THE IMPACT OF NC MACHINERY UPON MANUFACTURING INDUSTRY

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SUMMARY

The changing face of industry due to the adoption of 'New Technology' is briefly discussed, along with the changing pattern of the workforce resulting from that change. The adoption of NC machinery is identified as one of the major innovations affecting the structure of industry.

The development of NC machinery, and of relevant programming techniques are reviewed, and the problems arising from its initial sponsorship by the aerospace industry are highlighted.

The diffusion of NC across Europe and America is reviewed, and the results of various surveys of the diffusion process are examined.

Skill patterns adopted for NC use in Britain and Germany are discussed, and classifications of the various levels of skill adopted for operators and supervisors are derived. These classifications of skill levels are used to examine the organisational structures adopted by companies utilising NC machines. The greater use made of higher level shop floor skills by German companies is discussed.

The results of two surveys of the use made of NC by companies in the North East of England are presented. The first survey covered seven companies over a three year period, and the second survey covered the use made of NC machines by thirty four companies during January - June 1986.

Effective company organisation for NC use is described, and lack of foresight is shown to lead to vulnerability problems where skills can become concentrated in a few key people. This lead to closure of a company in one instance.

It is shown that small sub-contract companies have adopted the "German" pattern of a highly skilled shop floor workforce, and that they have survived in the present hostile economic environment, whilst companies who have used NC to de-skill the shop floor have contracted dramatically in the same period.

The lack of awareness of the potential for reviewing the product design in relation to the flexibility of NC, and hence the corresponding potential for reductions in work in progress levels, is highlighted.

Recommendations for skill structures appropriate to various sized companies are presented, as are suitable training programs to ensure that the full potential of NC machinery is achieved.

KEYWORDS: NC, new technology, adoption, skills

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This project has entailed contact with many senior local industrialists, without their support this project could not have been contemplated. I would like to thank them for sparing me time from their busy work schedules. They must remain anonymous, but their acceptance of my intrusion was remarkable and invaluable.

Thanks also to Mrs L. Hanlon for such an excellent typing job which has contributed a great deal to the end result.

V. Chiles

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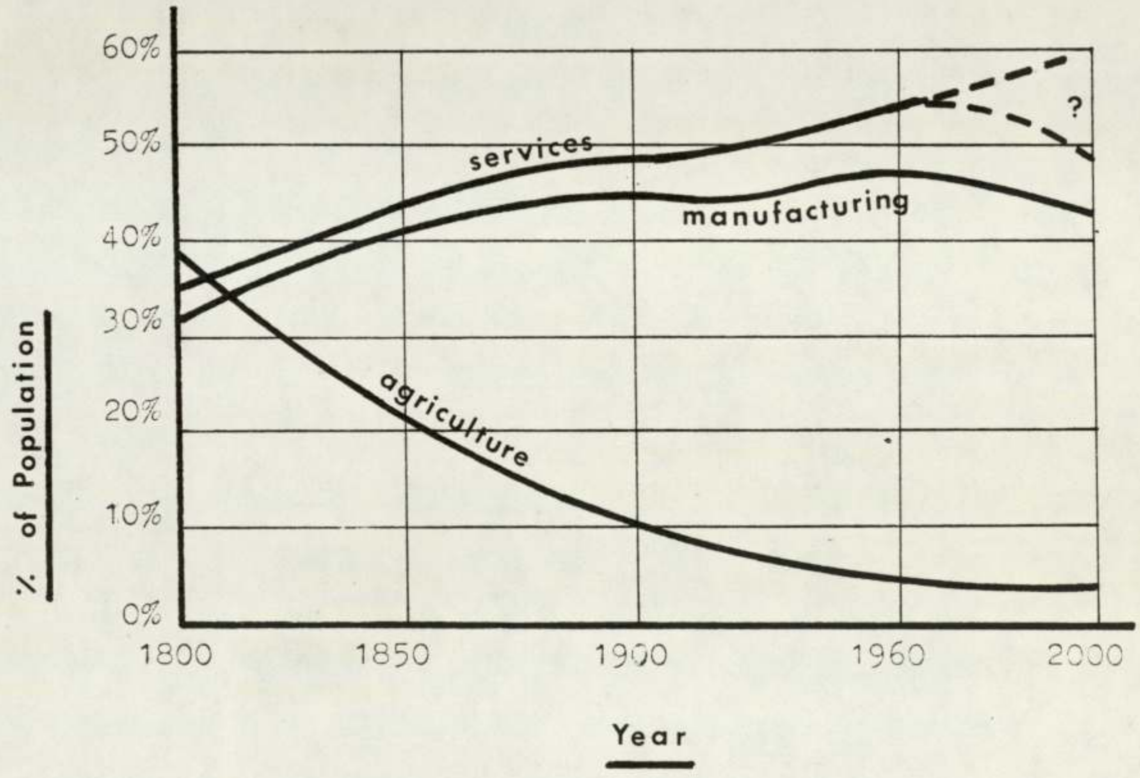
The pattern of employment changes that occurred in Britain as it changed from an agricultural to an industrial society are briefly reviewed, and the current trend to increase the Gross National Product alongside a reducing workforce in manufacturing industry is shown to be a major challenge to society. A survey of the structural employment changes anticipated from the adoption of New Technology in Tameside is presented. This survey concluded that the particular technology likely to cause change was the adoption of NC machines, it was felt, however, that the high price of NC machines would limit their adoption rate. The price trends of NC machinery are reviewed to demonstrate that there have been big reductions in their prices, and thus they are now being more widely adopted.

Chapter 1, Changing Patterns of Employment

1.1 Historical Perspective

The Industrial Revolution caused a massive growth of manufacturing industry, and the people were drawn from farming into factories. Farm output went up greatly though, as various inventions were applied to agriculture. The farming industry has had an enormous increase in mechanisation leading to a much higher crop yield, whilst the manpower employed has decreased from being more than all other industries until now it is only around 3½% of the total British Workforce.

Figure 1: Changing patterns of employment *



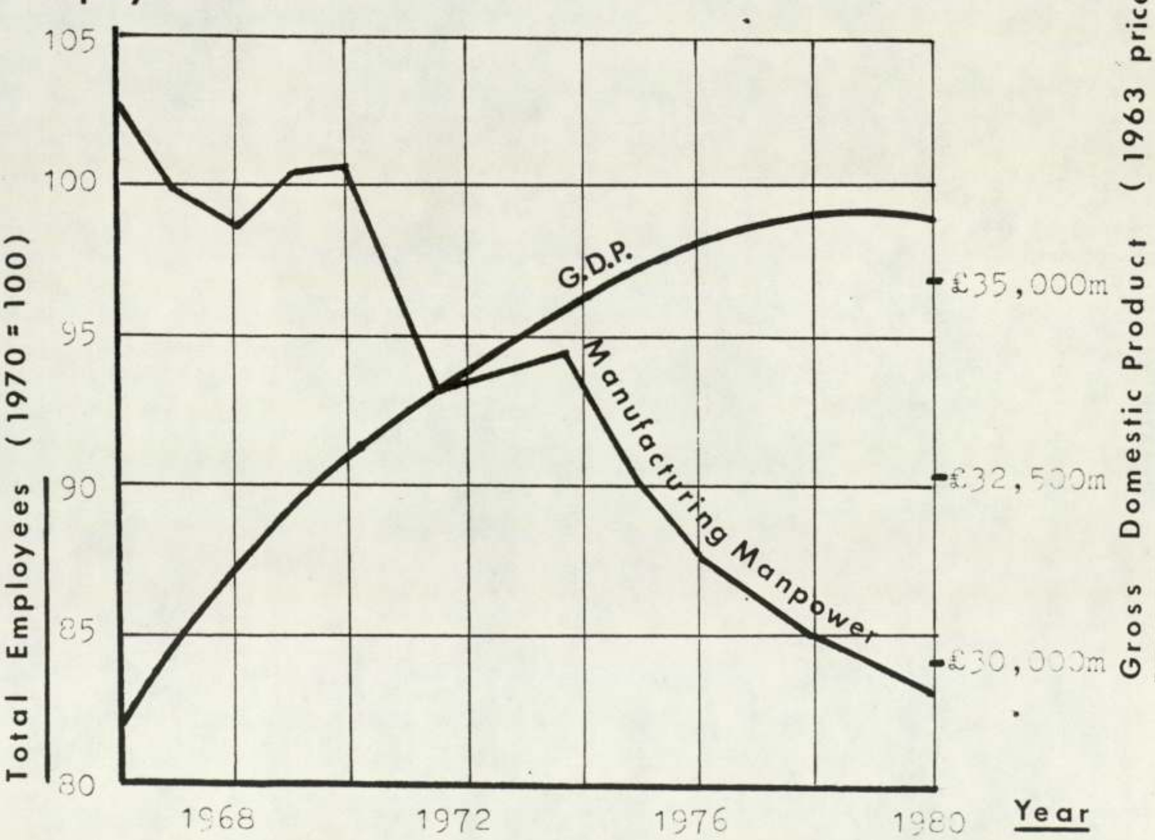
The labour that was released has moved gradually into manufacturing and service industries contributing to an ever increasing Gross Domestic Product - the trends in manufacturing since around 1960 show however that output has continued to increase whilst the workforce employed in manufacturing has been shrinking significantly in all western countries*. This is due to increasingly sophisticated

*Ref 1

manufacturing techniques - what is known as "Hard Automation", i.e. Transfer Lines and Automatic Machines,- so called "Soft Automation" (Robots, numerical control machines, computers, etc) is much more recent, and is having an accelerating affect on displacing manpower.

This reduction in the manpower needed by industry should be contrasted to the INCREASE in the working population now occurring. Due to the increase in the birth rate during the 1960's, and a coinciding decrease in the number of people due to retire, the workforce available will have increased by 1,400,000 by 1985 (Department of Employment Gazette). It has been estimated that we need a 3% GROWTH RATE in the economy just to absorb the ADDITIONAL workforce - let alone to start actually reducing the present 3,000,000 unemployed to a reasonable number. We would need a very large growth rate to cancel out the present problems. The Economist Intelligence Unit report (Ref 1) estimates that a growth rate of 10% per year may begin to solve the problems.

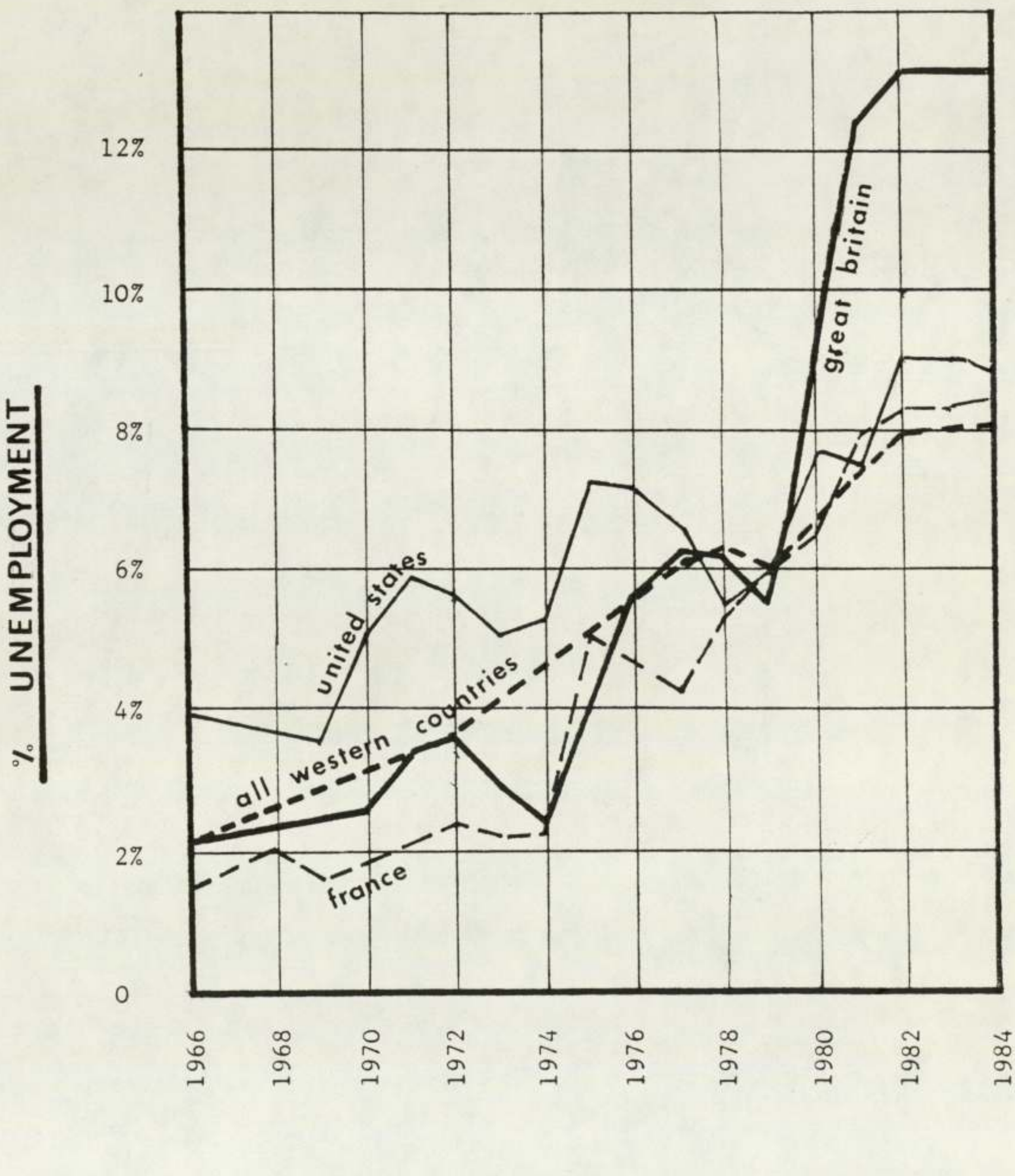
Figure 2: Gross domestic product and manufacturing employment *



*Ref 1

These problems are not peculiar to Britain, Figure 3 shows that unemployment levels here are only typical of Europe for the last 15 years, apart form the last three years. Over the same period, the USA has had a much worse history of unemployment.

