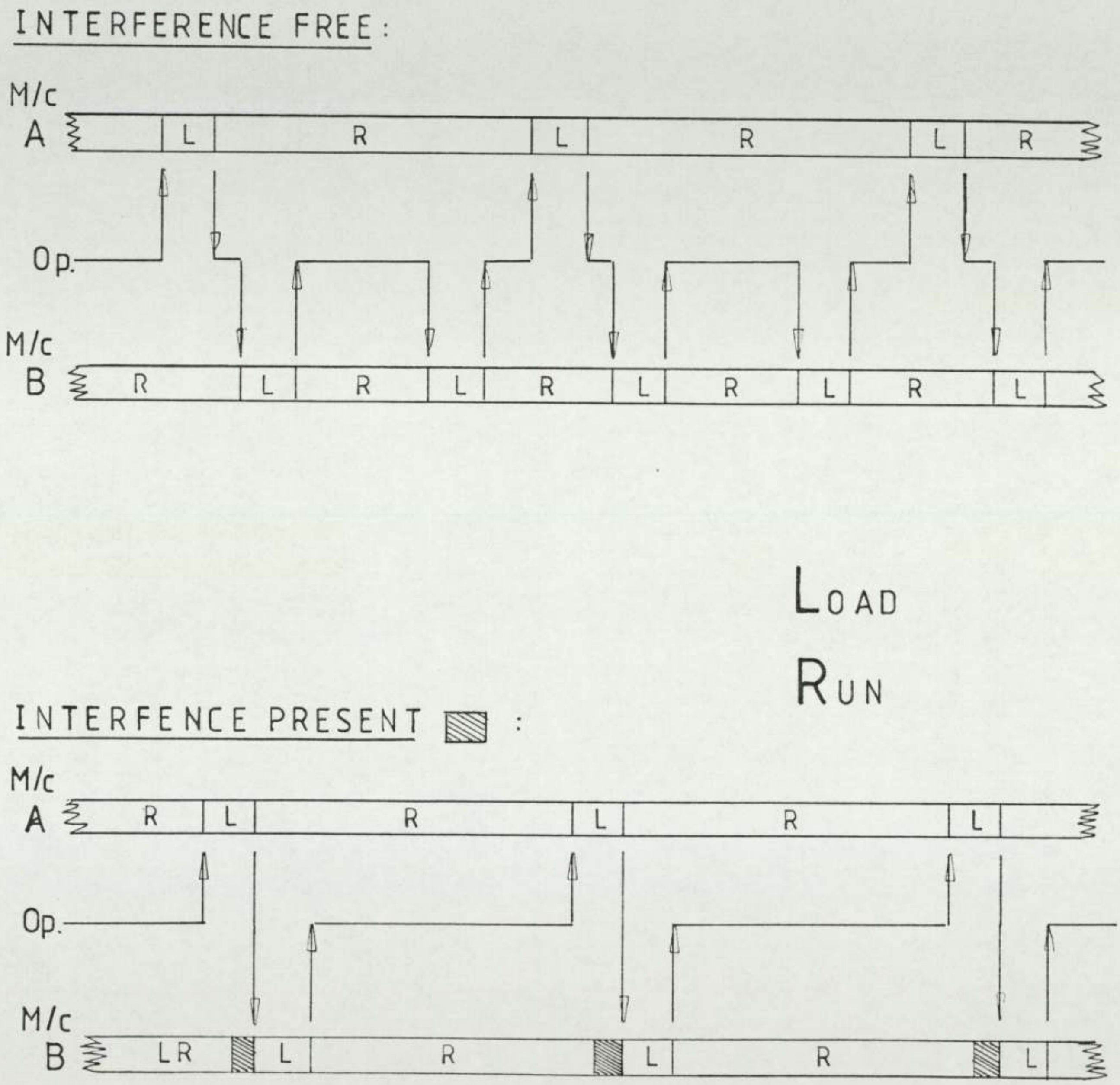


FIG 28 MACHINE INTERFERENCE

MACHINE INTERFERENCE

CASE	1	2	3	4	5	6
CYCLE TIME A	240	60	46	30	180	25
CYCLE TIME B	180	46	36	36	150	30
Utilisation A	99.1%	94.5%	99.4%	88.2%	99.5%	88.6%
Utilisation B	98.9%	97.1%	83.4%	99.7%	98.5%	99.6%

(All priorities on Cycle Time A)

FIG. 29: INTERFERENCE SIMULATION RESULTS

4.2. CASE 2: THE SERVICE TOOLROOM

4.2.1. Background

The Toolroom within the Company served to provide a complete toolmaking facility. It had the capability to produce forging dies of varying degrees of complexity for both conventional and Hatebur forging processes as well as jigs fixtures, cutting tools, jaws and gauges. Wherever possible, it was the policy to make rather than buy, the aim being to maintain control over the production of tooling, the priorities of which could change on a daily basis due to production rquirements. Only when there was an overload would work be sent out: overtime would be used to its maximum before this alternative route would be taken.

The equipment in the Toolroom was varied and comprised a full range of machines from lathes and millers to spark erosion machines and optical profile grinders.

However it was a particular product range which was causing concern. This was the tooling used on the Hatebur high speed hot forging transfer machines which produced components, such as capnuts for the water fittings market, at 9000 parts per hour. A tool-kit was required for each different component, comprising of approximately 100 pieces, including an allowance for the duplication of certain wear parts, which were replaced as necessary. The majority of these parts were turned on centre lathes. Some required other operations, such as spark erosion of die pockets, milling of flats and keyways, and drilling of air holes. Most required hardening and grinding.

The main bottleneck occurred at the turning stage. The lathes were unable to cope with the workload required, with the result that lead-times were unacceptably long. New tool kits were late or incomplete and the Hatebur presses were forced to wait in mid-batch whilst a replacement wear part was manufactured.

The implementation of CNC machining was therefore studied, to provide the manufacturing areas within the Company with an improved service.

The project spanned a period of 12 months and resulted in the purchase of a single 2-axis CNC lathe.

4.2.2. Definition of Terms of Reference

The decision to investigate the use of the CNC machining techniques was the result of the difficulty experienced by the Toolroom in providing a satisfactory level of service. The project was therefore jointly driven by the Manufacturing Director and the Toolroom Manager.

A Project Leader controlled the project, but there was a great deal of involvement by the Toolroom personnel in terms of data collection and machine tool selection.

The objectives were:

- To reduce unit costs
- To improve service.

It was required that the justification be made in financial terms, with the use of unquantifiable benefits to be avoided. This was simply because the data needed for calculating the effects of a reduction in lead times, for example, was not available. This policy was similar to that adopted for the Machine Shop installation.

The turning section of the Toolroom was working with a high level of overtime to cope with the load. In addition, labour was transferred from other Toolroom sections (to their own detriment) to supplement the existing manpower. It was agreed that the project should aim to reduce the manufacturing time and therefore cost.

Throughout the project, the 'team' approach was adopted so that members of the Toolroom could participate, by putting forward their views and comments. Again, the aim was not paint the picture of a foregone conclusion, but to demonstrate that the project would be driven by the Toolroom personnel themselves. The Hatebur tooling designers and users were also included.

4.2.3. Assessment of Existing Situation

The Toolroom was found to be out on a limb in terms of factory data collection. This was probably because, unlike the production function, the monitoring of manufacturing costs was difficult and costly. The Toolroom, by its very nature, had to perform a variety of tasks with short batch quantities. In the limit, a single component might be manufactured on one occasion only. Unlike a contract Toolroom, the toolmakers were paid for their attendance, rather than for the amount of work carried out in a given period.

The total cost of running the Toolroom was regarded as a factory overhead which was apportioned to the various production cost centres: tool costs were not regarded as an extraordinary item.

This paucity of data was considered unsatisfactory in terms of plant acquisition and justification; it was thus necessary to carry out a detailed analysis of the turning activity.

It was not simple to carry out. Detailed discussions were necessary with the toolmakers, their managers and their Union representatives before a satisfactory system could be agreed. The timing of manufacturing process in an previously unmonitored environment can generate ill-feeling and unease if handled carelessly.

The need for such information was explained at length, and assurance had to be given that the data was to be used purely for justification purposes, and would not be used for assessment of individual performance. It should be pointed out that the objection was not to CNC machine tools "per se", but to the work measurement which had to take place. The protracted debate resolved, no further difficulty was encounted throughout the project.

i) Product Mix Analysis

General

A complete kit of Hatebur tooling consisted of approximately 35 different pieces, which typically totalled 90 components, allowing for duplication of wear parts. The batch quantity for each part varied from 1 to 12, depending on its function and projected Hatebur production call-off.

The tooling was designed in such a way that a functional part in one kit was of similar general profile to the equivalent functional part in other kits designed to fit the same size machine. There were two machine sizes, known as AMP20 and AMP30. This similarity of component styles was also true, to a somewhat lesser extent, across the two machines. Component style similarity eased tool design, but also made it ideal for CNC machining using family part programming techniques. Therefore, a certain component style could be classed as a single component type.

Shape and style

Hatebur tooling fell in to two categories:

.	Chucking work	50mm - 120mm diameter
		10mm - 100mm long
.	Centre work	8mm - 50mm diameter
		50mm - 240mm long

Within these two categories, turning techniques required included:

- Rough facing and turning
- Finish copy facing and turning
- Taper turning
- Short hole rough drilling
- Deep hole fine drilling
- Rough boring
- Finish boring
- External square and V grooving
- Internal square grooving
- Parting off

Profiles were simple, defined generally by straight lines between points, joined by blend radii and chamfers.

Materials were generally hot work tool steels, class BH10 to BS4659. Some cold work steels were also used. Raw stock was in the form of sawn billets or short bars for smaller diameter work. Unspecified tolerances were $\pm$ 1mm with some tied to $\pm$ .006mm. Some parts required milling, drilling and spark erosion following turning; most were finally hardened and ground. Certain parts required letter cutting. All parts were identified with punched drawing and serial numbers.

Usage

An analysis was carried out which covered the new and replacement tooling requested in a 12 month period. Tooling for 21 different new products was included in this analysis. This showed that total of 232 different component styles were manufactured, representing 2935 parts in 968 batches, giving an average batch size of 3.03. It was also found that 21 components styles accounted for 50.05% of the total.

The production of Hatebur tooling was monitored for a 3 month period to establish production times of a range of components. 366 pieces were made in 652.5 hours, with 94 different components styles represented. The average production times was 1.78 hours. There was 76% match between the leading 21 styles and the time data collected, indicating that the time data could be considered representative. A sample of the data collected is shown in Fig. 30. 7% of the components made (22% of components styles), were non-standard or semi standard parts. 42% of the components made were for new tooling kits. It was estimated that the annual requirement for replacement tools would increase by a further 25%, because existing tooling stocks were being run down.