Figure 3: Recent employment trends *



* Ref 2

Until the last few years the service sector has been the major growth area and has counteracted the decline in employment in manufacturing and primary industries. Between 1951 and 1977 agriculture, mining and manufacturing industries lost 1,610,000 jobs between them, while banking, insurance and scientific services gained 1,900,000 jobs and the public sector (Health and Education) gained 1,650,000 jobs.

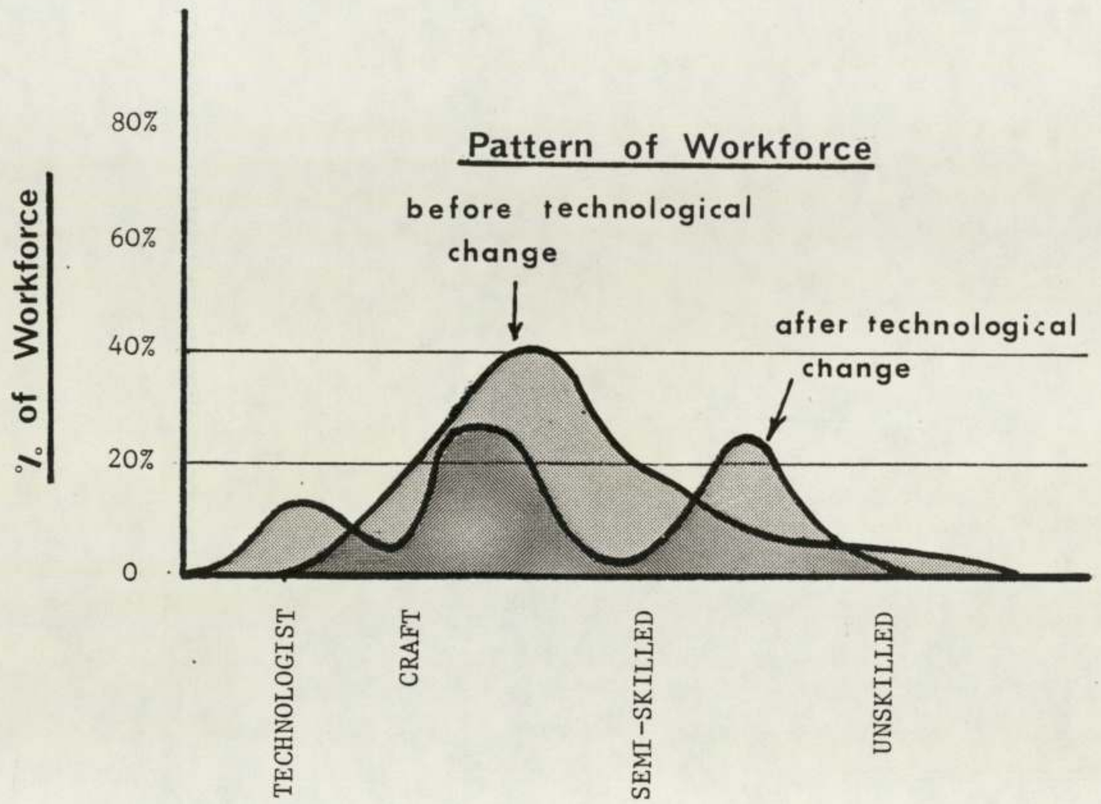
The service sector, though, is the area where jobs can be most rapidly displaced by word processors and mini computers. The present investment per office worker is in the region of a few hundred pounds, and there is little reason to employ old techniques when new ones are readily available. The pace of change in factories will be very much slower since the amounts of money involved are large, and existing equipment and skills will only be gradually replaced.

The general trend seems to be that "New Technology" requires a small number of highly competent and well educated people, but that it de-skills many operators jobs, or completely displaces them. Figure 4 shows the changes in skill requirements in the engineering industry* resulting from the introduction of N.C. machining. Each machine costs two to four times as much as the conventional machine that it replaces, but it produces three to four times the output from a much reduced floor-space and workforce. The skills required are changed, fewer skilled people are needed to operate the machines, but those who are left become programmers or more technically competent operators, while many other jobs become downgraded to merely loading and unloading.

In a recent survey* of 100 companies in the North East one third of the companies expected the occupational structure of their labour force to change. Most significant was the expectation of fewer clerical jobs and more managerial, professional, and technical jobs. There seemed to be a tendency towards fewer traditional craft jobs.

* Ref 3 * Ref 4

Figure 4: Skill patterns in the toolmaking industry *



The impact of New Technologies was largely recognised as requiring greater flexibility in skilled occupations. Flexible working practices were found to be more common and more readily achievable in small firms.

Industry is thus undergoing a process of rapid change as various 'New Technologies' are introduced into existing organisations. The process of adaption to this restructuring of industry is seen to be a world wide problem, and Britain cannot sit back and let the rest of the world pass it by.

We are thus now faced by two main problems:-

(1) How to implement New Technology effectively so that British Industry remains competitive in the world market.

(2) How to cope with the structural employment changes caused by this New Technology.

*Ref 3

This report concentrates upon the first question and presents the results of a study of the impact of one type of New Technology (NC Machines) upon manufacturing industry.

The second question is a much wider political question which affects the structure of industrialised societies around the world. The Economist report "The Jobs Crisis" (Ref 1) summarised the scale of the problem very forcefully:-

> "In summary it seems fairly clear that the OECD countries will not under any forseable circumstances be able to generate sufficient jobs on the conventional definition to prevent their unemployment ratios from rising, let alone reducing to anything like to pre 1974 levels. If this is so it is inevitable that, in order to avoid the inability to provide enough employment, the very concepts of employment, full employment, and unemployment will have to be re-examined and re-defined so as to ensure that the benefits of economic activity are adequately shared among the population.
>
> The link between employment and incomes must be lowered if income and consumption needs are to be better satisfied. This means that the need to be formally employed at all in order to have an adequate means of living is now obsolete."

This report was written in 1980, and yet the problem is still being ignored by all governments. World wide unemployment has become a major problem in the last six years, the days of large factories employing many thousands of people are now definitely a thing of the past. Factories used to employ the whole spectrum of people for jobs ranging from unskilled to highly skilled, but the bulk of the people being disciplaced from factories are the unskilled or semiskilled people whose prospects elsewhere are extremely limited.

1.2 Technological Change in Tameside

It is not easy to quantify the extent of the changes due to the advance of technology. The only blanket survey of a particular area undertaken so far is one of Tameside. A summary of this follows, together with a few relevant comments.

This survey* was commissioned by the council in 1979 to cover all industries in Tameside to help them plan their job creation policies for the next 5-10 years.

The basis of this was a detailed questionnaire to help define the employment pattern and types of products for all the firms in Tameside. Eight full time interviewers (and back up staff) were employed as part of a Steps programme and they spent 3 months taking the questionnaire to every firm in Tameside. Questions about the impact of Microelectronics were put into the questionnaire by the Manchester University team.

This obviously covered the whole perspective of industry in that area, and predicted an overall drop of workforce of between 1.9 – 3.1%. The effects within Mechanical Engineering (S.I.C. orders VI, VII, VIII, IX, X, XI and XII - strictly referred to as Metal Using) were considered to be ZERO. This was because most of the industries tend to be making large heating and ventilating equipment and Steelwork, producing customised products for the process industries, and involving a considerable amount of large scale cutting and welding not easily handled by the types of micro based machine tools and robots which will be available in the 1980's.

*Ref 5

The three areas of effects resulting from microelectronics in Mechanical Engineering were expected to be:-

(a) Major Production Innovations - e.g. Cash Registers - which are now NOT Mechanical Engineering products.

(b) Use of N.C. Machine Tools - Reduction in price is needed to make these more attractive to employers since they are very much more expensive than conventional machines.

(c) Machinery with Separate Control Systems - i.e. process machinery - this was felt to be little affected by the use of micro's - the basic plant would not change significantly, although the control equipment side would obviously improve its performance.

Within Tameside few companies were involved in products such as cash registers subject to revolutionary change, and the main effects were felt to be from a gradual adoption of N.C.

Comments

N.C. Machinery is reducing in price in real terms thus the adoption threshold is becomming much less of a hurdle. For example sales of N.C. machines have risen from 6% to 18% of total machine tool sales between 1972 and 1981*.

Further evidence of this is readily available - for example Newcastle Polytechnic has recently replaced a Moog point to point N.C. miller which cost £11,000 in 1972. The replacement 'Manual Data Input" machine matches very closely the facilities of the original 1972 machine, but has cost £9,000. This is obvously £2,000 cheaper in cash terms, but less than one third of the price when ten years of inflation are allowed for.

*Ref 6

A full 3 axis C.N.C. machine is available for £22,000 which offers far more sophisticated programming capabilities, and yet it is still considerably cheaper in real terms than the above MOOG machine.

1.3 Price Trends of NC Machinery

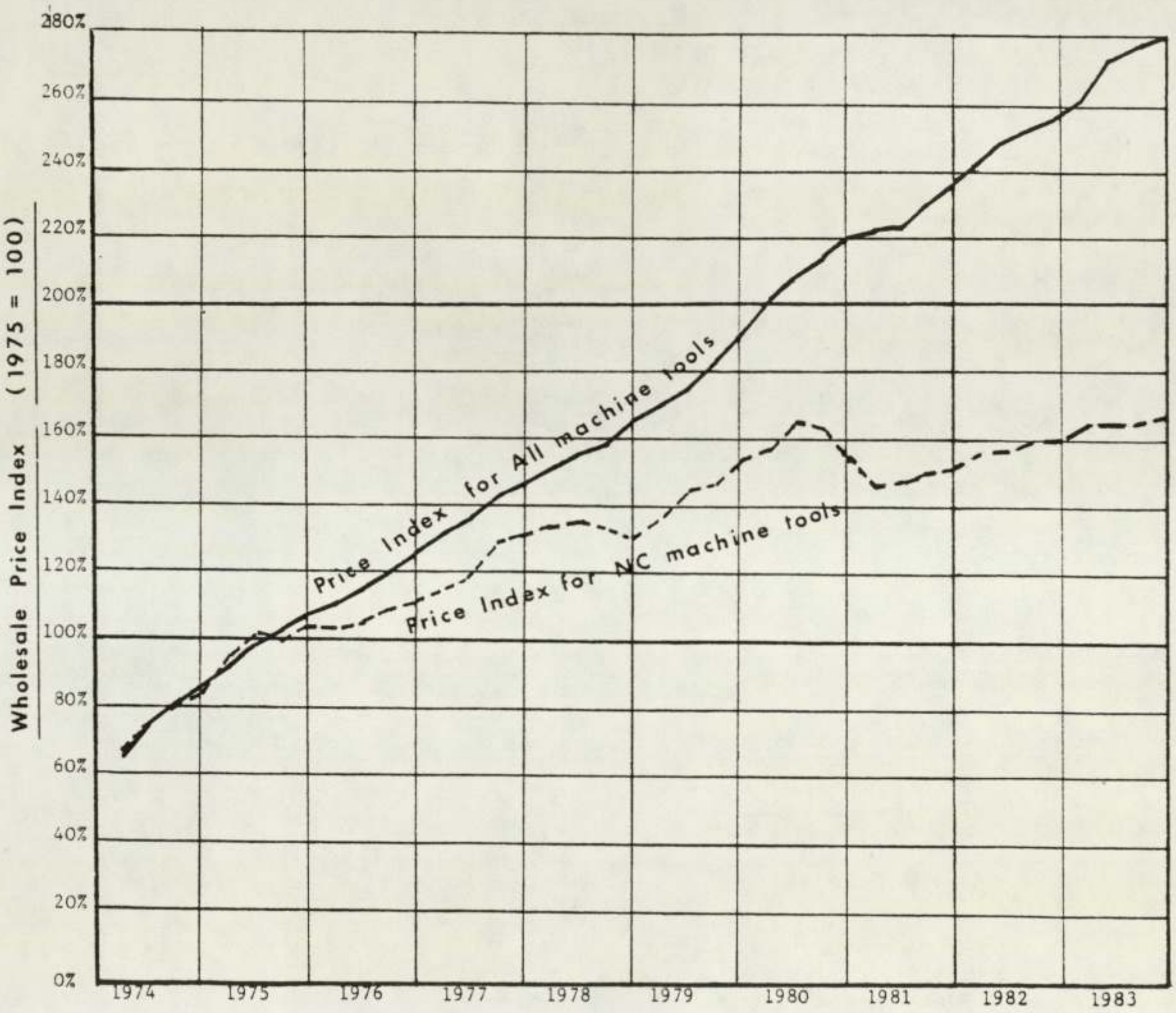
Statistical evidence of the overall trend is available from MTTA statistics. Figure 5 shows the changes in wholesale prices of machine tools between 1975 and 1984. Overall machine tool prices rose by 282% between 1975 and 1984, while NC machine prices only rose by 183%*, i.e. they had become very much cheaper in real terms. This comparison, however, understates the comparative price reduction of NC machines, since NC machine prices are included in the price index for all machine tools. Unfortunately, it is not possible to extract them from the aggregated data, but it is obvious that the price index for conventional machine tools must be higher than that shown.