HATEBUR TOOLING PRODUCED 08/83—07/84 WITH TIMES 16/8/84

PART NO	OF	DESCRIPTION	QTY/BATCHES		TIME	
D 101140	1	THRST PAD	10/7		1.75	
D 101187	1	GLND	6/6		2.5	
D 101187A	1	GLND	1/1			
D 101285	1	PNCH	25/10		3	
D 101285A	1	PNCH	1/1			
D 101286	1	DIE	12/5			
D 101287	1	EJ	16/6			
D 101322	1	HLDNG PEG	28/11		1.5	
N 101322A	1	HLDNG PEG	2/1			
D 101330	3	EJ PIN	9/3			
D 101331	3	CMPN PIN	5/3			
D 101558	2	DST PIN(SETS)	15/3			
D 101560	3	PRCNG PNCH	32/6	1.09%	1.17	
D 101561	3	PRCNG DIE	116/25	3.95%	2.5	***
D 101561A	3	PRCNG DIE	6/1			
D 101562	2	SLV	10/4		2.13	
D 101562B	2	SLV	6/2			
D 101563	2	FRMNG PNCH	53/18	1.81%	1.71	
D 101566	2	FRMNG DIE	2/1		1.67	
D 101905	3	GLND	3/1			
D 101906	3	STRPPR PLT	10/6			
D 101909	1	EJ ROD	7/7		1.63	
D 101910	1	PRESS PAD	12/8		1.25	
D 101915	2	GLND	5/5		3	
D 101915A	2	GLND	3/3			
D 102500	3	SCRNG RING	5/3			
D 102501	3	LFTNG SLV	9/4			
D 102502	2	CMPN PIN	6/1			
D 102503	2	COMP PIN	8/4			
D 102506	2	DST PC	41/9	1.40%	.8	
D 102507	2	PEG HLDR	21/7		1.67	
D 102508	2	DST BSH	8/4		3	
D 102509	2	DST PC	18/6		.96	
D 102511	2	CMPN PIN	39/7	1.33%		
D 102512	2	HLDNG PIN	17/5		1.05	
D 102513	2	SLV	5/2			
D 102513A	2	SLV	3/1			
D 102514	2	FRMNG DIE	8/4		1.75	
D 102515	2	EJCTR	21/7		1	
D 102516	2	RING	9/4		1.2	
D 102517	2	DST PC	35/7	1.19%	.8	
D 102518	2	DST PC	[illegible]		1.25	

FIG. 30: EXTRACT HATEBUR TOOLING ANALYSIS

Other Components

In addition to the Hatebur tooling, many other items required extensive turning. They included:

- Internal cutting tools, prior tipping and grinding.
- Pegs for conventional turning.
- Ancillary tools and gauges.

Profiles were generally simple, with point-to-point geometry: this type of work is easily programmed and cut on a CNC machine tool.

Large conventional press dies were much larger than the items above and did not fall into the machining envelope of Hatebur tools. They required a heavier machine tool which would be unsuitable for the smaller work.

ii) Plant Survey

The Toolroom had a total of 11 centre lathes with an age range of 4½ - 24 years and an average age of 12 years. 4 of the lathes were over 20 years old and were at the end of their useful life. The specifications of the newer lathes was found to be suitable for the function and were in reasonable condition. They were fitted with positional encoders and digital readouts which were found to give a production advantage. Only the machines so equipped were included in the data collection exercise.

In addition, the toolroom possessed a single CNC lathe, which was six years old. It was a large machine with a 14" chuck used, in the main, for the production of large circular friction-press dies. It was found to be unreliable and required continuous maintenance.

The tooling used on the centre lathes was a mixture of HSS, ground by the toolmaker to suit a particular purposes, and carbide insert tooling similar to those used on CNC machine tools. Form tools were generally not used because of the small batch quantities involved.

iii) Assessment of Manufacturing Systems

The Toolroom possessed two CNC machine tools: the CNC lathe has already been mentioned. The other unit was a CNC miller used for the machining of complex die forms and for repetitive work such as the production of jaw set for multi-spindle automatics.

Both these units were over 5 years old and their processing capabilities were limited by modern standards: the lathe's canned cycles, for example, were unsophisticated and inflexible.

The two machines were double shifted: the four operators were supported by a programmer, who relied on a land-line link to a Computer Aided Part Programming (CAPP) bureau service.

The GNC (Graphical numerical Control) system used had 2½-D capabilities, and was particularly well suited for the generation of miling programs where non-linear and non-circular forms were required. The following is an outline description of the system:

> Graphical Numerical Control (GNC) is a system used in Computer Aided Design (CAD) and Manufacture (CAM) of essentially 2½ dimensional components. A 2-D shape can be represented by lines and circles drawn in a plane and machined by driving a cutting tool around the shape. The cutter nose can describe discrete vertical movements, while the axis of the cutter follows the horizontal profile of lines and circular arcs.
>
> Information is taken from a conventional engineering drawing and unambiguously represented in a mathematical form called a "K-Curve". The k-Plus program provides a means of accurately defining two dimensional shapes without the user having to perform tedious geometry calculations. Relevant unbounded geometry elements, i.e. points, infinite straight lines and complete circles, are first defined. Secondly, a K-Curve representing the 2-D shape is described. This is referred to as 'bounded geometry' and is constructed of spans from the unbounded geometry. The shape defined in this way can be manipulated, scaled, rotated and displayed on a visual display unit (VDU). It is then possible to describe a 2-D machining process such as milling, turning, punching and flamecutting, in which the K-curve constrains the movement of the cutting tool.

> Once the computer design has been created, it is possible to visualise important sections, tool offsets and the machining sequence on the graphics terminal so that any modifications can be easily made.
>
> The details of the K-curve, geometry transformations and machining sequences are then converted into data for a specific numerically controlled machine using a post-processing program. The machine instructions are then ready for production to commence.

The GNC system overcame the relatively limited features of the machine tool control systems, usually by expressing all data in the simplest terms. For example, a threading cycle called up through GNC would pass simple point to point data to the machine tool rather than use a canned cycle.

GNC is a well known system and was well established within the Toolroom. The Company had attempted to use a 3-dimensional equivalent for the machining of complex dies but had met with little success. In addition, some progress had been made in the introduction of a Computer Aided Drafting system, with the aim of generating a single source of geometrical data for each part which could be used for tool and die design, as well as for CNC machining. The bureau costs at that time had proved prohibitive and the Draughting system virtually abandoned.

Thus the majority of product data was stored as drawings. The Hatebur tooling drawing system was particularly good, although the lack of a comprehensive quick access index, together with the shear quantity of drawings, resulted in the inadvertent replication of design activity.

Orders for new tooling came from two sources:

- Tool Design Department.
- Hatebur Shop Management.

New tooling was required when a component was ordered by a Customer for the first time. The tool kit would be designed and drawings then forwarded to the Toolroom together with a bill of quantities and a due date. A repeat batch for replacement tooling would be ordered by the Hatebur Shop when parts were worn or damaged. Again, a bill of quantities, with a due date, would be forwarded to the Toolroom.

There was no formal routing for each part. Toolroom supervision would ensure that the parts conformed to drawing before being sent to the Hatebur Shop, and would aim to carry this out by the due date stated.

Thus there was little formal control over the sequence of events and there was not the data available to do more than plan with a limited horizon. It is fair to say that this is inherent to any toolroom, where required leadtimes are tight, if not non-existent. Materials and cutting tools were issued to the shop from a store, which worked on the principle of re-ordering when stocks appeared low.

It was evident that any new plant installation should be designed to fit the environment which could itself only be altered in minor detail.

iv) Assessment of Personnel

Six toolmakers were permanently assigned to turning work on the centre lathes. This manning level was supplemented by an additional two toolmakers, who would have normally carried out other duties. This was found to be necessary because of the volume of tools required.

The existing CNC lathe was manned by a further two men working a double day shift.

The majority of the turners, together with the CNC operators, were under 40 years of age and had served a formal apprenticeship. They had, therefore, a good level of technical and numerical skill and a solid basis of product knowledge. The CNC programmer was younger than the toolmakers and had a high level of technical skill but was necessarily limited in his experience of metal cutting.

The Toolroom manager recognised the need for change, and had a good understanding of the role of his current CNC machining capacity, and realised the limitations. He too was an experienced toolmaker, but lacked in-depth knowledge of the progress CNC technology had made since the 2 CNC machine tools were purchased.

The above personnel took an active interest in the progress of the project. They had certain pre-conceptions, many of them misplaced, of what CNC could achieve, and were impressed with what they saw when they visited a large machine tool exhibition and when they witnessed cutting trials on components with which they were familiar.

The problems in agreeing data collection methods were not repeated: there was an eagerness to learn and contribute to the modernisation of their working environment.

4.2.4. The Options Reviewed

The Company was faced with a number of options:

- Purchase CNC turning capacity
- Increase conventional turning capacity
- Continue to use overtime at a higher level
- Send work out to sub-contractors.

The Company had a stance which would colour the argument.

Firstly, there was a determination to do something about the lead times for tooling, which were proving to be a major problem in satisfying final Customer delivery dates. However, there was a policy of maintaining indirect labour at a minimum level, of which the Toolroom formed a major part, along with labouring, maintenance and other production support personnel. Thus an increase in labour, either through recruitment or by extending the use of overtime, was regarded as an unsatisfactory solution to the problem, even though it contained the lowest risk.

Secondly, it was generally agreed that buying out parts caused its own problems. Sub-contractors cannot cope with constantly changing priorities, which was a feature of the toolmaking function, and was a direct result of the nature of the jobbing industry, where parts are made to a Customer order, rather than for stock against a forecast of trade. Placing lead time responsibilities outside the direct control of the Company was not regarded as a positive step forward.

In spite of this view, sub-contractors were asked to give quotations for a number of Hatebur tools, on a free issue of material basis. It was found that the prices were competitive with a price advantage of between 2% and 10%, compared with in-house costs, and that projected lead times were approximately equal to those required.

This exercise was carried out at a time when sub-contractors were working with spare capacity and were quoting on a marginal basis. The buy-out option was finally rejected because it was felt that any subsequent lift in the manufacturing economy would be reflected in sub-contractor price increases and extended lead times. The policy of in-house control was to be maintained.

Thus the option chosen was to investigate CNC machining.

There were a number of sub-options which were to be revealed through the product mix analysis, the assessment of existing systems, and the machine tool study.

- Technique-for-technique substitution where several centre lathe operations are required, a fewer number of CNC operations are substituted.

- Multiple technique replacement, by eliminating other non-turning operations such as milling and drilling, achieved through the use of 3 axis CNC machining (X, Z and C axes). Alternatively the grinding operations would prove unnecessary if the required tolerances could be achieved by CNC turning.

The 3 axis option was found to be unacceptable because of the constraints placed upon tooling layout, since powered tools on the turret reduced the number of turning tool positions available.

An investigation was carried out to study the elimination of grinding. Grinding served several purposes:

- Machining to tighter tolerances and finishes than could be achieved on a centre lathe.

- Removal of scale which was the result of the hardening process.

- Elimination of the effects of distortion through hardening.

It was evident that elimination of grinding required the elimination of the effects of hardening either by changing the method or by rendering the operation redundant.

Salt or vacuum hardening was necessary to achieve good wear characteristics: a hardness range of 48-50 Rockwell (C) was specified. The use of a pre-hardened material was not possible on its own, because the 38-40 Rockwell hardness was unsatisfactory. The application of proprietary surface hardening treatments such as titanium nitriding requires a base hardness higher than that obtainable in a prehardened material. To date, it has been found that conventional hardening is required. Thus is was concluded that grinding could not be eliminated with the materials available at that time.

The reduction in turning operations was deemed to be possible and gave positive advantages in terms of machining costs. The use of advanced techniques such as deep hole drilling would be required. These techniques were investigated and a suitable one found which was a development of the gun-drilling process.

The review of options, which was continuous, indicated that 2-axis turret style CNC lathe, with a long bed and reasonably high spindle speed capabilities would be appropriate. The final set of options concerned the programming and data storage system to be used. The GNC system, previously described, was found to be working to full capacity. Moreover, its method of post-processing to a limited series of addresses made even minor on-machine program modifications extremely difficult.

The nature of the products to be machined, in terms of component similarity, indicated that family part programming methods could be used to advantage. The facility to set variable values on the machine itself would eliminate the real problem of non-standard feedstock sizes, and would minimise the leadtime required for a component program to be prepared. For the concept to operate, it was necessary to hold previously written programs on a fast access data base: the traditional paper tape medium was therefore unsatisfactory.

CNC machine tools have a measure of user memory which can hold programs even when the machine tool is shut down. This is usually achieved by the use of bubble memory or by CMOS memory with battery back-up. Extension of memory is possible, but is relatively expensive and limited. This memory is volatile, and therefore requires external back-up. Again, this is conventionally the reserve of paper tape.

External bubble memory can be used, which also is expensive in terms of £/byte. The best value is a floppy diskette medium, which is approximately 75% cheaper than paper tape, is reusable and gives fast access time. The option selected was to take a personal microcomputer equipped with twin diskette drives and an interface port to allow direct communication between the data base held on diskette and the machine tool control system. Suitable microcomputers were found and one selected.

The Option Review Tree summarising the decision process is shown in Fig. 31.

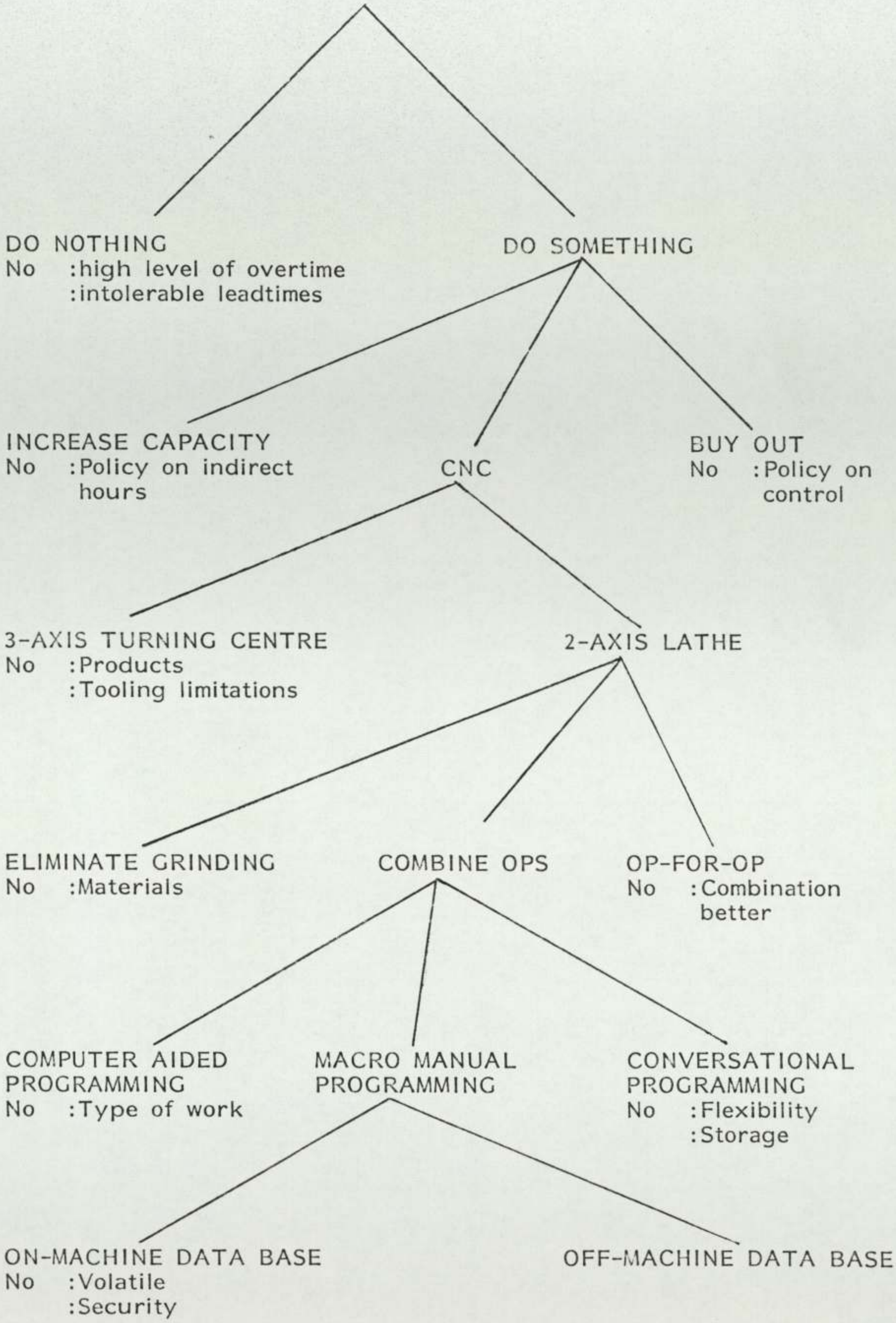


FIG. 31: TOOLROOM OPTION REVIEW TREE

4.2.5. Target Specification

The Option Review, together with the Product Mix Analysis and Systems Audit allowed the target specification to be drawn up; this is shown in Fig. 32.

4.2.6. Machine Tool Selection

48 Machine tool suppliers were furnished with the Rough-Cut Target Specification; this led to 52 machine tools being considered.

It was found that many of the machine specifications did not match the target and were immediately discarded. The resultant twelve machines were examined in detail using the analysis chart, shown in Figure 33. This narrowed the field to four machine tools, three Japanese and one of UK origin.

A specification summary is shown in Figure 34.

It will be seen that the four machine tools all satisfied the target specification.

A number of installations were visited, including one where a similar range of components were being produced. This, together with the suppliers audit, confirmed that the Takisawa was the optimum choice, and matched the target budget price.

MACHINE TARGET SPECIFICATION

Machine Type	.	CNC Lathe.
Application	.	Service Toolroom, hot and cold work tool steels.
Primary Objective	.	To economically replace centre lathes turning operations.
Machining Envelope	.	200mm dia x 500mm long.
Spindle Power	.	15HP (11 KW).
Chuck Dia	.	200mm.
Speed Range	.	100 - 4,000 r.p.m.
Tooling Positions	.	12 minimum (to allow deep hole drilling).
Control System	.	Full 2 axis contouring.
	.	Automatic tool nose radius compensation.
	.	Canned cycles for profile roughing and finishing.
	.	Full screen editing facilities.
	.	Sub and macro - (parametric) programming facilities with conditional testing.
	.	Tape/remote computer date input/output.
Special Requirements	.	Fully programming tailstock.
	.	Swarf Conveyor.
	.	Full Supplier technical support.

FIG 32: ROUGH CUT TARGET SPECIFICATION: TOOLROOM

CNC LATHE SPECIFICATION SUMMARY

DATE:
BY:

MANUFACTURER: VERSION: ORIGIN:

CONTROL: OPTIONS: :

UK AGENTS: BASED:

MAX TURNING DIA: SWING OVER BED: SWING OVER X/S:

STD CHUCK DIA: SWING OVER TOOLS: MAX BAR DIA:

MAX SHAFT LENGTH: MAX STROKE WHEN ON CL:

BED MATERIAL: BASE MATERIAL:

BED ANGLE: WEIGHT:

HEIGHT: WIDTH: LENGTH:

SPINDLE MOTOR: CONT HP: 30 MIN HP:

MAX POWER RANGE: AC/DC: PROTECTION:

TOTAL RANGE: RANGE 1: RANGE 2:

GEARCHANGE:

SPINDLE NOSE: FRONT BEARING: REAR BEARING:

HOLE THRO' SPINDLE: BAR DIA:

	STANDARD	£ OPTION
1.CHUCKING CYLINDER:		
2.CHUCK:		
3.ALT CHUCK:		
4.MANUAL TAILSTOCK:		
5.PROG QUILL:		
6.PROG TAILSTOCK:		
7.STEADIES:		
8.PARTS CATCHER:		
9.SWARF CONVEYOR:		
10.TOOLHOLDERS:		
11.CUTTING TOOLS:		
12.TOOLKIT:		
13.INSTALLATION:		
14.PROG COURSE:		
15.OP COURSE:		
16.MTCE COURSE:		
17. ____________ :		
18. ____________ :		
19. ____________ :		
20. ____________ :		

MACHINE PRICE: £

PLUS OPTIONS: ( ) £

QUOTE: / / EXCHANGE:

REMARKS: Date:

	X AXIS	Z AXIS
SLIDEWAY MATERIAL:		
SLIDEWAY WIDTH:		
LUBRICATION:		
PROTECTION:		
STROKE:		
MOTOR TYPE:		
TORQUE:		
THRUST:		
RAPID:		
BALLSCREW DIA:		
PROTECTION:		
ACCURACY:		
REPEATABILITY:		

MANUAL TAILSTOCK: PROG.QUILL: FULLY PROG:

QUILL STROKE: BODY STROKE: SPEED:

CLAMPING ACTION: QUILL ACTION: LUBRICATION:

QUILL BORE: QUILL DIA: BED WIDTH:

TURRET SHAPE: NO. OF TOOLS: CENTRELINE:

INDEXING ACCURACY: INDEXING MECHANISM: TIME 1-2:

CLAMPING FORCE: RING DIA: C/BALANCE:

PROTECTION: UNI/BI-DIR: TOOL TYPE:

CONTROL POSITION: JOG TO ZERO RETURN: Z/R INDICATOR

SPINDLE JOG: SPINDLE OVERRIDE: FEED OVERRIDE

FEEDHOLD: COOLANT: prog/on/off INDEX:

CYCLE START: TAILSTOCK: f/b QUILL: f/b

JOG TYPE: X-AXIS: Z-AXIS:

FIG. 33: SAMPLE SPECIFICATION ANALYSIS CHART

MACHINE SPECIFICATION SUMMARY CHART

MACHINE	TARGET	TAKISAWA TS20	IKEGAI AX20Z	MORISIEKI SL3H	HC3/15*
Supplier	-	TI Rockwell	NC Eng'ing	Elgar PMT	TI Matrix
Country of Origin	-	Japan	Japan	Japan	U.K.
Axis	2	2	2	2	2
Chuck Dia.	200mm	200mm	210mm	210mm	160mm
Turning Dia.	200mm	210mm	200mm	200mm	200mm
Turning length	500mm	700mm	700mm	610mm	700mm
Z Axis Stroke	500+mm	620mm	700mm	560mm	800mm
X Axis Stroke	150+mm	170mm	250mm	160mm	155mm
Turret Centre Line	Z	Z	Z	Z	Z
Turret Chuck Dist.	500+mm	602mm	550mm	500mm	800mm
Tool Type	25mmsq	25 mm sq	25 sq mm	25 sq mm	25 mm sq
Max. Tool Clear.	250mm	300mm	250mm	250mm	250mm
Tool Positions	12+	12	12	12	12
Spindle Speed Max.	4000+	4000	4000	4000	5000
Spindle Power (HP)	15CONT	15 AC	15 DC	15	20
Rapid Traverse x/z	5/5mm/min	5/10m/min	10/12m/min	5/10m/min	7.5/7.5m/min
Configuration	Slant/Flat	45°Slant	Flat	45°Slant	45°Slant
Control	6TB/2000T	6TB	6TB	6TB	6TB/2000T
Tailstock	Fully prog.	STD.	OPT+£8117	OPT+£4202	OPT+£4144
Swarf Conveyor	OPT.	OPT+£2370	STD	OPT+£3827	STD
Height	-	1805	1740	1910	1800
Width (mm)	20001 max	1705	1650	1795	1700
Length (mm)	4000 max	3460	3180	3680	4500
Weight (kg)	6000 max	4300	5700	4250	4000
Delivery (mths)	Shortest	2-3	2-3	2-3	4-5
Price with options		£62348	£71924	£68179	£67776
Total installed	£70000	£69972	£79548	£75803	£75400

* Special long bed version.

FIG. 34: TOOLROOM CNC LATHE COMPARISON

4.2.7. Financial Justification

The financial justification of the machine tool was based on a reduction in unit costs resulting from an improvement in machining times. The effect of improved lead times and of the elimination of the bottleneck at the turning stage was not quantified since the data was not available.

The primary cost of the tooling was labour: there would be no reduction in material or tooling costs following the purchase of a CNC lathe. Neither was a reduction in scrap costs projected, since the nature of toolmaking resulted in negligible reject levels.

The benefits were therefore limited to a reduction in labour content.

The analysis yielded a straight payback period of 2.13 years, a DCF of 29.8%, and an NPV of £57000, representing 81.4% over the period of the investment.

The sanction was given to purchase the machine based upon the above results.

4.2.8. Order

Once the proposal had been approved by the Company, orders could be placed for the machine tool and ancillary equipment such as tooling and data storage systems. A training programme was arranged.

There was a significant time lapse between the submission of proposal and the sanction date. The capital costs were calculated of the exchange rates ruling at the proposal date. During this period, there was considerable movement of exchange rates. After protracted negotiation, a fixed price contract was agreed which proved to be advantageous since the exchange rate fell significantly before machine delivery which would otherwise have caused the machine cost to rise.

4.2.9. Personnel Selection and Training.

The structure of the Toolroom limited the selection of CNC operators such that it was virtually "fait accompli". No formal interviews were necessary, because the turners involved would move from a centre lathe to CNC lathe.