The dramatic effects arising from the use of N.C. will come from revolutionary applications rather than the direct replacement of existing techniques. These arise when companies gear themselves up to using the integrating capabilities of N.C. machines, either by undertaking more complex operations at one station, or by using CAD/CAM techniques to reduce manufacturing lead times. At present only 20% of firms use computer aided N.C. programming even if they have N.C. machines.

Investigation of the ways in which companies are using N.C. machines, and the effects it has upon the companies is thus an important topic with major implications for the pattern of technological progress and employment.

*Ref 6

Figure 5: Price trends of machine tools *



*Ref. 6 (Table E1)

Chapter 2, A Local Example of Technological Change

This chapter presents the results of a study of the overall impact of technical change within a local high volume producer of consumer products. This illustrates the trend to automation and labour displacement now occurring in manufacturing industry generally, and is but one example which is used to illustrate the rapid pace of change necessary for commercial survival nowadays. This demonstrates that the adoption of NC machinery is only one of many changes which industry needs to consider in order to survive.

Chapter 2, A Local Example of Technological Change

A review of the effects of new technology at a local consumer goods factory has recently been completed. They are facing intensive competition in a fiercly competitive international market, and they have had to cut back on their output. In order to regain a competitive edge and to respond to market conditions the company has worked hard at improving the efficiency of each department. The amount of time needed to produce 1000 items of product 'A' has been cut by two thirds in the last ten years, and the time needed to produce 1000 items of product 'B' has been cut by half in the same period.

2.1 Labour Force Changes

Their sales successes had built up the workforce of the company to a maximum of 1450 people by 1974. They were then hit by a slump in sales and had to make one third of the workforce redundant towards the end of 1975. Their product is highly specialised, with a highly developed manufacturing technology. They no longer hold a monopoly of the market, and are now selling production expertise to Iron Curtain and third world countries. The export market is consequently declining, and home markets are shrinking in the face of severe European competition. Output is therefore down, but in order to survive the company has invested heavily in increasing the productivity of their processes. Some new processes have been introduced, but greater effort has been placed upon further development of existing processes and products on site.

The major cause of loss of employment has been due to loss of markets, and in response the company has worked very hard to lower unit costs in order to survive. It is not possible directly to attribute the reduction in employment to technological change, but it must be a significant factor.

*Ref 7

The company lost a further three hundred people in 1978, and a further three hundred people in 1979. The company thus employed approximately 600 people in 1981. Three hundred and fifty people were employed in the manufacturing area, eight people were skilled, and fifty were monthly paid staff. The most drastic cut backs have been made among the semi-skilled workers, although office and other monthly paid staff have been reduced by 50% since 1974. Cut backs, where necessary, have been scheduled and most employees opted to take voluntary redundancy when it was offered to them. In 1974 more people applied for voluntary redundancy than the company needed to lose at that time. It has been company policy for some time to absorb people into other areas whenever possible, rather than to make them redundant.

Figure 6 shows this employment history diagrammatically.

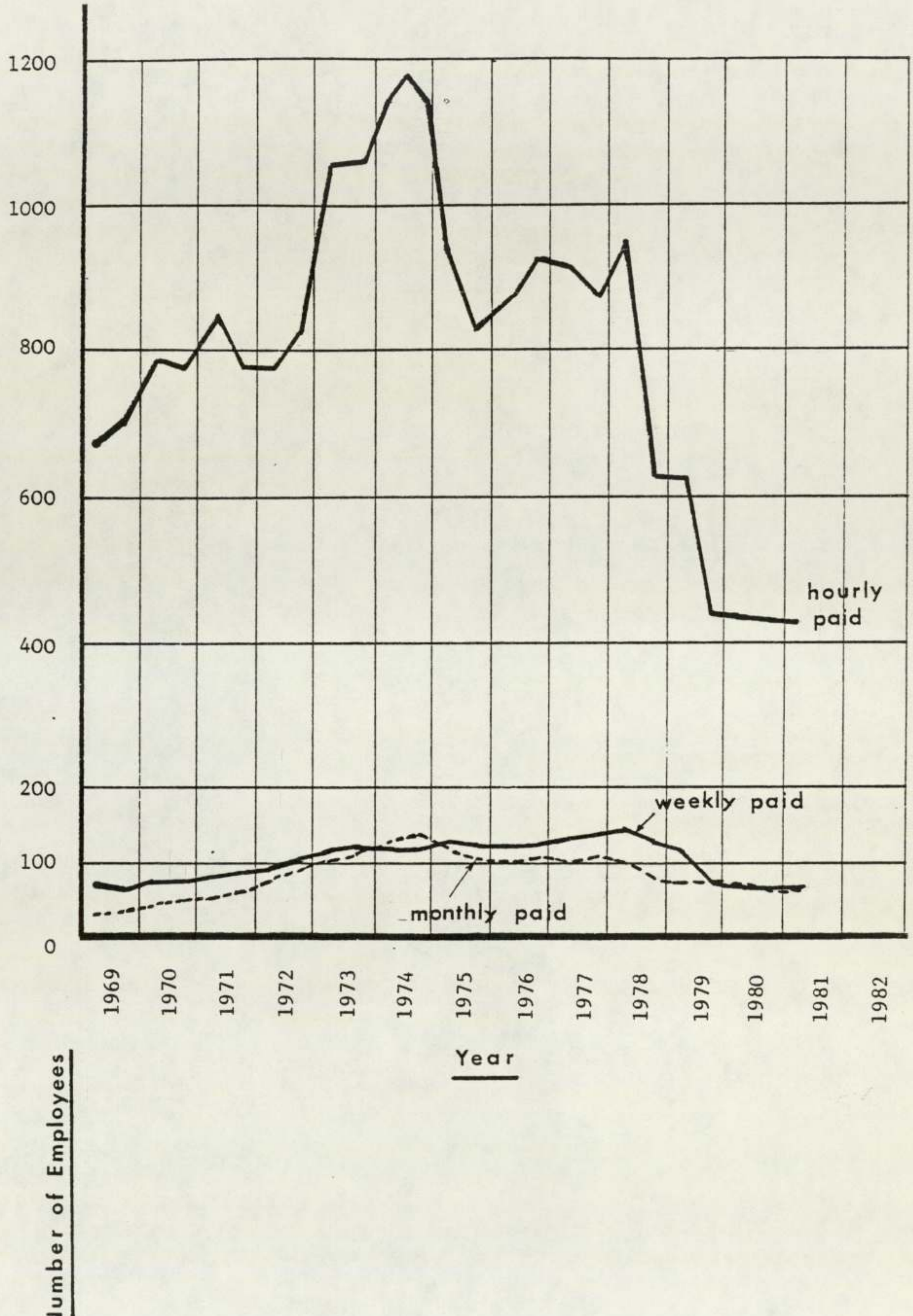
2.2 Process Changes

An analysis of the major process changes showed that they could be grouped into the following broad categories:

- Introduction of new machinery or automation
- New Tooling
- Increased speed of production lines
- Reduced manning levels
- Improved quality control
- Improvement to existing machinery or methods
- Development projects
- Improved product design

Department 'A' has had the most change, the greatest emphasis has been upon the improvement of existing machinery. The second main factor has been the increasing speed of the processes, for example the throughput speed of the conveyors through the furnaces is now 42 feet

Figure 6: Employment patterns at a local company 1969 - 81 *



* Ref. 7

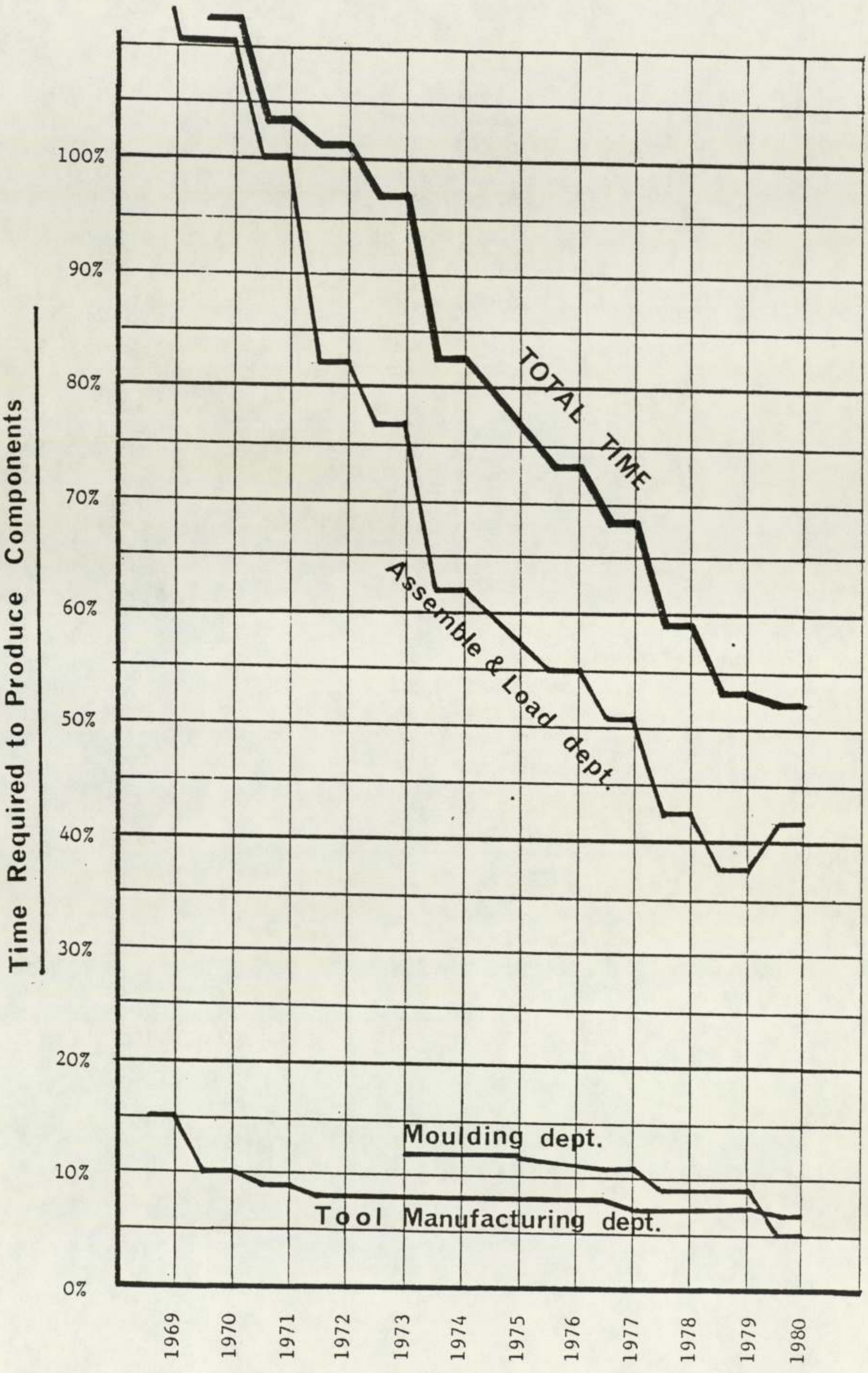
per minute, while it was 28 feet per minute in 1969. Changes in manning levels have included the elimination of the inspection function and widespread reduction in all sections of the department.

Automation and the introduction of new techniques has also occurred in Department 'B' over the last ten years. Assembly and loading sections have undergone major process changes during the same period. Packing speeds have increased from 60 to 85 items per unit of time.

Overall a high level of automation has been achieved in the last ten years, with increased use of handling devices such as vibratory bowl feeders.