The toolmakers had the necessary numeracy, so that training concentrated on the machine and programming systems. There was to be no change in job titles or remuneration levels: this precedent was established when the Toolroom took delivery of its earlier CNC machine tools. In fact, although two of the turners were officially assigned to the existing CNC lathe, they were covered during holidays and sickness by their colleagues. Thus they all had a measure of CNC knowledge which would act as a firm base for future training. A manual was constructed to act as a guideline document during the training period.

4.2.10. Installation.

At the time of writing, the machine tool ordered for the Toolroom application is expected to be delivered shortly. Thus no comment can be made at this stage on the installation itself.

It has been noted that the lathe would be supported by an external data storage and handling system. This was based upon an IBM PC with 256kb RAM and twin 360kb disk drives, equipped with asynchronous communication hardware.

A software package was required to satisfy the following:-

- CNC program creation, storage and editing.
- Two way communication to allow the transfer of information between diskette storage and machine tool system.
- Job tool selection from a master tool library.
- File handling such as renaming, copying, deletion, viewing and printing.
- Diskette maintenance such as formatting diskette back-up.
- Help Facility.

There were a number of software packages available: none would carry out all the functions required.

A menu-driven package was therefore developed, running in Advanced Basic under PC-DOS. It was designed to work on single keystroke option selection, with full error trapping and file security.

A sample "help page" is shown in Fig. 35 with a number of Menus and outputs in subsequent figures.

Serial communication was achieved by using RS232 interfacing with full handshaking set up between the machine tool control system and the IBM PC.

Thus programs could be written and edited before being sent to machine tool memory. Further editing could take place (if necessary) during program prove out before being downloaded for archiving on disk.

In addition, tools could be selected from a master tool file for placing in a job tool file which was presented to the operator during set-up. This file included details of carbide insert geometry, where appropriate, and tool overhangs.

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*** CNC FILE STORAGE AND RETRIEVAL SYSTEM ***

*** PJ SCOTCHER 1985 ***

CNC OPERATING NOTES

This program allows you to CREATE, EDIT, DELETE, COPY and RENMAE files on disk which contain CNC data in the form of G, M, codes etc,. to control the CNC machine tool.

This data can be SENT to the CNC machine memory by using the COMMUNICATE facility. In addition, programs created or edited on the FANUC control system can be RECIEVEd for storage on disk.

RECEIVE may be actioned manually, using the COMMUNICATE feature, but as a safeguard, any data sent from the machine tool will be automatically detected and stored on disk under LASTPROG headings.

Whole disks can be DISKCOPied as a means of data protection. All file EDITs and DELETEs are recorded. An EDITed file is kept in its original form under FILENAME.BAK.

The TOOL FILE facility allows tools from the MASTER TOOLING FILE to be selected and stored for a particular job. This JOB TOOL FILE can be inspected and ammended at any time, as can the MASTER TOOL FILE.

SPECIAL KEYS FOR FILE EDITING AND CREATION

[line N] I	INSERT lines of text ahead of line n
E or Q	END edit session & store(E)/not store(Q)
[line m],[line n] D	DELETE text block from line m to line n
[line m],[line n], line p M	MOVE text block from m to n ahead of line p
[line m].[line n], line p C	COPY text block from m to n ahead of line p
[line m],[line n] L	LIST text block from line m to line n
[line m],[line n]R WORD1 F6 WORD2	REPLACE WORD1 with WORD2 from m to n
[line m],[line n] S WORD	SEARCH for WORD from line m to line n
[line n] T B:filename	TRANSFER data from filename ahead of line n

To EDIT a line, enter line number, and use curser controls, INS & DEL keys.

FIG. 35: SYSTEM HELP PAGE

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*** CNC FILE STORAGE AND RETRIEVAL SYSTEM ***

*** PJ SCOTCHER 1985 ***

CNC OPERATING NOTES

```
C.N.C. OPERATING MENU
1. COMMUNICATE WITH MACHINE TOOL
2. TOOLING MENU
3. EDIT PROGRAM
4. COPY OR RENAME FILE
5. DISKETTE MAINTENANCE
6. CREATE NEW PROGRAM
7. LIST ALL FILES
8. DELETE FILES
9. INSPECT/PRINT A FILE
0. HELP
Select option
```

```
*** TOOL FILE MENU ***
1. SELECTION OF TOOLS FOR JOB
2. ENTRY OF NEW TOOL TO MASTER FILE
3. INSPECTION OF MASTER TOOL FILE
4. INSPECTION OF TOOL FILE FOR JOB
5. INITIALISE MASTER FILE
6. RETURN TO CNC OPERATING MENU
Select choice
```

```
BUILD NEW ENTRY TO MASTER TOOL FILE

ENTRY OF TURNING TOOL      (  1- 20)
ENTRY OF TURNING TOOL      ( 21- 40)
ENTRY OF BORING TOOL       ( 41 -60)
ENTRY OF BORING TOOL       ( 61 -80)
ENTRY OF DRILL             ( 81-100)
ENTRY OF DRILL             (101-120)
ENTRY OF MISC 1 TOOL       (121-140)
ENTRY OF MISC 2 TOOL       (141-160)

PRESS ENTER TO FINISH WITH THIS MENU

ENTER NEW INVENTORY REFERENCE
```

FIG. 36: SYSTEM MENUS

**** MANSILL BOOTH AND CO LTD ****

**** TOOL FILE LISTING ****

TOOL FILE FOR JOB 0001

POS	CODE	INSERT	DESCRIPTION
1	NUMBER 4		* CENTRE DRILL O/H=40MM
2	PCLNR 25 25 M12	CNMG 12 04 08-15 415	ROUGH TURN/FAC O/H=35MM
3	PCLNR 25 25 M12	CNMG 12 04 08-15 415	ROUGH TURN/FAC O/H=35MM
4	SVJBR 25 25 M16	VBMM 16 04 04-53 415	35 DEG COPY O/H=35MM
5	AL 25 3	EX RH 2.0 ISO K20	* THREAD 2.0MM O/H=35MM
6	11mm		* T/S DRILL O/H=140MM
7	S10K STFCR 09	TCMM 09 02 04-52 415	10MM B/BAR TRI O/H=45MM
8	SGTBN25/6 + SGIH32/3	GTN 3 656	PART OFF 3MM O/H=45MM

END OF DATA Press any key to continue

* = NON-INVENTORY TOOL

FIG. 37: JOB TOOL FILE

**** MANSILL BOOTH & CO LTD ****

**** MASTER TOOL FILE LISTING ****

REF	CODE	INSERT	DESCRIPTION
1	PCLNR 25 25 M12	CNMG 12 04 08-15 415	ROUGH TURN/FAC
2	PCLNR 25 25 M12	CNMG 12 04 08-61 415	FINISH TURN
3	CKJNR 25 25 M16	KNUX 16 04 05R11 S1P	SMALL DIA TURN
4	SVJBR 25 25 M16	VBMM 16 04 04-53 415	35 DEG COPY
41	S10K STFCR 09	TCMM 09 02 04-52 415	10MM B/BAR TRI
42	S16R SCLCR 09M	CCMM 09 T3 04-52 415	16MM B/BAR RHO
43	E M15 V06 R	EPMX04 02 04-15 S3X7	6MM B/BAR STRM
81	R416.1-0400-20-04	WCMX 06 03 08R51 015	40 MM U DRILL
101	SPEEDBIT 4.1MM		170 MM LENGTH
102	SPEEDBIT 6.1		240 MM LENGTH
103	SPEEDBIT 8.0 MM		215 MM LENGTH
104	SPEEDBIT 10MM		230 MM LONG
105	SPEEDBIT 12MM		240MM LENGTH
106	SPEEDBIT 14MM		235 MM LENGTH
107	SPEEDBIT 16 MM		230 MM LENGTH
110	4.1MM S/BIT PILOT		PILOT DRILL
111	6.1 MM PILOT		PILOT DRILL
112	8 MM PILOT		PILOT DRILL
113	10 MM PILOT		PILOT DRILL
114	12MM PILOT		PILOT DRILL
115	14 MM S/BIT PILOT		PILOT DRILL
116	16 MM S/BIT PILOT		PILOT DRILL
121	R150.21-25 25 -3	N 150.2-300-5E 435	GROOVE/PROFILE
123	SGTBN25/6 + SGIH32/3	GTN 3 656	PART OFF 3MM
125	SGTBN25/6 + SGIH32/4	GTN 4 656	PART OFF 4MM

END OF DATA

FIG. 38: MASTER TOOL FILE

```
****     MANSILL BOOTH AND CO LTD        ****

****     LISTING OF FILE CALLED 0001     ****          12-01-1985


NC CODE                               COMMENTS

:0001                                 PROGRAM NUMBER
(SAMPLE PART PROGRAM)                 COMMENT LINE
G21 G50 X280. Z300. S5000             METRIC, MAX SPEED, START COORDINATES
G00 X100. Z100.                       RAPID MOVE TO TOOL CHANGE POSITION
/M01                                  OPTIONAL STOP

(FACE OFF)
G96 S200 T0200 M04                    SPINDLE ON, CONSTANT SURFACE SPEED 200m/min
G00 X110. Z0 T2 M08                   RAPID TO DIA, COOLANT, OFFSET 2
G01 X-2. F.1                          FACE OFF AT .1mm/rev
G00 X100. Z100. T0                    RAPID AWAY, CLEAR OFFSET,
/M01


(CENTRE DRILL)
G97 S1000 T0100 M04                   SPINDLE ON AT 1000 RPM,TOOL 1
G00 X0 Z1. T01 M08                    RAPID MOVE TO JOB, OFFSET 1,COOLANT ON
G01 Z-6. F.01                         FEED INTO JOB 6MM FEED .01mm/rev
G00 Z1. M08                           RAPID OUT
X100. Z100. T0 M01                    RAPID TO TOOL CHANGE POSITION

(ROUGH TURN)
M32                                   TAILSTOCK QUILL ADVANCE
G96 S200 T300  M04
G00 X110. Z1. T3 M08
G71 P36 Q44 U.4 W.2 F.35 D400         ROUGHING CYCLE CALL. FOLLOW PROFILE DEFINED IN LINE
                                      36-44 LEAVING .2mmSTOCK. DEPTH OF CUT 4M
M
N36 G00 X23. Z1.
N37 G01 X30. Z-5. F.05
N38 Z-20. F.1
N39 U10. W-5. F.05
N40 Z-55. F.1
N41 U-10. W-5. F.05
N42 Z-80. F.1
N43 X80. R-5.
N44 Z-125.                            LINES 36-44 DEFINE FINISHED PROFILE WHICH IS FOLLOWED BY ROUGHING TOOL

G00 X100. Z100. T0
/M01
```

FIG. 39: CNC CODE LISTING

A proportion of the parts to be produced required deep hole drilling techniques, if the philosophy of "1-operation machining" was to be followed.

A development of the gun drilling process was found to be the most appropriate. A sample component using this technique was found to have a bore tolerance of ± 0.0008" with similar concentricity and a surface finish of RA 15-25 micro inch. This ½" bore was machined over a length of 8" at 2000 rpm at a feed rate of 0.001"/rev, yielding a machining time of four minutes. This was superior to the results achievable by conventional drilling.

The tool used consisted of a hollow rolled tube with a carbide cutting edge. It was designed in such a way that a specially formulated cutting fluid was delivered directly to the tungsten carbide cutting tip in the form of a lubricating and cooling mist. The offset cutting edge transferred the cutting forces to the tips' bearing pads, creating a burnishing effect and accurate size control, whilst reducing the high thrust forces encounted in twist drilling. Outer and inner cutting edges caused the material to divide into two separate pieces which, converging upon themselves, broke up further into short chip coils. These chips were then forced back in one continuous movement along the D-shaped flute clearance by the air pressure which had delivered the mist.

The cutter was mounted in the turret using a standard holding arrangement, in such a way that the mist delivery system (auctioned via auxiliary function within the machine tool control system) engaged when the turret settled back on its curvic coupling following indexing.

The tool is illustrated in Fig. 40, together with its cutting characteristics graph.

4.3. CONCLUDING REMARKS

This chapter has outlined the way the general framework was applied to a number of CNC machine tool installations.

The next chapter will compare and contrast the cases and discuss the relevance of the literature.

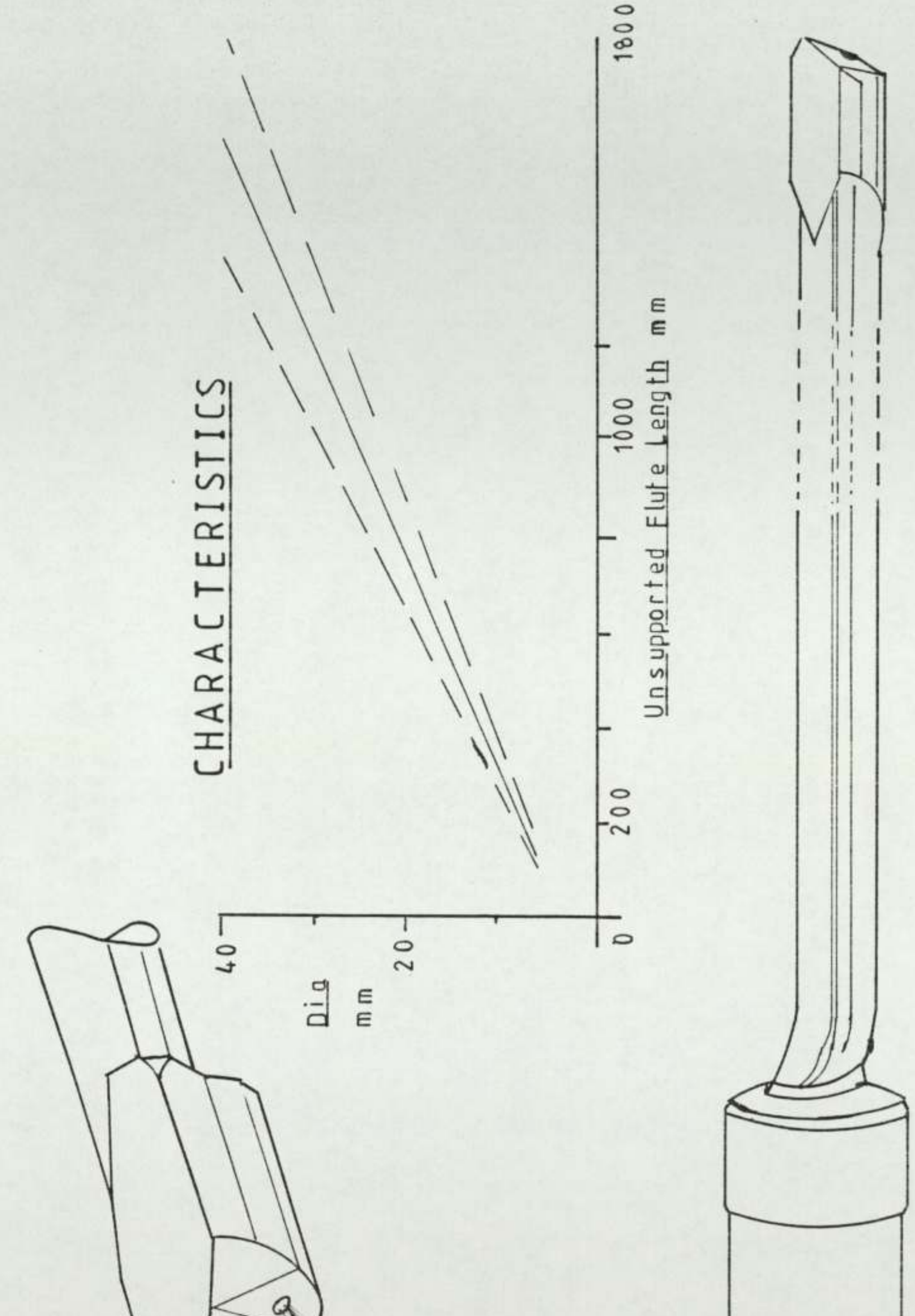

FIG 40 DEEP HOLE DRILLING TOOL

5. DISCUSSION

The preceding Chapter has outlined the major steps which were taken and decisions made which resulted in the installation of a number of CNC machine tools.

This chapter firstly reviews some aspects of the cases, comparing and contrasting them to enable some empirical conclusions to be drawn.

The following section will then consider the cases with reference to the literature.

5.1. GENERAL

The cases can be usefully compared because, as with a laboratory experiment, some major variables could be kept approximately constant.

Both applications were within one Company, working from a single site. Although there had been some minor organisational changes the fundamental objectives and conditions remained the same, as had the market in the Company served. Thus the overall management philosophies which affected the decision making were unchanged.

By the same virtue, there were no external factors which differed, such as the ability to obtain finance, eligibility for grants, Regional/Company direct and indirect cost differentials and Group purchasing arrangements.

At a more detailed level, the problems were tackled in a similar structured style. This commonality of approach ensured that the same questions were asked, that the cases were justified in similar ways, and that the implementation was carried out in the same manner.

The time lapse was small enough to eliminate the effect of time in terms of technological change. Indeed, the machine tool control systems adopted were of the same general specifications, and at the time of writing remain state-of-the-art. In the same way, there was no great change in cutting material technology.

In addition, there were no major changes in Government grant policies which would otherwise have affected net returns.

Thus it can be fairly stated that the two cases were independent of time, and that any differences between them were as a result of the applications and immediate environments. Useful comparisons can be made to show how the decisions were affected by:

- The Products
- The Systems

5.2. PRODUCT BASED COMPARISONS

Finished products may be classified in several ways:-

- By end user.
- By function.
- By feedstock.
- By size and shape.
- By manufacturing processes required.
- By volume.
- By accuracies required.

Where the aim is to replace a part of the manufacturing system, the product end user and function are of no importance, providing that neither is affected detrimentally. It can therefore be assumed that any substitutional change does not affect the fitness for use of a product. The other five factors affect the target specifications of the machine tool to be used to manufacture the component. Each is now considered with respect to the two cases.

4.2.1. Feedstock

The materials used affected the target specifications in two ways. Firstly, the material itself determines recommended cutting speeds and horsepower required; secondly, the feedstock form has a bearing on both material removal and workholding techniques.

The Machine Shop specialised in the machining of non-ferrous forgings, principally brass. This is a free machining material, where cutter wear is minimal. Moreover, the forgings were designed to allow the minimum of excess metal, so that depths of cut were small, and high speed finishing cuts only were usually required.

The Toolroom worked in toolsteels from bar or billet, which required slower cutter surface speeds and caused higher levels of toolwear, especially where greater volumes of stock were to be removed.

Spindle speed is determined from the following equation:-

$$n = \frac{s \ . \ 1000}{d \ . \ PI}$$

Where n = rotational speed, r.p.m.

d = cutting diameter, mm

s = cutting surface speed, m/min

Cutting surface speeds are recommended by tooling manufacturers.

- For brass: s = 300 m/min (Though experience shows that 500 m/min is more realistic for finish-turning of brass forgings with no significant tool wear penalty)

- For toolsteels: s = 200 m/min.

Thus for a 30mm dia pass, the corresponding spindle speeds would be:-

- 5300 r.p.m. for brass.
- 2100 r.p.m. for toolsteels.

Now power required is given by the following equation-

$$Pm = \frac{Kp\ C\ Q\ W}{E} \qquad [77]$$

Where Pm = Power at the motor (KW).

E = Machine tool efficiency.

Kp = Power Constant.

C = Feed Factor

W = Toolwear Factor.

Q = Metal removal rate.

The empirical factors and constants may be found in tables.

For a typical roughing cut on toolsteel, the power required is approximately 11 kw, compared with 5 kw for a finishing pass in brass. It is apparent that material specifications and conditions called for a lighter powered, higher speed machine in the Machine Shop than in the Toolroom.

The shape of the forgings in the Machine Shop placed special constraints on work holding systems. Some cylindrical forgings could be held in a conventional 3 jaw chuck, as could all the bar and billet work in the Toolroom. The softness of brass required the use of soft jaws bored to size, whereas the black bar in the Toolroom needed hard jaws. Other forgings were more complex in outside form, requiring the use of a two-jaw chucking system with specially manufactured jaws. In addition, secondary turning operations required the use of expanding mandrels where concentricity was important. The Toolroom application centred around completing the component in one operation, obviating the need for this style of arrangement.

Therefore the nature of the feedstock form in the Machine Shop required more detailed planning for work holding than in the Toolroom where the problem was more straightforward. It will be seen in the next sub-section that the swing, and hence the chucking capacity, was similar for the two applications.

However the nature of the feedstock in the toolroom indicated that a larger chuck would be required to accept up to 50mm diameter short bar. A chuck which can accept bar is known as an open-centred chuck, and is operated by the action of a hollow tube linking the chuck with the hydraulic draw cylinder. The maximum bar diameter is determined by the bores of the chuck or of the draw tube, whichever is the smaller. It was found that a 250 mm chuck with a bore of 52mm would be necessary for the Toolroom: no such constraints were placed on the Machine Shop lathes.

5.2.2. Component size and shape.

The feedstock shape has already been seen to have had a bearing in terms of workholding arrangements required. The size and shape also affected the target specifications in other ways.

The product mix analysis showed that the emphasis in the Machine Shop was on chucking work, where as the Toolroom Mix included a proportion of shafts, and therefore required a tailstock.

The machining envelope for the two applications was similar in terms of diameter but not in length. This might be summarised as follows:-

$$Dm > Lm$$

$$Dt < Lt$$

$$Dt = Dm$$

$$Lt > Lm$$

Where Dm = Typical Machine Shop component diameter

Lm = Typical Machine Shop component length

Dt = Typical Toolroom component diameter

Lt = Typical Toolroom component length.

The Toolroom required a machine with a longer bed capacity but with a similar swing.

The family part nature of Hatebur tooling made the use of macro-programming techniques feasible, and indeed necessary. No such product similarity was found in the Machine Shop. This had implications in terms of data access and storage (See 5.2.4).

5.2.3 Manufacturing Processes

The total manufacturing chain is determined by the component itself and by the market for the component. There may be several completely different ways of arriving at the final product.

In both cases studied, the aim was to change a part or parts of the chain, rather than the complete system.

It is important to treat each discrete process as part of a whole system, however, because upstream processes affect those further down the chain. In addition, it may be possible that one operation can replace several, which need not necessarily follow each other.

In the Machine Shop, the processes to be studied were towards the end of the chain. The total cost of scrap and of WIP was high. The Toolroom process formed the first stage in the chain. However, both cases were similar in terms of the nature of the processes studied, the general category being metal cutting, the specific sub-category being turning.

The Machine Shop components also included some processes not normally associated with lathe work, such as axial pitch circle diameter (PCD) and radial drilling. These could be incorporated using 3-axis machining techniques. Some of the Toolroom parts also required second operation work, but these could only be included if turning stations were sacrificed, which would have led to a compromise in terms of a standardised turret. This was found to be unacceptable, and the 3-axis route was not pursued.

The elimination of post-operation grinding was found not be possible with the current range of materials used in the Toolroom.

The nature of the manufacturing chain also determined what benefits could be projected for the purposed justification.

The Production environment allowed the use of reject and tooling costs as well as production times. In the Toolmaking situation, only time-based benefits were acceptable. However, the conventional methods used in the Toolroom indicated that production time reductions alone would justify the installation: this was not the case in the Machine Shop.

The manufacturing chain had determined historically the plant used traditionally. The existing machinery involved differed in that the current machines were capstan lathes in the Machine Shop where cycle times were important, rather than the centre lathe in the Toolroom, where the emphasis was on versatility.

5.2.4. Volume

The expected volume of a product to be made throughout its life plays a major part on determining the manufacturing chain. Once established, the chain itself can affect the batch size, as can the cost of stock. The actual requirement for the product sets the frequency of call-off.

The Machine Shop section of the manufacturing chain developed to serve the upstream processes of hot forging, which were used for economic volume production of components. Thus the processes were geared to higher volumes than in the Toolroom, which by its nature served to produce small quantities of components used elsewhere in the main manufacturing chain.