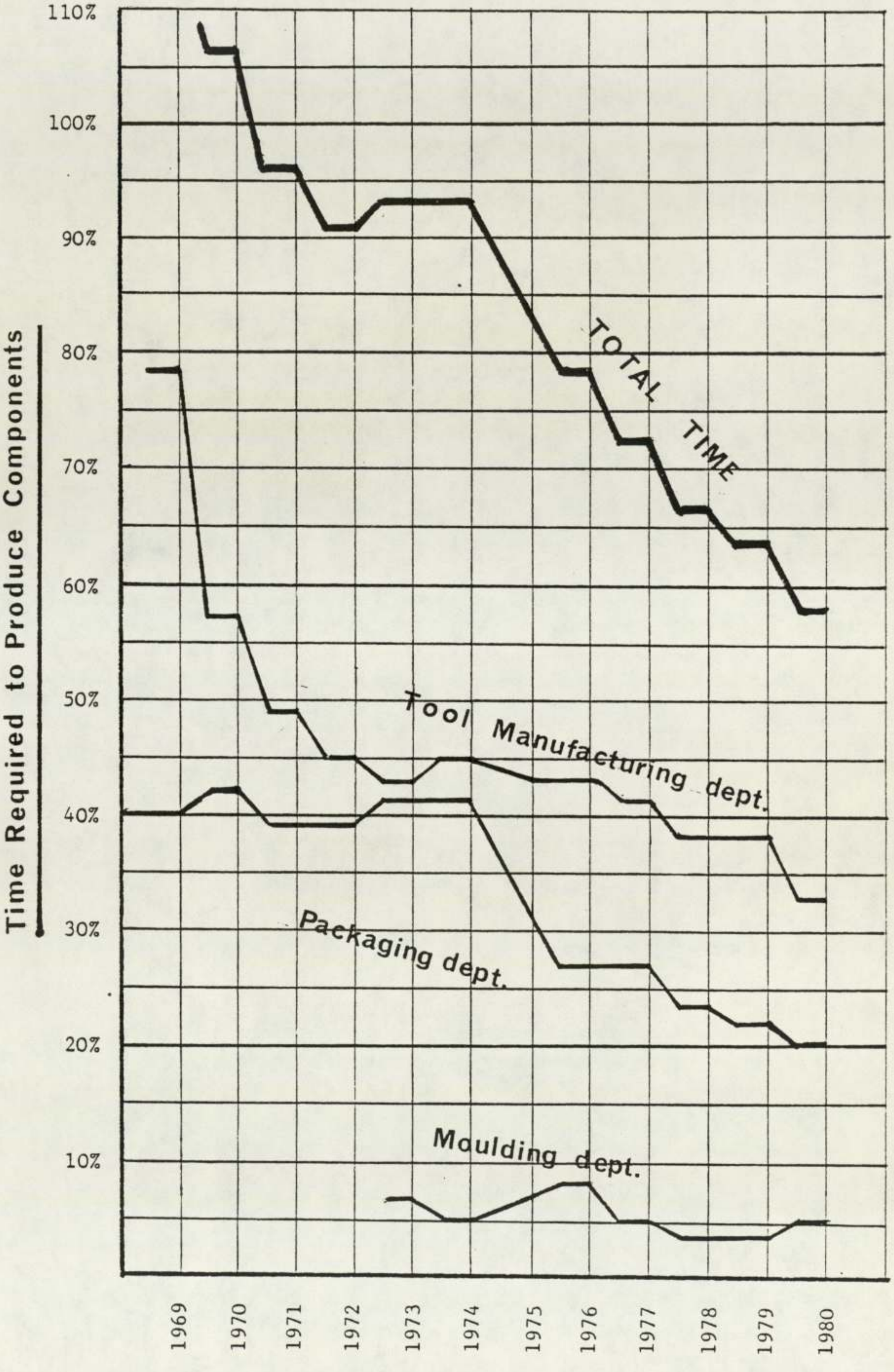
The nett effect of these changes is clearly shown in figures 7 and 8 which follow.

Figure 7: Department 'A' productivity 1969 - 81 *



*Ref 7.

Figure 8: Department 'B' productivity 1969 - 81 *



* Ref. 7

General Comments about the Changes

Although it is not possible to correlate the levels of employment in the factory with specific technical and production changes, certain conclusions can be drawn from the data:

1. Employment has dropped from 1450 in 1969 to 600 in 1981 but production has only dropped by under half.
2. Productivity levels in the plant have therefore increased.
3. Such productivity has been achieved by the introduction of new machinery, increased speed of the process, and improvements being made to existing machinery and methods.
4. Reduced manning levels have been possible due to the above innovations and improvements, but after scheduled cutbacks were made, employees have been absorbed into other areas of the factory.
5. More recently, a change in the product mix has created a surplus of operators.

2.3 Supervisor's Interviews

Informal interviews were held with the Production Manager, Assistant Production Manager and the Maintenance Supervisor, in order to obtain their views on the introduction of technical change in the Company. These were not structured in any way, consequently a descriptive report is given of their outcome.

The over-riding theme of all the interviews was an emphasis on high profitability and the means of achieving it, but only in so far as the industrial relations of the firm would allow. Management have cooperation and flexibility agreements with the trade unions, and any new projects are brought "onto the table" at the regular joint negotiating meetings. The policy is that wherever possible, people are absorbed into other areas of the factory.

A great deal of emphasis is placed upon the quality of the product. The company has a strong quality assurance section, and is becoming more and more aware of the need to meet consumer satisfaction. Mention was made of plans to bring microprocessors at some time in the future to carry out inspection work, but this was seen to be difficult to justify in terms of the large capital outlay. At the moment, operators at various stages in the process are responsible for their own quality control, a complete change-over from the past when several inspectors were employed in each department to carry out tests. Results from the present method of inspection are encouraging.

Maintenance in the plant is carried out on two levels, either breakdown or development work. When new machinery is introduced into the plant, the Training Officer prepares a tape/slide presentation which is given to the men as soon as possible. This tends to cut down any problems of familiarization which may occur, and is seen as a useful management tool. Fitters also take it upon themselves to find out about new equipment whilst it is being installed, on a more informal basis. A definite demarcation exists between electrical and mechanical fitters, but it was predicted that at some stage in the future the two disciplines will converge. Maintenance skills are mainly diagnostic, with other skills being secondary. It was felt that pressure has increased over the years to keep up production levels, and so breakdowns have to be rectified as quickly as possible. Thus, there is often little time for men to take a pride in their work, and job satisfaction suffers as a consequence.

Chapter 3, The Development of NC Machines

This chapter reviews the history of the development of NC machines in response to the demands of the aerospace industry to machine complex components, as jet aircraft were developed in the 1950's. The parallel development of NC programming languages is discussed and the problems of non-compatability of the various manufacturers individual machine languages are highlighted.

Chapter 3, The Development of NC Machines *

3.1 NC Machine Development

The first attempt to 'capture' the skills of the machinist in a memory was the development of the 'record-playback' machine in 1946-7 by General Electric and Gisholt. This was a development of gunfire control technology during the war, it involved having a machinist make the part while the motions of the machine were recorded on magnetic tape. After the first piece was made, identical parts could be made automatically by playing back the tape. However, it appeared, and vanished without being adopted by industry.

The second solution to programmable machines was "numerical control", a name coined by Massachusetts Institute of Technology engineers William Pease and James McDonough. Punched cards had been used to control the Jacquard Loom back in 1804, but electronic logic to control machines was the brainchild of John Parsons in 1948, an airforce subcontractor in Michigan who manufactured rotor blades for helicopters.

The machine tool industry's products are designed to please the major customers, who have money to spend on 'high technology' products. There is thus a concentration on sophisticated solutions to suit these valued customers. The need at that time was for more complex shaped parts to be made from one piece of metal in order to achieve a lighter overall structure, e.g. for helicopter blades, or for parts for supersonic aircraft. Record-playback did not meet these needs, since it was limited to making conventional parts more cheaply.

The development of N.C. was in response to this need of a small (but high spending) sector of industry. John Parsons conceived the idea while trying to figure out a way of cutting the difficult contours of helicopter rotor blade templates to close tolerances.

*Ref 8

Since he was thinking of using a computer to calculate the points for drilling holes (which were then filed together to make the contour) he began to think of having the computer control the actual positioning of the drill itself. He extended this idea to three axis milling when he examined the specification for a wing panel for a new combat fighter. The new high performance, high speed, aircraft demanded a great deal of difficult and expensive machining to produce airofoils, integrally stiffened wing sections for greater tensile strength and less weight, and various thickness skins.

Parsons took his idea, christened "cardomatic" after the IBM cards he used to Wright Patterson Air Force Base, and convinced them in 1949 that the air force should underwrite the development of this potent new technology. When he got the contract, he sub-contracted it to MIT's Servo-mechanism Laboratory,which had experience of gunfire control systems. Between the signing of the initial contract in 1949 and 1959 when the Air Force ceased its formal support for the development of software, a total of $62 million had been invested in the research, development, and transfer of N.C. Until 1953 MIT and the Air Force had tried hard to interest machine tool builders and the aircraft industry in the new technology, but only Giddings and Lewis was sufficiently interested to put their own money into it.

In 1955 the N.C. promoters managed to persuade the Air Material Command budget for machine tool stock-piling to change its specification from tracer controlled machines to N.C. machines. At that time the only N.C. machine in existence was in the MIT Servomechanisms Laboratory. The air force undertook to pay for the purchase installation and maintenance of over 100 N.C. machines in factories of prime subcontractors. The contractors, aircraft manufacturers, and their suppliers would be paid to learn to use the new technology. The airforce thus created a market for N.C. Not surprisingly the machine tool builders were galvanised into action and R & D expenditure in the industry multiplied eight fold between 1951 and 1957.

This involvement of massive funding by the airforce helped to shape the machines being built at that time. Cost was not a major problem, machines were designed to meet performance and competence specifications for the government funded users in the aircraft industry. The builders had little concern with cost effectiveness, and absolutely no incentive to produce less expensive machinery for the commercial market.

3.1a A Social Perspective

An interesting perspective of the view taken by people at the time of the development of NC technology and which also provides a lead into the difficulties of NC programming is provided in the novel "The Piano Player" written in 1953 by Kurt Vonnegut. He was a publicist for General Electric and saw the record-playback lathe which he took as the theme for his novel portraying a future society where a ruling class lived in luxury, but the workers were redundant, dispossessed, and forever employed in the army or in job creation schemes.

The page describing these lathes in action is quoted in full in appendix 1.

3.2 NC Program Development

The development of the machine tools is only half of the story. At the onset no-one appreciated the difficulty of getting the skills of the production workers on tape. Few of the MIT scientists had any machining experience before their involvement in this project. They were mathematicians and control engineers who thought that they could readily synthesize the skills of the machinist. It did not take them long to discover their error. In order to control the machine to make a complex shape the motion had to be translated into a series of vectors about ½-1 mm long covering the 3D surface in such a way as to leave a good finish, and to drive the cutter at a suitable speed and feedrate for the material being cut.

Tape preparation systems now had to be invented! The first programmes were prepared manually, a tedious time consuming operation performed by graduate students, then "Whirl wind" (MIT's first computer) was enlisted to the task.

The earliest programmes were essentially sub-routines for particular geometric surfaces, which were compiled by an executive programme. In 1956 MIT received another Air Force contract, this time for software development, and a young engineer and mathematician, Douglas Ross, came up with a new approach to programming. Rather than treating each separate problem with a separate subroutine, the new system (called APT)* was essentially a skeleton programme for moving a cutting tool through space. This skeleton was to be "fleshed out" for every application. The APT system was flexible and fundamental and it met airforce specifications that the language must have the capacity for up to five axis control (X,Y,Z, and two rotary functions). The Air Material Command cooperated with the Aircraft Industries

* Automatically Programmed Tools.

Assocation Committee on Numerical Control to make APT the industry standard. The machine tool and control manufacturers followed suit, developing "post processors" (translation packages between APT and the individual machine language) to adapt each particular manufacturers systems to interface with APT.

There was initial resistance to APT within some of the industry, who had developed simpler in-house languages to meet their own needs, but before long it became the industry standard. The disadvantages of APT were that it was a very fundamental system, capable of highly complex geometrical calculations, the programmer needed to be carefully trained, and it occupied 256K of memory in a computer just to store its features. Since the industry wanted the defence contracts, they had little choice but to adopt the system. The exclusive use of APT was enforced, thus began what Douglas Ross himself has described as the "tremendous turmoil of practicalities of the APT system development", the system remained erratic and unreliable and a major headache for the aircraft industry for a long time.

The standardisation of APT had two other consequences. Firstly, it inhibited for ten years the development of simpler languages which might have made N.C. more accessible to smaller factories. Secondly, it forced those who ventured into N.C. into a dependence on those who controlled the development of APT, on large computers, and on sophisticated programmers. Commercial users without aircraft contracts had a very large barrier put up to their adoption of N.C. techniques. APT served the airforce well, but at the expense of those not in the magic circle of defence contractors.

The history of N.C. described above demonstrates the taking over of a technology by a major vested interest to the detriment of the majority of manufacturing industry. Battacharyya* argued in 1976 that N.C. use

* Ref 9

in Britain was held back because research and development on N.C. machine tools was "too much concentrated on the sophisticated end of the market which is primarily entering for the minor aerospace industry".

Whatever happened to "record playback"? Small firms never saw it. The Gisholt system designed to be accessible to machinists on the shop-floor was shelved when that company was bought by Giddings and Lewis, one of the major N.C. manufacturers. The G.E. system was never really marketed, since demonstrations to potential users in the machine tool and aircraft industries aroused little enthusiasm. Giddings and Lewis did in fact purchase a record-playback system for a large profile "skin mill" at Lockheed, but switched over to a modified N.C. system before production got under way. GE's magnetic tape system was initially described as having a record-playback option, but mention of this feature soon disappeared from the manuals, even though the system actually retained the record-playback feature.

Why was it so unsuccessful? The airforce specifications of four and five axis machining of complex parts were beyond the capacity of manual methods, and therefore of record-playback, and they dominated the use of N.C. The little user who wanted to make say, five similar shafts never knew of the system.

N.C. programming languages in the machines themsevles were based on an industry standard (EIA RS-267A) which was designed to be used with APT post processors, and thus the languages used standardised code words to describe machine functions. The machine languages today often still suffer from this straighjacket, they are very unfriendly. Nowadays most companies (who are now the small ones) have to program in statements such as

G00
G01
G84
G79

which are translated as

G00 - move rapid
G01 - move at feedrate
G84 - tap
G79 - circular interpolation mill

It would be much easier to be able to use statements such as

Rapid - (Which the machine reads as G00)
Mill - (Which the machine reads as G01)
Tap - (Which the machine reads as G84)
Circ Mill - (Which the machine reads as G79)

Much of the mystery of programming would be stripped away at a stroke, and adoption of N.C. would be much easier.

This is now starting to happen (30 years later) with Manual Data Input machines which question the operator with a series of standard questions e.g.

What feedrate?
What movement?
What spindle speed?

The same machines also have a record-playback facility - once again!

The development of a standard programming system which depended upon large mainframe computers was thus a major barrier to the spread of N.C. to small companies. The only cheap way was to program in "machine code", which restricted their ability to machine complex shapes. The machine language can deal with straight line and circular motions, but 3D shapes and other 2D curves (e.g. ellipse, parabola) are not available on the machine.

Various software houses thus offered either a programming service, or to rent terminals to the company. The company could then write their own programmes, and have them processed via a telephone line, they thus gained access to a mainframe computer by paying for the time they used.

More recently mini-computers have meant that a small company can get a desk top unit with a simplified version of APT installed on it (e.g. Fanuc sell Fanuc APT on a Desk top unit for £10,000*. In 1984 a £3000 desk top system was introduced (E-JAPT by JAPAX Inc) - but it is limited to straight lines and circles.

This means that computer aided programme preparation is now affordable by all companies, but 94% of small companies have been programming in machine code until very recently.+

It must be pointed out that the use of "G" and "M" codes may be universal, but it is totally non-standardised. Every manufacturer seems to have adopted their own version of this code, and programs are not interchangeable between very similar machines although later versions of a machine controller will usually accept programs from their predecessors. A good example of the irritating (but still serious) differences can be illustrated by reference to the two CNC vertical millers at Newcastle Polytechnic, one purchased in 1982, and one in 1984. Both come from the name manufacturer and the later machine has a considerably improved controller. This controller can, however, be switched back to the "Issue 5" language made on its predecessor from its "Issue 8" language. The only difference then preventing programs from the first machine being used on the second machine is that feedrates are expressed as "F250" on the first machine (250 mm/min) and "F250." on the second machine. This means that all programs need editing and they are not immediately interchangeable in either direction.

This means that the computer prepared programs referred to previously all have to be put through a "post-processor" tailored to the specific machine to translate from the interchangeable computer output to the specific language for the machine. These are not cheap, the post processor for the millers at the Polytechnic cost £2,500.

*ref. 10 +ref 11

The post processor also contains many machine-specific words which need to be included in the main computer program, so that the original computer program ends up being written in two languages at once - the standard NC language for the computer system plus those post-processor words. Thus the universal APT program suddenly becomes non-universal.

This problem can become a nightmare for large companies, and efforts have been going on to introduce some standardisation into the situation. Rockwell International in the mid 1970's decided to upgrade the controllers on their 31 major NC machines*. They needed 23 post-processors to translate

programs to cover this range of machines, which did make life difficult for the programmers. At that time they specified that the controllers should be modified to accept the standard output date from an APT program - the CLDATA (cutter Location Data). The major controller builders were not interested in building a new form of controller to adapt to everyone else's controls, so Rockwell only had four tenders from smaller companies. Rockwell and Vega (the successful bidder) worked on this system together and found that the major problem was the vast amount of data contained in the CLFILE, translating this data into the specific machine language was a mainframe computer task.

Rockwell thus developed a software package which stripped away unnecessary data and then translated the remaining data into a 32 bit binary format subsequent to the APT run on the main computer, greatly reducing the time needed for subsequent machine specific processing. This became known as the CL-converter, and while it does not remove the need for translation to the machine language, it does greatly reduce the task. Rockwell have been promoting the adoption of this as a national standard, and have encouraged its diffusion by making their CL-CONVERTER available free of charge. In 1980 the Electrical Industries Association set up a study project

*Ref 12

to examine the proposed new standard, and in 1983 they issued EIA - RS494 32 bit Binary CL Exchange (BCL) input format for NC machines" as a new standard to be adopted by NC controller manufacturers.

The intention is that the controllers will accept the BCL data on a standardised floppy disc format, and the controller itself will then post-process this data to suit the particular machine. Hopefully this will mean that major customers like Rockwell can send the floppy discs to their machine shop, or to subcontractors for production of parts. Obviously the machine sizes must be similar, and workholding must be as specified on the work planning sheet, but the achievement of this interchangeability would be a major step forward.

Vega now market an NC controller to suit this new standard, and other major NC producers such as Cincinnatti and White Sundstrand will modify their controllers by the installation of a new microprocessor board in the controller. General Electric plan to offer a BCL input option for their new GE 2000 controller. Vega also offer a CL Exchange Processor which can be added to other people's controllers to allow them to accept BCL.

We now have to see how this diffuses across industry in the next ten or twenty years!

Chapter 4, The Relevance of Batch Manufacture

This chapter briefly reviews the structure of industry and points out that most articles are made in discrete batches, which is exactly where the versatility of NC machines becomes beneficial. The capabilities of NC machines are reviewed to demonstrate their adaptability to changing circumstances.

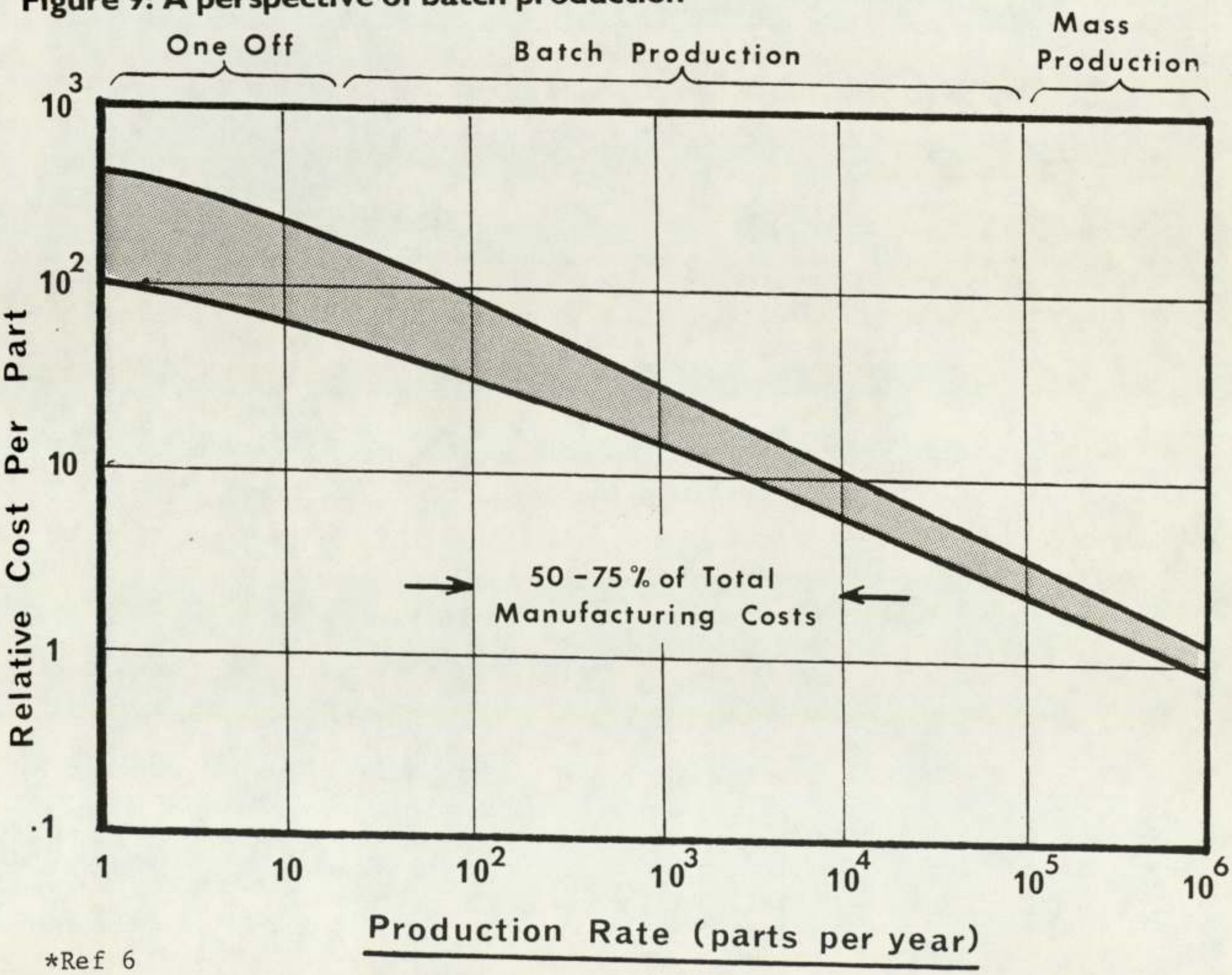
Chapter 4, The Relevance of Batch Manufacture

4.1 The Role of Batch Production

Numerical Control machines are most successfully applied to production of parts in small batches of 10 to 150 parts, depending on the complexity of the part. It is important to realise that batch manufacture is the predominant method of making goods. The extent of batch manufacturing was well described recently in an article in the Scientific American:*

"The cost of production of typical industrial parts declines by a factor of perhaps 100 in going from "one of a kind" production to mass production. The term "batch production" applies to parts manufactured in lots ranging from several units to more than 50 for which the total annual demand is fewer than, say, 100,000 units. When the demand exceeds that volume depending upon the specific product use of special purpose machines can generally be justified. The author estimates that batch production methods accounted for 50-75% of rational expenditure for manufactured parts. By making greater use of computer -technology it should be possible to reduce the cost of producing parts made in small quantities".

Figure 9: A perspective of batch production *



*Ref 6

We are frequently told that we live in a mass production age, but in reality most parts are made in batches. One of the advantages of N.C. is the ease of changing the machine over from making item A to making item B. This can often be done in a few minutes compared to probably two to four hours for a conventional machine.

The pressure for maximum output each month means that the long changeover times on conventional machines have to be counter-balanced by runs of several days on each part in order to keep the proportion of setting time down to an economic level and thus the machine utilisation at a reasonable level. The use of N.C. can break out of this cycle and permit different parts to be run on the same day if necessary. This permits a radical rethink of the amount of work in progress needed to keep the work flowing smoothly through the factory. The savings achieved by reducing the amount of work in progress are often just as important as the direct time savings on the machine.

The logical extension of grouping operations together onto one machining centre is to group various N.C. machines together so that all the operations on the parts can be done under automatic control. This then becomes a Flexible Manufacturing System, which can make any of its programmed range of parts completely under the control of a central computer. About forty of these systems are now operating world-wide, and Britain's first one started production in 1980*

In this system the lead time for producing a complex family of parts has been telescoped from 18 weeks using conventional batch manufacture to 8 days, since each kit of parts for the assembly is progressed through the works together, instead of many separate batches with different lead times needing careful coordination to arrive on the assembly bench together.

*Ref 14

The company involved, Garrett Normalair, specialise in high technology aircraft sub-assemblies and have sales of £60,000 per annum per shop floor employee in their conventional factories. The new FMS unit is now producing sales of £260,000 per employee, and only needs 3 employees per shift to run it. They have since ordered two similar units.

4.2 The Advantages of NC

The 1970's have seen the spread of CNC control systems of greater versatility than earlier NC systems, because of their use of easily modified stored programs (software) and the accessibility they provide with regard to management information. Movements of the machine tool are controlled from information presented in mathematical form by the programming system.

CNC therefore involves the incorporation of a computer into NC systems in place of the conventional special-purpose-built control system connected to a machine tool. The limitations of the use of a dedicated or 'hard-wired' approach (NC) results in a relatively inflexible system in which new developments can only be incorporated by rebuilding the control unit and its associated equipment.

Conversely, CNC utilising stored programs or a 'software approach' can provide for manufacturing establishments:-

(a) Greater capability for the efficient manufacture of complex shapes because of its ability to perform previously non-standard operations by changing the logic system. It is probable that adaptive control could be made technically and economically more realistic when developed as part of a CNC system with its capability for making complex decisions at high speed.

(b) The ability to make greater use of an operator's skill and experience.

(c) Improved quality due to additional measurement and control facilities which can be incorporated.

(d) Better control of manufacturing operations, because of improved communications between management, operators and machines and vice versa.

(e) Programs are readily available for correction and alteration, as they are held in magnetic stores with rapid access facilities.

(f) Greater versatility - updating of systems to meet new requirements are met mainly by changes in software rather than by redesign and rebuilding of hard-wired equipment.

(g) Increased reliability - hardware is reduced in quantity as well as being standardised and vigorously tested.

In general NC and CNC machines are essentially versatile general-purpose machines suitable for the manufacture of a variety of components in small batches. These techniques provide higher rates of production at a lower cost. Their increasing use is a reflection of the tendency for an increasing proportion of manufacturing to be in small batches, in order to meet growing consumer requirements for new products, variety of choice and improved performance. When these requirements are coupled with a need to produce more complex components to higher standards of accuracy and reliability, it is clear that NC and CNC are bound to grow in importance. However, for the full potential of such systems to be realised they should be combined within the context of an overall integrated manufacturing system, with particular emphasis on integration and management control. The direct benefits of NC/CNC compared to conventional methods can largely be attributed to direct cost savings at the machine, because of the reduction in floor-tofloor times. These time savings result from faster positioning due to continuous measurement and feedback, automatic tool changing and the use of optimum speeds and feeds, coupled with better machine utilisation and a reduction in the number of separate operations and set-ups.