This difference of batch size and frequency indicated a difference of required machine style. The gang type CNC lathe adopted for turned only parts in the Machine Shop was unsuitable for the Toolroom because:

- the gang system is limited to two tools if a tailstock is fitted.
- the gang arrangement must be changed for each component, which was unsatisfactory for the short batch quantities in the Toolroom.
- the gang-type machine is designed for higher volume work where cycle time is important, as was the case in the Machine Shop.

The volume consideration also played a major role in determining the methods of operation: the adoption of a standard turret arrangement was imperative in the Toolroom where set-up times formed a major segment of the production time. The Machine Shop application sought to reduce cycle times, indicating that tailor-made turret arrangements were desirable to minimise indexing idle times.

A proportion of the toolsetting time is spent locating CNC programs and loading them into the memory. The quick turnover of different programs in the Toolroom indicated that the expense of a disk-based mass storage device was justified. The higher volumes found in the Machine Shop did not require fast access, so that a paper tape data base was found to be acceptable.

5.2.5 Accuracies

Accuracies are determined by the function of the part.

The Machine Shop components were specified by the Customer: the Company had no part in defining tolerances required. Here the tolerances were generally wider than those necessary on the Hatebur tooling made in the Toolroom, although many of these were achieved by post-operation hardening and grinding.

CNC machine tools have a control system resolution of one micron, which leads to a machining repeatability of the order of 10 microns. This was superior to any of the tolerances required in either application.

However, there was a Customer trend towards precision machining in the Machine Shop, and a possibility of obviating the need for grinding in the Toolroom. This suggested that such accuracy capabilities would not be inappropriate.

5.3. SYSTEM COMPARISONS

The processes forming the manufacturing chain require supporting systems in order to operate. Two major categories are considered, Personnel and Information.

5.3.1. Personnel

People form an integral part of the chain, both directly and indirectly. Their knowledge, skill and creativity affect the performance of the chain. There was extensive product knowledge in both applications studied.

There was evidence to suggest that the toolmakers were technically more skilled than the toolsetters and operators in the Machine Shop. This was to be expected: traditionally, a toolmaker served a formal apprenticeship, whereas a tool setter learned "on the job", and was often a former operator himself. However, it was apparent that the younger toolsetters had a measure of latent ability which could be developed given suitable training.

The Toolroom was already operating some CNC machine tools whereas the Machine Shop possessed none. While such prior knowledge might be seen to be advantageous, it proved to be a drawback because of the preconceived notions on the benefits (or otherwise) that further CNC machines would bring.

Hence time spent in the Machine Shop explaining the principles of CNC technology was equally spent in the Toolroom destroying the myths which were apparent.

Reaction to the proposed changes was similar. Initial worries over security and ability to cope had to be treated with sensitivity in both cases. The Toolroom personnel were found to be more resistant to the change, not in terms of the machine tool itself, but because of the level of data collection which was necessary to allow justification to proceed.

This was probably because:

- as skilled toolmakers, work measurement of any kind was an anathema.
- there was no form of data collection in operation in the Toolroom.
- the method of payment in the production Machine Shop required the collection of information: the precedent had already been set.

In addition, the toolmakers prided themselves on their level of skill, the difficulty of their work, and the quality of their product. What some might call an "illusion of grandeur" was not apparent in the Machine Shop. However, once a working relationship had been established with the toolmakers, these initial difficulties were not to reappear.

5.3.2 Information

It has already been noted that cost data for the Toolroom application was non-existent, requiring a new data collection exercise to be carried out. The Machine Shop possessed the necessary data, but it was found to be unreliable, so that a process of verification was needed.

It would be expected that technical data would be superior than the production environment that in the Toolroom. This was not the case.

Component drawings in the Machine Shop were often inadequate, unclear, or damaged. Tooling layouts were non-existent (much has since been done by the Company to improve this aspect). Whilst there were no routing details for each component in the Toolroom, the drawings were always of a high quality.

5.4. CONCLUSIONS FROM THE CASES

The two cases described in Chapter Four were carried out in accordance with the general framework proposed in Chapter Three.

It is concluded that the use of a structured approach leads to good decision making, ensuring that the options are considered correctly and that none are rejected by default.

It has been shown that the application does not affect the approach but can colour the decisions.

The financial justifications were carried out in such a way to be acceptable to the Company concerned.

5.5. THE LITERATURE

Chapter Two surveyed the relevant literature on the subject of NC/CNC machine tools and associated topics. It will be recalled that the subject was categorised as follows:

- Design
- Application : Tooling and fixturing.
  : Methods.
  : Programming techniques.
- Justification/Economics
- Managerial
- Machine tools and system selection
- Journalistic and Commercial Literature

This section discusses the relevance of the literature to the cases presented in Chapter Four.

5.5.1. General

It was noted that Cookson [1] found that in 1979, the literature covering the subject was not comprehensive:

> "The available books provide only a rather patchy incomplete and generally out of date knowledge of (NC) machine tools. The situation is not improving, as can be seen from the lack of recently published books in this field"

The situation has not improved.* Cookson believes that no single work has been published because:

- The subject is "too big"
- The rate of technological change would render such a work obsolete before going to press.
- The financial rewards from publishing do not justify the effort required.

Thus the potential CNC user cannot refer to a single text for guidance in all aspects of the subject. He must find information as required; The split outlined above is a useful categorisation.

5.5.2. Machine Tool Design

It is important that the potential user is in a position to understand the functions and layout of machines, so that he may critically examine specifications and not be swayed by glib salesmen who may over emphasise an irrelevant feature and ignore a major disadvantage.

The inference from the literature [5] is that machine tool design is a subject in its own right which should only be addressed where a design point affects the functioning of the machine tool or control system. There is little modern material which outlines critically the choice of features. Appendix 1 is such an outline, specific to CNC lathes.

* Personal communication: 2nd April 1985

Older texts do not contain the "state of the art" information on machine tool control systems. The reader of such literature could be given the impression that they are difficult to use and unreliable. This is far from true, as the users of modern machine tools will testify. Thus in terms of features and functions, the potential user of CNC machine tools must learn by experience.

5.5.3. Application

A dichotomy of views was established on the relative importance of cutting conditions and utilisation.

The cases indicated that the emphasis of effort is determined by the application. Within the Machine Shop, cycle times were important because of the high batch quantities. The activity of "chasing the seconds" was justifiable. Change-over times, whilst important, could be amortised over a reasonably large quantity of components.

The Toolroom application however, relied on a smooth, fast transition from one component to another. The small quantities involved did not justify effort in optimising cutting conditions, but did require a fast data management system.

The conclusion from the cases is that both matters are equally important: generally, neither should be attacked at the expense of the other. Indeed, it is possible to go too far.

Consider a batch of 500 components, with a total floor-to-floor time of 1 minute and a setting time of ½ hour:

Machine Time = 500 min

Total Time = 530 min

Suppose that the cycle time is reduced by 5% but that it takes ½ hour to improve the cycle, by finding more appropriate cutting speeds:

Machine Time = 475 min

Total Time = 535 min

If the batch is never to be repeated, time has been lost; this would not be the case for a repeated batch. In addition, the increased cutting speeds can have a detrimental effect on carbide insert life.

Taking the example above, suppose that the original conditions were planned to give a 15 minute edge life, that only one tool was used, with a triple edged insert, and that the contact time was 30 seconds (50% of cycle time)

Number of inserts used = 5.6 for complete batch.

If the uprated cutting conditions yielded an edge life of 10 minutes, with a subsequent contact time of 27 seconds, then:

Number of inserts used = 6.8 for complete batch.

Not only does the consumable tooling cost rise: machine downtime is affected because the tool must be maintained more often. The problem of finding the most suitable cutting conditions is therefore complex. There are many variables: too many to allow true optimisation in a manufacturing environment. The previous example demonstrated how the benefits of change may be approximately calculated, but assume that other parameters were unchanged (tool geometry, tool overhang, coolant concentration, material hardness, machine rigidity).

The best sources of raw cutting data are probably the tool manufacturers themselves, although their material ranges are limited, and a high rate of toolwear is in their interest commercially. For less common materials, Trade Associations may be useful [72].

From this start point, the user must either:

- Conduct his own "laboratory" tests.

or

- Accept that true optimisation of cutting conditions is unfeasible.

It is likely that the latter is actually the only option open for the majority of manufacturing companies.

Astrop's note [10] that holidays, weekends and unused shifts should be used to advantage presupposed the following:

- People are prepared to work these periods

or

- The process can be sufficiently automated to allow partial total unmanned production.

and

- The market is available to justify the increase in working hours.

The cases studied could not satisfy either of the first two conditions but could the third. Before any further capital acquisition of CNC machine tools could be contemplated serious consideration would have to be given to using more of the available hours. The Company had had some difficulty in achieving this goal; there were also doubts about its effectiveness as a solution. This is confirmed by Marris who:

> ".... as a result of five years' research and reflection,.... no longer believes that a miraculous acceleration of economic growth could (or should) be achieved by knocking together the heads of managers and trade unionists in order to persuade them rapidly to convert us into a universal double shift society".

He went on to conclude:

> ".... automation may permit more intensive capital utilisation with constant or declining proportions of human shift work".

The literature touched on the concept of axis addition to increase the flexibility on machine tools. The components of "Complex" style on the Machine Shop application were amenable to 3-axis machining. However, the references were all commercial and one could be led to believe that such techniques would always be appropriate. For example, the installation of a 3-axis turning centre in the Toolroom would not have been satisfactory because of the constraints placed on tooling arrangements.

5.5.4. Programming

It was noted that the choice of programming methods is wide and that the modern literature is of little help. The options found were:-

- Computer aided programming off-line (off-machine)
- Computer prompted conversational on-line (on-machine)
- Manual off-line
- Manual on-line.

The Company had access to a bureau service which offered a sophisticated Computer Aided Part Programming (CAPP) system, but was not used in the two installations described. Coleman and Lunn [27] concluded that for simple components, manual programming was "very competitive", but computer assist was more appropriate for complex parts. It should be noted that his measure was time. CAPP facilities cost approximately the same as the cost of the man operating the system (Company costs), indicating that CAPP must be twice as fast to break even.

The experience in the Toolroom application indicated that manual programming with the full use of canned cycles was economic where the part geometry was simple and well defined, or "point to point". For more complex profiles with non-perpendicular lines joined by arcs, CAPP was faster and more accurate.

The recent development of on-line conversational programming systems would appear to be an ideal solution: instantaneous programming, with no overheads of off-line processing. However the systems are rather inflexible and difficult to edit quickly: shop floor programming of this style may be useful for a single-machine installation, for example, in a small Company. Since this is a major growth area for CNC machine tool suppliers, the commercial pressure to purchase such systems is not surprising.

Off line CAPP is aimed at larger installations machining complex parts. To be truly viable, part geometry should be available as numerical data held on a drawing data base.

In other words, the designer draws the part and performs stress analysis calculations as necessary, using a Computer Aided Design system. The data is then used by the detailed draughtsman to produce complete component drawings, jigs, fixtures and tools, using a Computer Aided Design system. In turn, the CNC programmer takes the same raw data to produce a part program. In this way, the original geometry is generated once only, ensuring accuracy and integrity of the process of development to manufacture.

Again, the commercial pressures for this breed of system are growing daily. Their true value may be questionable:

> "CADCAM is frequently viewed as a cost reduction method when attempting to justify system purchase. Retrospective examination of installed systems in the UK very often shows that the promised cost reductions were not achieved."
>
> "The danger of these wide ranging systems is that most companies will find applications for many of the facilities they offer, but it is often hard to justify all or even any of these individually. The idea that somehow synergy between the various applications and their sharing of a common database will produce an overall justification is seductive. The risk is that the total of a number of unjustifiable subsystems may simply be an unjustified major system, but the fallacy may be harder to spot."
>
> [78]

5.5.5. Economics

It was noted that the literature referred to over 25 potential benefits which would accrue upon the implementation of CNC machining technology. Furthermore, these were generally classified as:

- Direct

or

- Indirect

However, there was a difference of opinion on where the split should be placed. The cases showed how this problem was tackled by agreeing with the Company the nature of acceptable benefits which could be expressed in financial terms.

In the production Machine Shop application, these were:

- Production Times.
- Toolsetting Times.
- Tool Cost.
- Scrap Costs.

In the case of the toolroom, the benefits were limited to the reduction in total manufacturing times.

In both cases the objective was to justify the implementation by achieving a certain level of cash flows: in other words, the case was to be compared absolutely (or relative to the status-quo), rather than incrementally with the other projects competing for the same source of capital.

Talking generally, a more cynical view may be taken. Having agreed an acceptable level of return, the implementer merely has to take each of the major benefits in turn and accumulate cash flows until the level of return is reached. This saves unnecessary effort in establishing in financial terms, benefits which will not affect the go/no go decision. Only if the total benefits from all available sources does not achieve the minimum acceptable return will the case be rejected.

This extreme view may contain an element of validity, but more importantly, it indicates that financial justification should form but part of the decision-making process.

Referring to the 25 potential benefits it can be argued that a suitable split would be:

- Financial
- Functional

The financial benefits can be quantified and presented as a series of cash flows. The functional benefits are those which cannot be expressed in financial terms, either because they cannot be quantified at the justification stage, or because they cannot be proved to exist during post-audit.

For example, following the installation of the turning centres in the Machine Shop, the Company found itself able to take on more sophisticated, complex components and manufacture them competitively. This improvement in flexibility cannot be quantified, but it is a true functional benefit.

The following question might be asked:

> "Why does the literature advocate the quantification of each and every benefit?"

Two reasons are proposed.

Firstly, much of the literature is dated, published when CNC (or formally NC) machine tools were relatively expensive, hard to program and un-reliable. In short, their purchase was difficult to justify. Every potential benefit had to be quantified in order to achieve an acceptable level of return. In real terms, the capital and running costs have fallen dramatically, requiring fewer benefits to allow justification.

The second reason is commercial. I.Prod.E [5] presents a worked justification example using a structure recommended by a " ... well known machine tool Company...". The danger is obvious: it is in the Suppliers' interests to advocate the maximisation of quantifiable benefits to increase sales. The Text goes on to argue:

> "... indirect savings ... are hard to measure. In fact, they can only be estimated ... but that doesn't mean that they should be ignored. These savings do exist, and, if the estimates are not made, they are being assigned a value of zero, which is almost certainly more incorrect than even incorrect estimates would be."

There is a fundamental fallacy in the argument: if a benefit is estimated to be positive and non-zero, it risks being overstated. Cumulatively, such estimates can present an over-optimistic projection of likely returns.

It was seen in the presentation of the cases that a conservative stance was deliberately taken: benefits which were unquantifiable were ignored financially but considered functionally. This avoided the risk of giving a "go" decision to a case which was too optimistic.

Specialist NC literature rarely attempts to use the more sophisticated investment analysis techniques which are advocated by the Economics-based references. The Company cited in the cases had a formalised procedure which presented DCF, NPV and payback values for consideration.

Discounting techniques are superior, although Payback measurement may be deemed acceptable for CNC projects, which tend to have uniform cash flows and short payback periods. Thus, probably for the wrong reasons, the NC literature stance of applying straight Payback measures may be appropriate. Wherever there is any doubt, DCF techniques should be adopted.

5.5.6. Managerial

It was noted in Chapter Two how the specialist NC literature did not deal with some of the important aspects of management of change. The cases indicated how a policy of change by involvement with a structured, logical approach will achieve satisfactory results.

For example, the existence of satisfactory data cannot be assumed. It has been seen that this can prove to be a major stumbling block which must be overcome with sensitivity: it cannot be achieved instantaneously.

In the same way, a formal training program is imperative. The cases showed that the final success of the implementation does not depend on an expert justification, for without the right people with the right skills, the plant will not run. The fact that the literature tends to deal with the machinery should not persuade the user to ignore the people.

Specialist NC literature made no mention of the problem of interference; most references to the problem [74,75] assume random stoppages rather than cycle time interference alone. The use of a simple simulation program is not mentioned in the literature reviewed, but has been used to advantage in the case described.

5.5.7 Machine Tool & System Selection

It has been noted that the literature cannot give comprehensive, up-to-date technical information on machine tools and their control systems. It has been shown that a satisfactory approach is to commence with a target specification which is then used to canvas Suppliers. This method is not mentioned specifically in the literature. The use of targets minimises the use of value selection, which sets arbitrary weighting to characteristics. It is preferable to commence with a firm concept which must be matched rather that allowing the target to be set by default.

5.5.8 Journalistic & Commercial Literature

It was noted that editorial articles in both Trade and Professional journals should be treated with caution. Most journals rely on a measure of advertising revenue, which is maximised if articles mention Products. In fact, much of the copy is written by the suppliers themselves. Often, an article will mention "Brand X" machinery with a colour advertisement of "Brand X" on the facing page. The article is unlikely to be critical, even in a constructive sense.

The usefulness of this type of literature is questionable. This Thesis has found little to commend it, above source of light reading.

6. FUTURE WORK

The Thesis has shown how the framework can be applied to implement manufacturing change within a Company.

The Company's next step should be to improve further its utilisation of capital by working the machine tools for longer hours. In the short term, this will require more extensive shift patterns. The use of robotics as an aid to automatic materials handling should be the eventual aim. It should be noted that this is a route to be adopted with caution: the Company's product mix, and stance in the market place indicates that current robot technology would have limited use.

Within the machine shop, the use of a small envelope machining centre would complement the range of turning centres and gang-type lathes installed. Again a structured approach using the proposed general framework can be used to advantage.

The toolroom is amenable to the implemention of CNC machining techniques in the grinding section, for both cylindrical grinding of Hatebur tools and profiling of cutting tools. Whilst the latter might merit immediate investigation, the former requires detailed study of materials technology to ensure that elimination of grinding of the Hatebur tools is not possible.

More generally, the Thesis has shown that the literature is often outdated and not always useful. A single source (an all encompassing bible) is probably unfeasible.

However technical journals, and perhaps some authoritative bodies, should take heed of the fact that commercial sources of material should not be presented as "Gospel".

7. CONCLUSIONS

Specific conclusions have been noted at the end of the preceding chapters. The overall conclusion of the Thesis are as follows:

- The literature is often outdated, and of little practical use.

- The concepts put forward are simplistic and occasionally based on commercial interests.

- The use of the general framework proposed is possible and can yield positive results.

- Personnel selection and training is fundamental, but often ignored by the literature.

- Justification should be based on properly quantifiable benefits: assumptions should be kept to a minimum.

- A conservative case should be presented: the literature's view that unquantifiable benefits should be estimated will lead to an over optimistic case.

- Computer Aided Programming is not always "best", despite the apparent trends.

APPENDIX ONE NC/CNC MACHINE TOOLS - BACKGROUND

Probably the most universally accepted definition of Numerical Control (NC) is that offered by the Electronics Industries Association.

> "A system in which actions are controlled by direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data."

In a somewhat broader sense, Numerical Control may be considered as an extremely versatile means of automatically operating machines through the use of discrete numerical values introduced to the machine by some form of stored input medium, such as paper tape.

The first NC machine was developed by MIT in the early 1950's and arose from a need to manufacture complex aircraft components to close tolerances on a repeatable basis. The technological development has continued apace since then, and shows no sign of halting.

In the early days, numerical data was prepared manually and transferred to a storage medium which traditionally was paper tape. Each block of information was read by the machine tool which would act accordingly before reading the next block.

There were two main difficulties with this method. Firstly, manual programming of complex forms was tedious and time consuming. Secondly, program faults (either through mis-punching, mis-reading or because of programmer errors) could only be corrected by making a new tape.

A great deal of work has been done to create off-machine computerised programming aids. These are now highly sophisticated, with the ability to take geometric data and convert it to coded instructions to which the machine will respond.

In addition, NC became CNC (Computer Numerical Control). Rather than have the machine tool respond directly to coded input, a CNC system interprets the information presented, performs calculations as necessary according to a set of previously defined rules, such as cutter radius compensation, and causes the machine elements to react accordingly.

The CNC system can continuously monitor the state of the machine and of itself. Variances between "expected" and "actual" performance can either be corrected automatically or reported. The addition of a working memory allows a program to be stored for later use, and modified without the need to create a new paper tape.

Mass storage and data transfer can use conventional computing methods such as diskettes or magnetic tape, with asynchronous communication. There are virtually no true NC machines now manufactured: the reduction in system costs has brought CNC within reach of more users (the phrases "NC" and "CNC" are now used interchangeably - the difference is apparently meaningless). Most CNC systems can, however, mimic an NC system, reading data directly from tape rather than from internal memory. This may be useful if memory size is insufficient to hold a complete section of cutting data.

This "machine intelligence" can be used to link several machine tools together, with the actions of one dependent on the state of another. The machines may be serviced by a robot and make use of automatic gauging, with tool offsets (which compensate for tooling inaccuracies) automatically updated. Machine tool control systems are now available which allow on-machine conversational programming. The operator is presented with a series of questions which he answers to build a component profile and relevant machining data. This is enhanced with graphic representation (sometimes in colour) of the component and cutting action, allowing the program to be verified prior to actual machining. This high level information is finally processed into numerical data.

Stripped of the control system, guarding and panels, a machine tool loses much of its mystery. The elements are standard - they are pieced together in a logical way. Servo-motors convert the cutter co-ordinate data into movements of the cutter and/or work piece. They have now been developed to a high degree of accuracy, speed and power, and usually form part of a closed-loop system. Feed-back information is taken from positional encoder, which may be linearly mounted along the slideway or in the form of a rotary unit on the back of the servo motor itself. The former is potentially more accurate because the true position is measured rather than a calculated position using the rotary count together with a rule governing the relationship between rotational and resultant linear movements. Subsequent errors such as backlash and leadscrew inaccuracies may however be compensated by the control system itself, which may also be used to tune the servo-system to optimise response.

Other machine actions such as tailstock approach, coolant control, spindle rotation, bar feed and tool change, as well as automatic force feed lubrication to the slideways, are all actioned by the control system. Relays and thyristors are merely used to interface between the low voltage logic circuits and higher voltage power circuits - there are no requirements for complex cascades.

CNC LATHES

The Thesis discusses the implementation of a number of CNC lathes. The following description is specific to that type of CNC machine.

The lathe operation of turning necessitates the rotation of a component about its centreline so that a non-rotating tool may be applied to remove metal. The tool is moved axially (z-axis in the NC terminology) and radially (x-axis) with respect to the component centreline.
A modern CNC lathe usually is equipped with a multi-station tool turret which can be indexed to present the appropriate tool for the operation. This turret may be a derivative of the conventional centre lathe tool post: that is a square turret with four positions rotating about a vertical axis. Alternatively, the turret may have up to 12 or 14 positions and be rotated about its horizontal axis in either x or z directions.

A tailstock is often required to support longer components. This usually has a quill which may be extended at will; the body may be stationary or it may be programmable, moving along the z-axis either powered directly or towed along by the turret. Another arrangement allows the tailstock to be swung off centreline when not in use.

CNC machining techniques are now being applied to higher volume work where it is becoming important to minimise machining time as well as set up time.

The cycle time consists of:

- Tool index time
- Rapid approach & movement time
- Cutting time

Two philosophies are apparent which can be used to minimise the cycle time. The first is to minimise in turn each discrete element; the second is to overlap each element.

Cutting time can be minimised by increasing feeds, speeds and depths of cut. This must be done with care since the resultant reduction in tool life or the requirement for more expensive cutting materials can lead to increased tooling costs. The machine utilisation will also fall because worn tools must be changed more frequently.

The rapid approach and movement times can be minimised by ensuring that cutting tools take the most efficient route around a component and that the servo-drives respond well. However, the turret must move away from the component to a position where it may safely index. The indexing time may be reduced by ensuring that the turret rotates in the shortest direction (bi-directional indexing), with no dwell or overswing.