The indirect benefits that may accrue include:-

(i) Improved management control; because of the need for detailed information and careful work scheduling to obtain the maximum utilisation from the equipment.

(ii) The work of production planning and control departments is greatly simplified. As components are frequently manufactured on a single machine, this eliminates the need for transfers between machines and consequent organisation of such moves.

(iii) Alteration of product design - as the firm has the ability to produce complex shapes with a minimum of jigs, fixtures and tooling.

(iv) Lead times reduced due to integration of several conventional operations on separate machines into one combined operation on an N.C. machine.

(v) Quality control and inspection simplified since the part accuracy is now a function of the machine accuracy.

(vi) Reduced factory area needed - because of reduced stocks and work-in-progress, coupled with the greatly improved output of an NC/CNC machine compared to conventional methods.

Moreover, machine availability should be of the order of 90-95% of time available compared to 20-30% for conventional machines on small quantity production runs because jig and fixtures are drastically simplified, and the NC set up should take less time. NC/CNC machines can therefore greatly reduce non-productive time required at the machine for setting up, organisation of the work and measuring. The actual batch size suitable for production by NC/CNC machines depends upon a number of factors, with component complexity of particular importance. A general guide is that the batch size be of the order of 10-150. For greater size of production, possibly automatic machines would provide an economic advantage. It is thought that NC/CNC machines may be particularly suitable for smaller firms, especially as simpler low-cost machines become available. To some extent, the shortage of skilled labour, especially machinists may have been a factor encouraging some firms to substitute capital for labour, because labour costs are still increasing at a rate that continues to balance out even higher investments in capital equipment.

Chapter 5 The Diffusion of NC

The diffusion process of NC machines is reviewed, various studies ofthe factors involved in their diffusion across Europe and the USA are discussed. A framework for assessing the relevance of NC machines to particular factories is discussed, and a study of the diffusion of NC machines in Britain which the author helped to devise is presented.

Chapter 5

The Diffusion of NC Machines

5.1 Diffusion of NC in America

In the early 1970's the American Government became worried that other industrialised nations had rates of improved industrial productivity consistently higher than those of the United States, and that the technology involved in small batch manufacture was undergoing profound changes because of the introduction of NC. Foreign countries were seen to be surpassing the US in using this technology to improve their industrial productivity. Consequently a Report to Congress was commissioned by the General Accounting Office in 1974 to examine the problem. The report was presented in 1976* and the following quotations confirm that NC was concentrated in a few high technology firms and that other countries were achieving a wider diffusion of NC:-

"In the area of advanced manufacturing technology the United States is generally using more than other countries, but it is highly concentrated in aerospace, electronics, and other firm producing defence related products". "It seems that foreign competitors have an advantage of being able to exploit, develop and diffuse manufacturing technology faster than the United States".

"Normally the U.S. Government would not be interested in this issue unless:-

- Private industry was neglecting or generally unaware of the issue;
- actions being taken by private industry were not in the best interests of our economy; or
- private industry was not advancing fast enough to sustain our socieconomic way of life."

"Although there are no outright indications of neglect, a broad cross

* Ref. 15

section of U.S. manufacturers do not know how advanced manufacturing technology affects them."

Consequently the General Accounting Office became interested in the evaluation of manufacturing technology and its impact upon productivity.

The approach to the diffusion of New Technology is different in the U.S.A. to that of its major competitors, the process is left primarily to the market place except where the national interest or other special considerations are involved. Other Governments have well developed national systems to diffuse their own and foreign technologies.

European productivity centres were a direct result of the U.S. aid to Europe after the war. The most important step leading to this was European Productivity Program initiated by the Congressional Mandate contained in Section 115 (K) of the Economic Cooperation Act of 1948. This program initiated the establishment of national productivity centres in 11 countries funded by the U.S. Government, private industry and the participating national Governments. The aims of these centres were to provide:-

- A general Information Program
- A Technical Information Program
- Advisory and information programs for particular industries
- Managerial exchanges
- Finance for research into particular productivity problems
- Extensive training facilities for management and labour
- Regional productivity centres to supplement the national centres
- Pilot plants to demonstrate productivity increases
- Rationalisation program for small and medium sized firms.

These centres were continued with a combination of public and private money after the withdrawl of U.S. aid.

A similar productivity centre was established in Japan with a contribution of $6 million between 1955-1962 with very similar objectives to the European centre. This has expanded into a network of 14 centres in different countries in Asia.

Japan particularly has a highly developed procedure for identifying industrial research objectives and then for pursuing them by long timescale projects. The Ministry of International Trade and Industry (M.I.T.I.) developed a policy plan to guide industry with various incentives. Under M.I.T.I. national guidance was provided to develop or acquire technologiesand industries most relevant to furthering Japan's economic progress. Areas such as chemicals, petroleum and machinery were selected as priorities, and resources marshalled to select the best technology from other countries. Encouraged by MITI business adopted the technologies, increased productivity, introduced new products, and developed export markets.

For example MITI developed a national plan to implement a totally automated batch production plant by the mid 1980's. The plan is known as 'Methodology for Unmanned Manufacture' and Government support amounts to $116 million, plus a large amount of funding from the participating companies.

This can be contrasted to a seven year project undertaken by one of the major U.S. machine tool manufacturers. Whilst they are a prominent machine tool company they are still a relatively small company, and they ran out of money after spending £5 million on a demonstration project that would have been a quantum jump forward in technology.

The United States also has no structure in the public or private sectors to help the diffusion of new techniques. The government has supported the development of technology for defence, aerospace, and energy, but not for general manufacturing industry.

The report concluded that America should set up its own National Productivity Center to monitor foreign developments and stimulate a national technology diffusion mechanisms for manufacturing industry.

The General Accounting Office report in 1976 was based upon a study which examined a sample of 178 companies spread across the 13 leading manufacturing states to ascertain the barrier to the diffusion of manufacturing technology. 17% of the companies had at least one N.C. machine installed, but this represented only .3% of the machines in use at the companies, and the major barrier to further adoption of N.C. was the high cost of the equipment. Not surprisingly the most popular proposal to enhance the spread of N.C. was the idea of additional tax incentive to encourage capital investment. This was the top preference for 59% of the companies surveyed. The second most frequent factor was the lack of knowledge of the capabilities of N.C. machines.

5.2 Use of NC by Small Companies in USA

Following on from the recommendations of the General Accounting Office report to Congress a contract was awarded to the IIT Research Institute in Chicago to examine the reasons why small companies were not using N.C., and to make recommendations as to how the barrier to its adoption could be overcome.

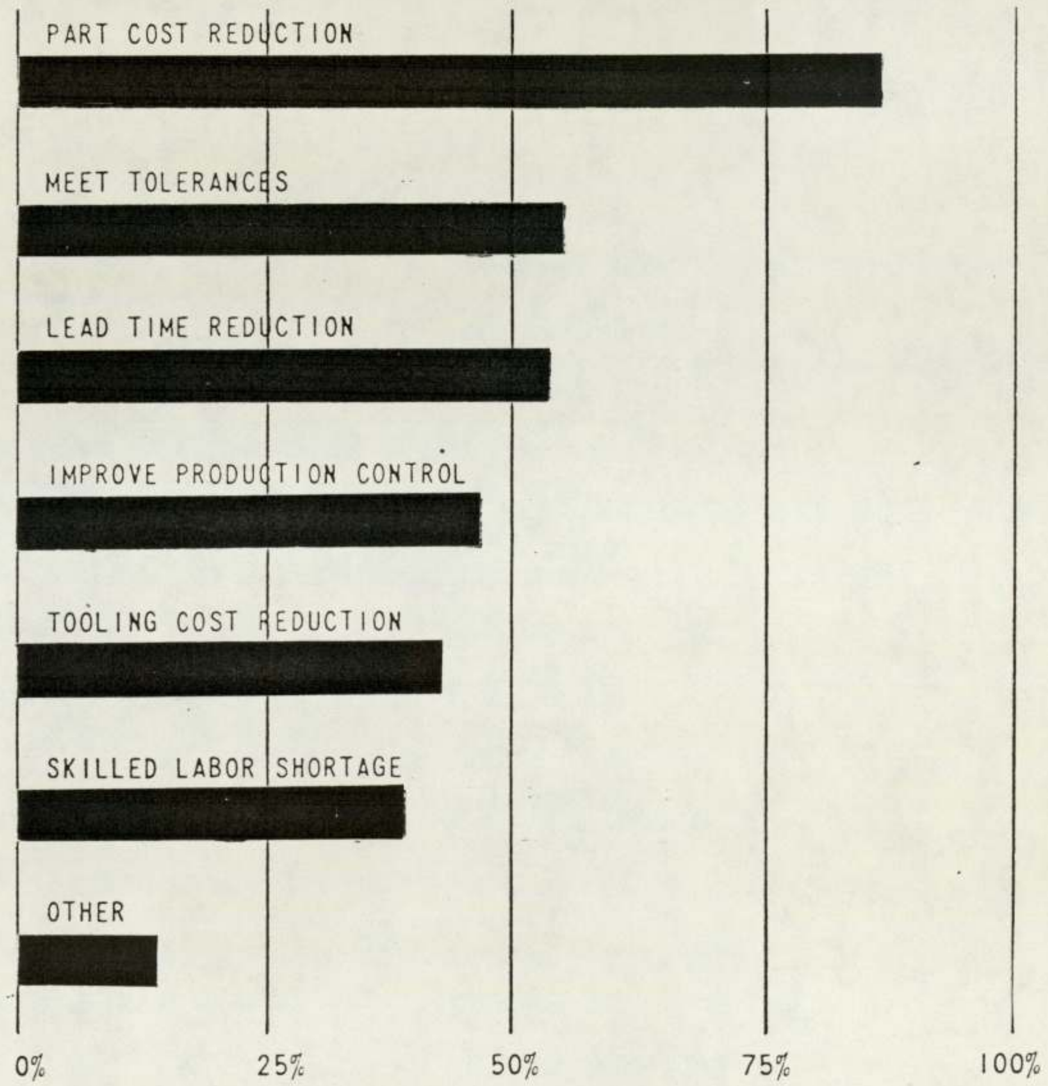
This contract resulted in a survey* of small companies across America with a questionnaire consisting of 46 questions which ascertained the type of plant, the complexity of the processes at the plant, and the reasons for using (or not using) N.C.

The questionnaire was aimed at companies with less than 200 employees, and was mailed across the 13 key manufacturing states (which account for

* Ref 16

Figure 10: Reasons for purchasing NC machines *

(n/c users only)



*Ref 16

73% of U.S. manufacturing establishments) in September 1978.

A summary of the responses given by N.C. users is shown in Fig. 10. Analysis of the replies showed differences in the company profiles of the users and non-users. The N.C. user more frequently:-

- had a greater number of employees
- designed and manufactured their own product
- was a division of larger corporations
- had more machine tools
- made more use of computers for manufacturing
- had more employees (users 100/200 people, non-users 50-100 people)

An analysis was made of the characteristics which described N.C. users and non-users of N.C. the main factors found in the users were:-

- a large proportion of the parts could be grouped in families
- speeds and feeds changed often within a set up
- many parts had contours defined by mathematical equations
- the lot sizes were small to medium
- part contours were defined by shapes other than lines or circles
- parts were geometrically complex
- set up times were large
- parts had tight tolerances
- part designs changed fequently

Not all of these characteristics would be expected to be present in a given company, but the results are summarised below:-

Table I: A Comparison of the Manufacturing Environment for Selected Key Items: NC users versus Non-NC Users *

	N.C. users	Non N.C. users
More than 25% of parts can be grouped in families	49%	44%
More than 25% of parts require 3 or more speed of feed changes in a single set up	48%	16%
Parts with contours defined by mathematical equations	45%	24%
Typical lot size is less than 50 pieces	44%	40%
More than 25% of parts contain contours that are not lines or circles	36%	29%
More than 25% of parts contain compound angles	30%	21%
Average set up exceeds 3 hrs	27%	13%
More than 25% of parts have tolerances of less than 0.01	24%	19%
Typical part design is changed more than 5 times per year	9%	8%

The differences between the N.C. users and the non N.C. users can be more effectively demonstrated if the numbers of these key characteristics for N.C. users versus non N.C. users are compared. The average N.C. user's environment incorporated 3 of the characteristics in his plant.

*Ref. 16

Table 2: A Comparison of NC Users and Non-NC Users Based on the Presence of Key Manufacturing Characteristics •

Number of key characteristics present in the plant	N.C. users	Non N.C. users
9	0	0
8 or more	0	0
7 or more	2.1	1.1
6 or more	6.2	1.9
5 or more	20.5	7.4
4 or more	36.9	16.4
* 3 or more	60.2	33.3 *
2 or more	84.2	61.5
1 or more	96.6	89.6
None	3.4	10.4

* greatest difference between users/non users

The conclusion of this report was that there were major differences in the links between government, industry and academics when the U.S.A. was compared to other governments, and that the links needed reinforcing in America.

The suggestion was made that an N.C. centre should be established and operated by an impartial group to be used to enable small companies to become familiar with N.C. technology.

The functions of the centre would be:-

- Demonstrating the capability of N.C. hardware and software - and allowing small users to get "hand-on" experience.
- Training people in managing, operating and programming N.C.
- Disseminating information by use of a technical library and an awareness of information resources.

• Ref 16

The need for this productivity centre was underlined by the General Accounting Office report,* from which it was deduced that there were approximately 22,700 plants in America with less than 200 employees who had not then adopted N.C. techniques.

The results of this survey showed that 33% of the non N.C. users possessed 3 or more of these key characteristics and were thus plants which should seriously examine the use of N.C. That is a total of 7,500 factories.

*Ref 15

5.3 NC Use in Britain

The background to this section is a study of the diffusion of various production engineering innovations across Britain*, to examine the factors which encourage or inhibit the spread of new technology in industry. The author was preparing a study of the use of N.C. in local industry, when he was approached to assist the Centre for Urban and Regional Development Studies at Newcastle University. Their proposed study had wider objectives, looking at various innovations which could be used to measure the technical advance of industry in different areas of the country. The use of numerical control machinery was seen to be one of the key factors when drawing up a list of recognisable recent innovations. Other innovative processes were laser cutting, Electron beam machining, Electrochemical machining, Electrodischarge machining, and adhesives for engineering fastening. The use of computers for commercial use, design, and for N.C. programming was seen as another measure of the degree of progress of a company, and the use of microprocessors by companies was also included in the study.

The authors' planned survey of local use of N.C. thus expanded into a national survey of the penetration of N.C. across the country. The results of this survey are examined, then used as a basis for more in-depth studies of local industry over an extended time scale.

The survey was restricted to those industries likely to be using these techniques i.e..

	MLH
Agricultural Machinery	331
Metal working Machine Tools	332
Pumps, valves and compressors	333
Contractors Plant and Equipment	336
Mechanical Handling Equipment	337
General Mechanical Engineering	339
Industrial Plant and Machinery	341
Electrical Machinery	361
Engineers Small Tools and Gauges	390

* Ref 11

These sections covered 11.7% of Britains manufacturing employment and 11.8% of output in 1979.

A search of addresses of these establishments revealed a total of 4983 manufacturing establishments within these headings and each establishment was sent a postal questionnaire. A total of 1234 usable replies were received, which after adjustments for closures and errors etc was estimated to form 40% of the identified companies. A series of interviews was held with 10% of the responding companies to explore the questionnaires in more depth between October 1981 and January 1982.

The results were classified into the below areas of the country, in order to examine variations in the uptake of the innovations across the country.

Area	Region
1. South East	South East
2. Non Assisted Areas (outside South East)	East Anglia, South West East and West Midlands
3. Intermediate Areas	Yorkshire, Humberside, North West
4. Development Areas	Northern, Scotland, Wales.

A further sub-division of the results was to separate out plants which were wholly independent plants, and thus reliant on their own resources, as compared to plants which were part of a group of companies, which could be expected to have access to larger scale finance or access to a higher level of expertise.

Figure 11 shows the results of this analysis. Independent companies have a significantly lower level of adoption of C.N.C. machines - approximately half that of group companies.

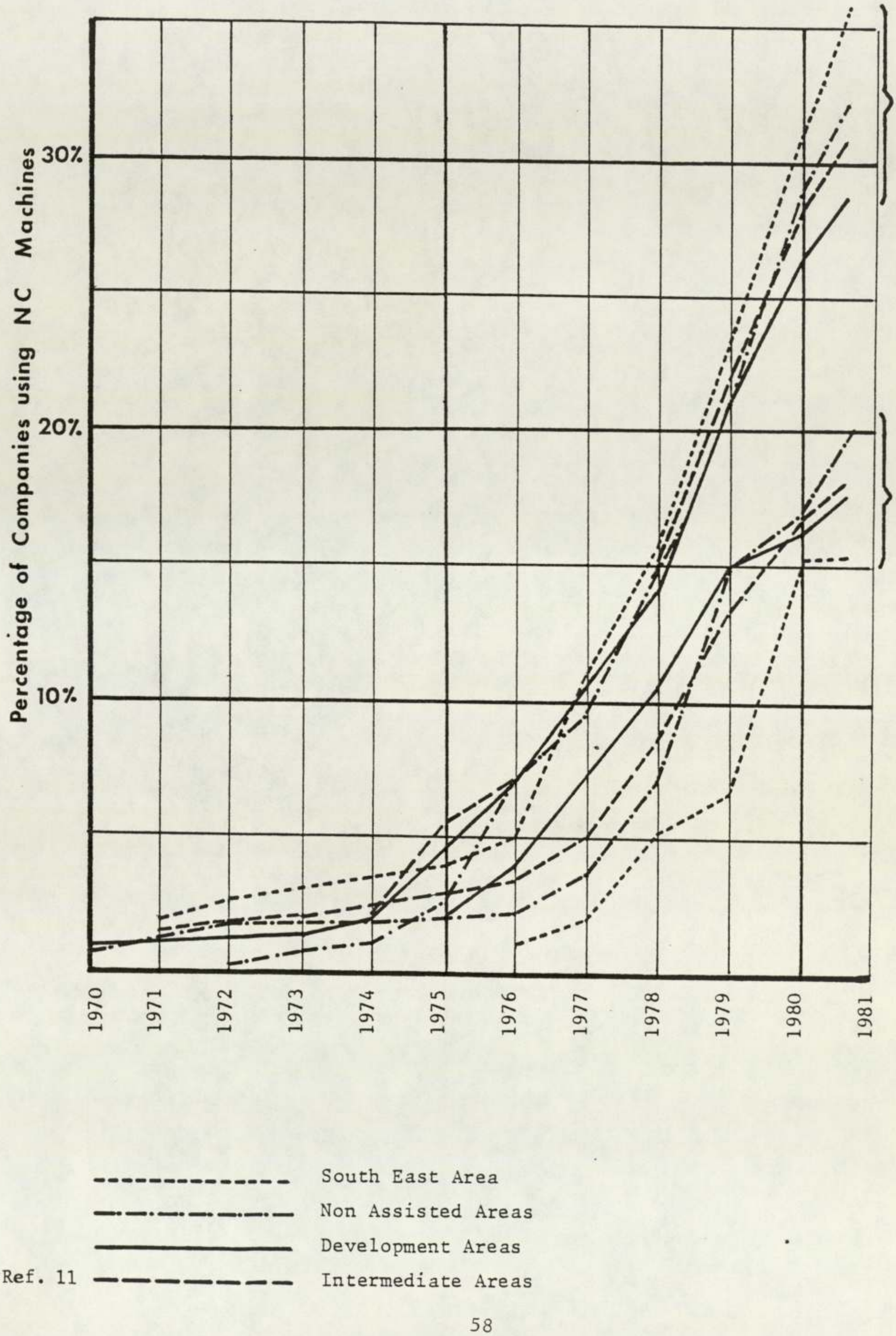
The use made of N.C. techniques was classified as below:-

C.N.C. Cutting 86%

C.N.C. Joining 2.5%

C.N.C. Forming 11.5%

Figure 11: Pattern of adoption of NC machines *



*Ref. 11

Table 3 below sets out the variations of the penetration of C.N.C. tec ues between regions of the country. Clearly there are marked var ons in the regional adoption of N.C. Significantly the North Wes cotland, Wales and the Northern Regions all have relatively poor rec , yet the last three are denoted as Development Regions, and get ge grants to encourage the introduction of new machinery.

Group Companies

Tab The Adoption of NC by Location *

Independent Companies

	% of responding firms adopting N.C.
1. h West	29.7%
2. Midlands	28.4%
3. hire and Humberside	28.1%
4. Midlands	25.9%
5. East	24.7%
6. Anglia	23.9%
7. West	22.8%
8. + tland	22.3%
9. + es	20.8%
10. + No thern	20.6%

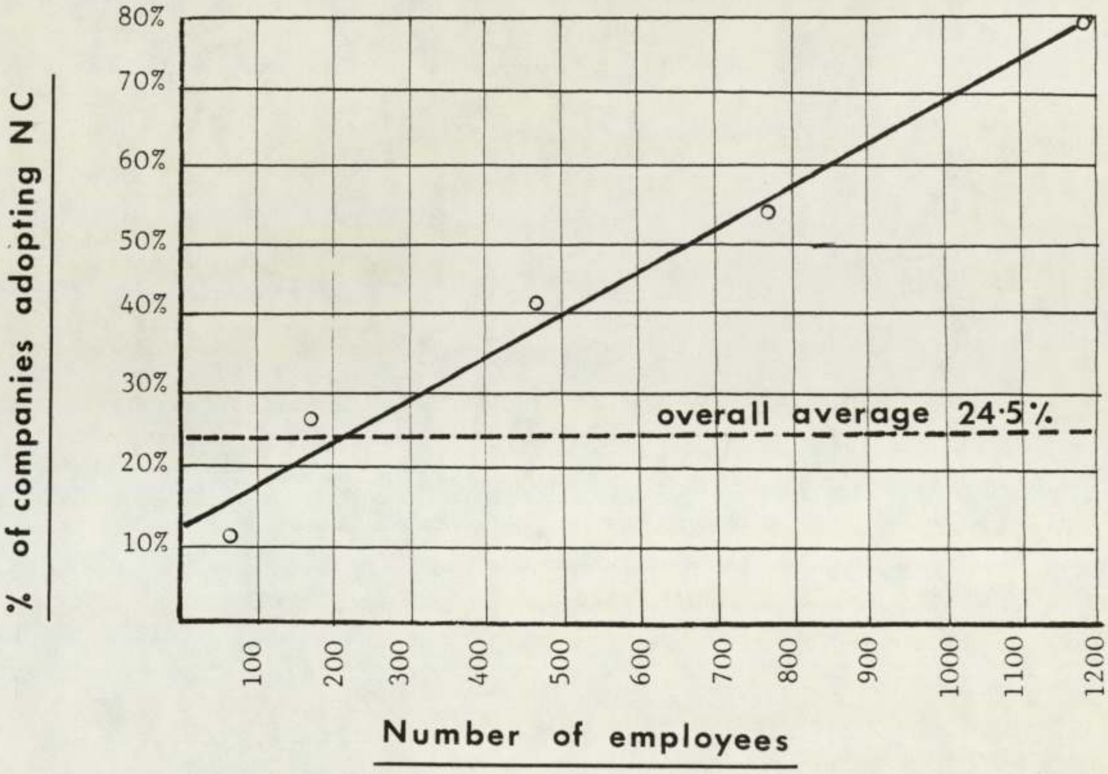
+ denotes Development Area.

The influence of plant size: It has long been accepted that larger plants adopt new techniques more rapidly than smaller plants, since they can more easily afford the risks involved in innovation and will be more able to select an appropriate work load for CNC techniques. This was confirmed by the survey and is clearly shown in Fig. 12, nearly 80% of large companies use C.N.C. but only 11% of companies with less than 100 employees use C.N.C.

There is a threshold to the size of the company which adopts the techniques, very few companies with less than 20 employees used C.N.C., companies with 30 people or more adopted C.N.C. much more readily.

*Ref 11

Figure 12: Adoption of NC by company size



* Ref. 11

Whilst large companies have obviously mostly adopted C.N.C., they are only a small proportion of the companies in the country, the chart below shows that most companies have less than 100 employees, and thus only 11% of the majority of companies have adopted C.N.C. technology so far.