Alternatively, the turret may be eliminated and the tools mounted on a table or platten: the tools are mounted so that the program control may transfer from tool-to-tool with no lost time for a major physical move of platten. These two arrangements are shown in Fig. A1.

This arrangement requires greater detailed planning than the turret style to eliminate the risk of collision, but may be used to advantage in certain circumstances.

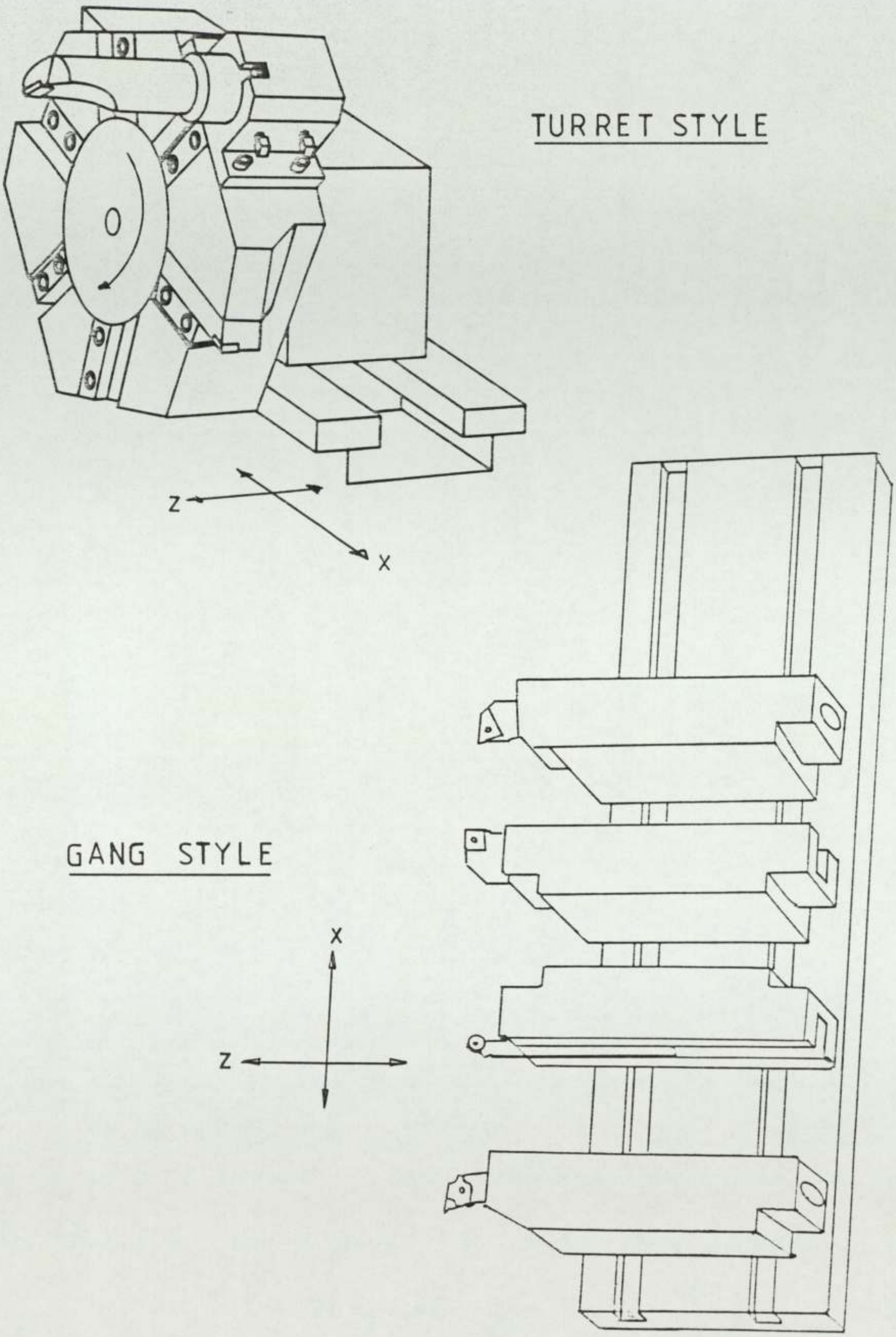

FIG A1 CNC LATHE STYLES

Element overlapping is achieved by the addition of a second turret working on the other side of centreline from the first. One turret can continue to cut whilst the other is indexing; or one can complete a roughing cut whilst the other performs a finishing cut, following a short distance behind. Alternatively, one turret can carry out external machining with the second working internally.

This 4-axis principle (or more correctly 2+2 axis) carries a price premium but can be justified if large quantities of material are to be removed. Like the gang-tool system, careful planning is necessary to avoid collisions.

Turning centres behave like a conventional CNC lathe but have some major additions. Firstly, the turret not only takes conventional turning tools but can also be fitted with rotating tools driven through and additional motor mounted behind or within the turret.

Secondly, the main spindle is stopped and held in known orientation positions to allow radial and off-centre axial holes and slots to be drilled, tapped or milled as required.

Orientation of the spindle may be achieved through a dividing head arrangement which allows the component to be indexed by fixed increments. This is sometimes known as $2\frac{1}{2}$ axis. A full 3-axis turning centre is equipped with a third servo-system (c-axis) which can accurately rotate the spindle at programmable feed rates to any orientation.

Complex forms can then be milled by the powered tools by interpolating in 3-axes. Once more, programming becomes more complex with the addition of the C-axis, and the machine becomes more expensive. However such machines can reduce the need for 2nd operation work and may be appropriate in certain applications.

A twin turret system (2+3 axis) with full spindle orientation and control may sometimes be used. The gang type tooling arrangement can also be fitted with the third axis.

Tooling for CNC lathes relies on the fact that a simple tool can be used to create complex shapes by appropriate control of the axis of movement. Some tools, such as drills, taps and reamers are identical to those used on a traditional centre lathe.

Turning, threading, boring and grooving tools are rather more specialised, consisting of the tool itself, fitted with a carbide cutting insert of suitable geometry and material grade for the operation in hand. Inserts often have a number of cutting edges to maximise its total life, they may be coated to improve cutting conditions, and may have chip breaking grooves to prevent the "birdnesting" of swarf. Inserts are available in a wide variety of grades, conditions and geometries.

This simplicity of tooling arrangement minimises job set-up time and in-batch downtime. Quick-change tools are now available which may be manually operated. Their major application however, is with an automatic tool-change facility, which is action by the control system when its senses an increase in spindle load, when a dimension goes out of tolerance, or when a certain number of components have been processed. In the limit, an automatic tool changer can render the turret redundant.

The CNC machine tool is only as good as the programme which controls it. The program consists of a series of blocks of information, each read in turn.

Each block is made up of a number of words which, when read, set their corresponding addresses to a certain state, to perform a function in a particular way.

System manufacturers use variations of a standard instruction set. Most differences are minor, though they can cause problems if system compatibility is required.

Briefly, the most commonly used addressed are:

G Word.	-	Preparatory function, causing data within the block to be interpreted in a certain way.
X, Y, Z, C.	-	Absolute coordinate works for each axis.
U, V, W, H.	-	Incremental movement words for each word.
S.	-	Cutting Speed.
F.	-	Feed Rate.
T.	-	Tool position and offset number.

There are a number of minor words which may be occasionally used to control other functions, such as coolant, spindle rotation, roughing allowances etc.

It should be noted how canned cycles can be used extensively to minimise programming time.

Family part programming can be achieved by replacing numerical values with variables. The main text is then called a macro-program, which is called by a macro-call program containing values for each variable.

Thus parts with similar shapes but differing in size can be machined using the same macro-program.

The macro may contain conditional statements which can test the validity of data and allow looping until a given condition is met.

Trigonometric formulae may also be incorporated to minimise manual calculations. These facilities are especially useful in 3-axis machining where interpolation in two or three axes is required.

APPENDIX 2. COMPANY BACKGROUND

The Company participating in the two cases discussed in the Thesis, Mansill Booth and Co. Ltd., is a member of the Delta Group plc.

The Delta Group p.l.c.

Delta Group p.l.c. is an international business with an annual turnover in excess of £590 million. Its products are designed and manufactured to control and supply electricity, water and gas and to serve numerous industries worldwide.

The Group's business, which is largely concerned with supply systems and controls is concentrated in four principle areas of activity: Electrical Equipment, Fluid Controls, Metals and Resource Services. Its income is derived from a good geographical spread of interests throughout the world. There are Delta subsidiaries in the United States, Europe, Australia, Africa, South-East Asia, Brasil and the Middle East.

Their largest area of business is Electrical Equipment, which accounts for just over one third of the groups total turnover. Next is Fluid Controls, accounting for about one quarter, then Metals - another quarter, with Resource Services contributing the remainder.

Indications are that the Group is overcoming the effects of the current recession by continuing a programme of rationalisation of manufacturing capacity. This is being achieved by sustained investment in new plant and products, and by selective shedding and acquisition of Businesses. Whilst turnover has remained relatively constant the past five years, pre-tax profits are showing signs of recovery following a trough in 1981. The number of employees has decreased in accordance with long term policies, to 18325 from a peak of 32250 in 1974.

Electrical Equipment Division

The Electrical Equipment Division is a leading manufacturer of power, wiring and communications cables together with circuit protection and control equipment for industrial and domestic markets. This section of the group is further subdivided into a Cables division, Switchgear and Accessories Division and the High Conductivity Metals and Services Division.

Fluid Controls Division

The Fluid Controls Division is a major manufacturer of plumbing products including tubes, couplings, taps and mixers and has investments in related activities in Australia, Canada and South Africa. In addition, gas control devices and industrial valves are supplied from U.K., Europe and Brasil to international markets.

Metals Division

The Metals Division is a manufacturer of both extruded and flat copper and brass products. It also leads the U.K. market as a supplier of forged and machined brass components and runs a network of metal stockists to serve the home market. A related company serves the South African Market. The Subdivisions comprise Brass Products and Other Metals.

Resource Services Division

Delta provides consumable products and services to the resource industries, mainly in Africa and Australia. Activities include the distribution, servicing and repair of off-road vehicles, mining machinery and electrical and hydraulic equipment. The division is also a major producer of electrolytic manganese and related chemicals. This division is subdivided geographically rather than functionally.

Mansill Booth & Co. Limited

Mansill Booth & Co. Ltd is a traditional hot brass stamping Company, established in 1920, within the Brass Products subdivision of the Delta Group p.l.c. It employs approximately 260 personnel on a single site in Smethwick and has an annual turnover of over £7 million. The company has a wide variety of mechanical presses and machine tools but generally the manufacturing base comprises low technology plant and equipment. The company does not market a range of products and is, therefore, essentially a jobbing shop, although certain product ranges are called off on a regular basis to suit customer requirements. Batch sizes range from 100 upward.

The company has been through a difficult trading period, but by severe pruning of personnel, rationalisation of facilities and management restructuring, they are entering a profitable stage and are poised to make further advances. Company activities are functionally organised and fall into two categories:

Production:	Hatebur Shop (high volume transfer forging)
:	Billet saw shop
:	Conventional stamping shop
:	Clipping shop
:	Machine Shop (Multi spindle chucking autos)
:	Machine Shop (Lathes, drillers, millers etc)
:	Bright dipping and despatch area

Service : Maintenance

: Toolroom

: Administration (Finance, sales, production control, drawing office etc.)

Ninety per cent of production is from stamping brass conforming to rod specification BS2874 and material designation CZ122, although Mansill Booth do stamp significant volumes of other non-ferrous alloys. The products themselves generally fall into seven categories namely:

: Water control fittings	: Mining Equipment
: Gas control fittings	: Ornamental wares
: Electrical switchgear products	: Sports goods
: Automotive products	

Over recent years one million pounds has been invested in the press shop on both friction and positive presses, but little attention has been paid to automation and work flow aspects. In an endeavour to become more competitive Mansill Booth have identified several specific problem areas:

: Production technology	: Financial control
: Production control	: Sales order processing
: Quality	: Costing
: Customer service	

To a certain extent, the areas of financial control, sales order processing and costing have been vastly improved by the introduction of business management software. Projects have been implemented in the remaining areas and distinct progress has been demonstrated to date.

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