Table 4: A Summary of Company Sizes in Britain *

No. of Employees	1-99	100-199	200-499	500-999	1000 and over
Per Cent of Establishments	55%	18%	14.1%	7.3%	4.9%

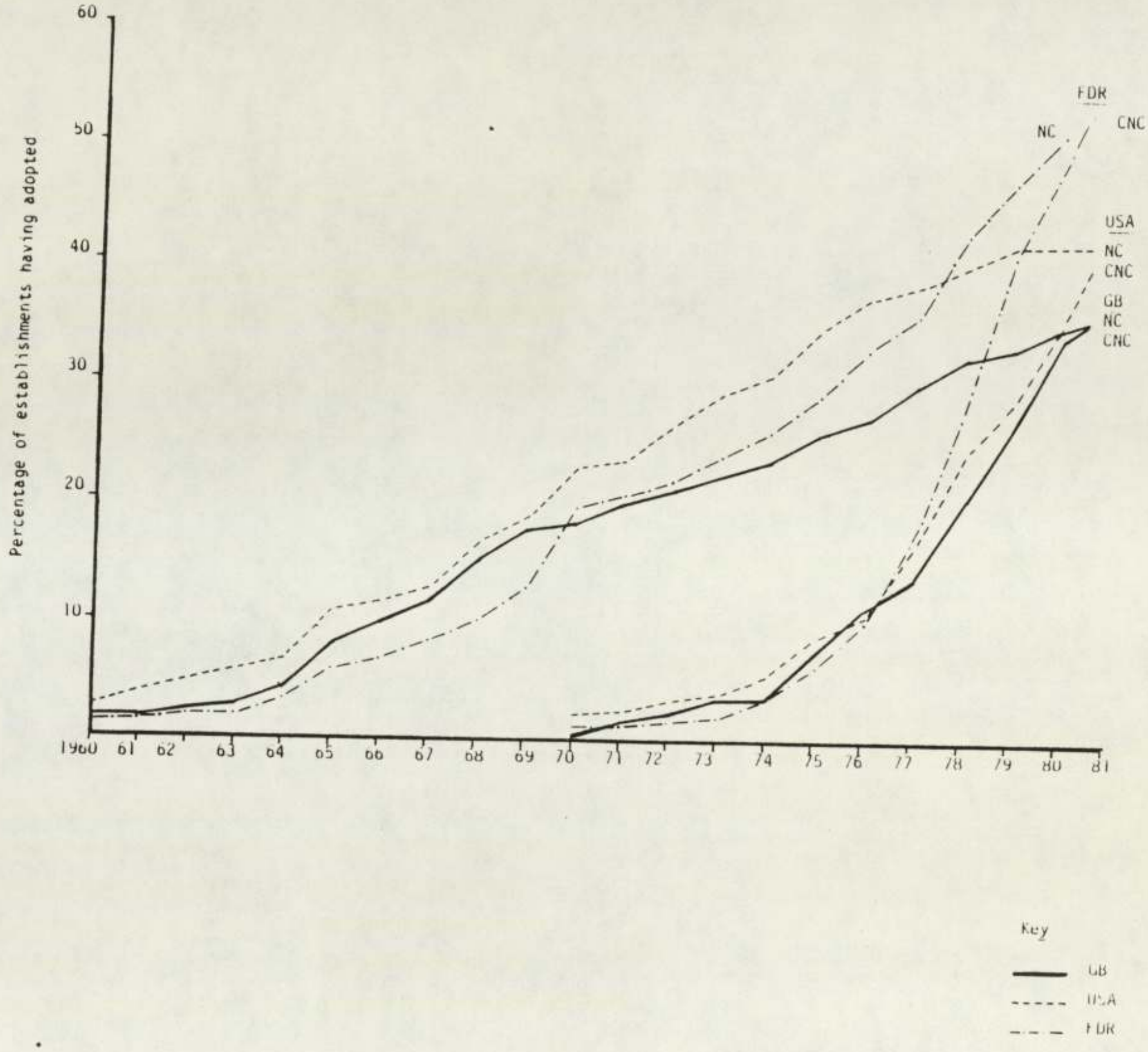
An international comparison of the adoption of N.C. and C.N.C.

Figure 13 shows contrasts between the adoption patterns for N.C. and C.N.C. machines for 3 sectors of industry which are directly comparable between Great Britain, West Germany, and the U.S.A.* (Agricultural Machinery, Metalworking Machine Tools and Construction Equipment).

In the case of N.C. the U.S.A. developed and maintained a lead in the adoption of this technique until 1977/8, when it was overtaken by Germany. Initially, Germany was slow in adopting N.C. and C.N.C., but by 1968 it had overtaken Britain in the adoption of N.C. machines, and a major acceleration in the adoption rate of C.N.C. and N.C. is apparent from 1976 onwards. By 1978 Germany was ahead of Britain and the U.S.A. A peculiarity of the German adoption of N.C. is that it continued to increase from 1977 alongside the acceleration of the uptake of C.N.C. Checks with consultants and manufacturers revealed that N.C. equipment was still in production in the late 70's in Germany. The adoption of C.N.C. in the U.S.A. and Britain appears to have reduced the uptake of N.C. as would be expected.

*Ref 11

Figure 13: The adoption of NC in Britain, Germany and the USA *



*Ref 14

Investment Appraisal

The adoption of C.N.C. means that the company invests a large sum of money into a new technique, so an examination of the investment decision making procedure between adoptors and non adoptors is relevant to the study*. Nearly 90% of adoptors used some formal evaluation method for investment projects based principally upon some form of payback periods (46%) or discounted Cash Flow (21.4%). In contrast 59% of the non adoptors claimed to use no formal or systematic evaluation methods, and relied upon ad hoc processes of assessment.

There was also a tendency for adoptors to require higher return on capital investment than non adoptors.

Independent plants relied principally upon internal finance and bank finance to fund investment, Group Companies relied almost equally on group funds and internally generated funds, with banks only playing a relatively minor role*.

West German industry by contrast with U.K. industry** employs a higher proportion of graduate engineers, who will be heavily involved in a detailed assessment of the proposals for new plant before it is submitted to higher management. U.S. industry exhibits a lack of financial data to base detailed cost justification upon.+

Government Aid

Over 90% of adoptors had used some form of Government aid, whilst 40% of non adoptors had used Government Aid. Aid was used to the greatest extent in the Northern Region and Scotland, where all C.N.C. adoptors had used this form of aid.

* Ref. 11 + Ref. 18

** Ref. 17

Labour Demand

50.8% of C.N.C. adoptors claimed that there had been a decrease in their work force since 1975, 39.7% said that the number of employers had remained the same, and only 7.5% showed any increase in unemployment.

Workforce Attitudes

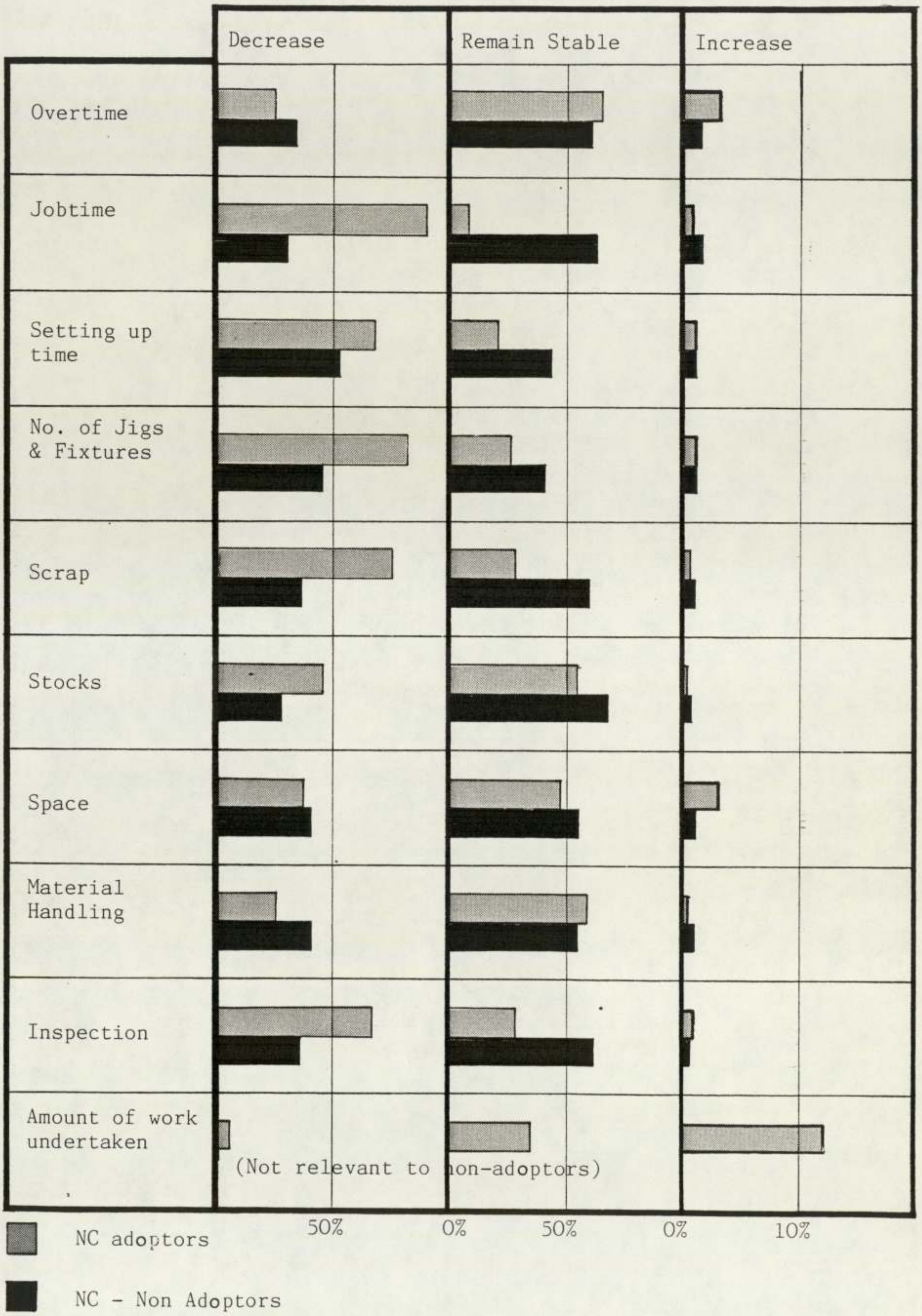
The view has frequently been expressed that shop floor attitudes inhibit the rapid adoption of new technology. This is not supported by the survey results, few adoptors reported any disputes (14.7%) over new technology, these disputes were confined to the large companies who form parts of a group. The majority of these disputes involved only minor industrial action, only four plants in the whole survey reported significant disputes due to this cause. Consultation with the workforce over their introduction of new technology was widespread, only 9.7% of adoptors claimed that they did not consult their workforce. 46% of non adoptors however claimed not to consult their workforce. The view expressed by one respondent "we do not consult our workforce, we tell them", was common amongst non adoptors. A different survey* of Northern Industry found that there had been important changes in trade union attitude to accommodate the introduction of new technology.

The ASP report* studied workforce attitudes to N.C. equipment in 1977 and concluded that they had not hindered N.C. adoption in either Britain or Germany, however Managers felt that N.C. had reduced job satisfaction among skilled workers substantially. The legal requirement for detailed workfroce consultation over the introduction of new technology in Germany contributed to its acceptance on the shop floor.

The same report also commented that the introduction in Britain had been alongside a declined market causing considerable redundancies, but in spite of this the new technology was acceptable, since it was not associated with the redundancies. Germany and U.S.A. had been in a period of growth and had no resistance to its introduction

*Ref 19 *Ref 4

Figure 14: A comparison of the effects of introducing NC on adoptors with the effects perceived by non-adopters *



* Ref 12

Unionisation

A large proportion of adoptors (85.5%)* had more than 50% of their work-force belonging to unions, compared to 31.7% of non adoptors. Union membership was especially high among large and group adoptors, conversely many large non adoptors claimed to have no union representatives on site.

Consequences of the introduction

Fig. 14 shows the extent to which C.N.C. adoptors have found the techniques beneficial through the reduction of various cost elements of the production process. Also most adoptors have found that C.N.C. has enabled them to take on more work. In general non adoptors have under estimated the extent to which adoption leads to a reduction in production costs. While it is true that C.N.C. is not always appropriate to the particular manufacturing operations in a plant, it is clear that the majority of non adoptors have a more pessimistic view of the potential effect of the technology, a view that is not supported by the experience of the adoptors.

It is interesting to compare the results of this British Study with the previous study of Putnam in America (see figure 12). The questions are not directly similar, but it is apparent that the strongest reason causing N.C. to be adopted in the American survey is the reduction in cost per part, and the British survey finds that job time is the highest factor, these are different descriptions of the same feature.

The second priority factor in the U.S. study is "meets tolerances", the British Study rates reduced inspection and reduced scrap as major factors. The third factor in the U.S. study is "lead time reduction", the British study has reduced stockholding and floor space as benefits of N.C. which would be related to lead time reduction.

Improved production control is only featured in the U.S. study, and thus no comparisons can be made.

*Ref. 11

Tooling cost reduction is significant in the U.S. study, and the British study has reduction in the number of Jigs and Fixtures as the second most important factor.

Overall it can be concluded that similar benefits are being experienced in both countries from the introduction of N.C. technology.

Employment Aspects*

A more detailed questionnaire to explore employment change was distributed to the 130 companies where interviews were conducted. This asked questions about the employment patterns of the plant over the last ten years, and only half (56) were returned subsequently, companies either regarded the information as confidential or were too busy to complete a further detailed questionnaire.

The results of this are thus of interest, but are based upon a small sample of companies. Overall 50% of companies reported an overall decrease in employment, whilst only 21% reported an increase in employment. Examining the figures in terms of adoptive versus non adoptive companies it was found that employment in adoptive companieshad increased in 55% of the cases, while 57% of non adoptive companies had decreasing employment during this time. Thus the adoption of new technology is not necessarily associated with employment decrease. A factor which could be underlying this changing employment pattern could be that innovative companies are surviving at the expense of non-innovators. Innovative companies increased their employment of operators, craftsmen and supervisors, as well as management and administrative workers. The non adoptors are the companies who are more likely to have displaced labour, particularly craftsmen.

*Ref. 11

Skill Shortage

The ASP report* found that German firms had some skill shortages in 1977, which they solved by upgrading semi skilled workers. British companies reported a higher level of skill shortages, but were less able to solve this by upgrading due to union pressures.

American companies at that time reported no skill shortages.**

German companies however made extensive use of graduates, who they found to be contributiong very soon after commencing employment, whereas the U.K. used very few graduates, and relied on promotion from the shop floor. The graduates they do employ usually need extensive training, hence they prefer to send apprentices on sandwich courses. British companies place more emphasis on in depth product and company knowledge, whereas German companies believed it essential to have new graduates in order to bring in new ideas.

*Ref. 19
**Ref. 18

Chapter 6, Organisation for NC

This chapter examines the skills needed to operate NC machines and the organisational structure which have been adopted by various companies to promote effective use of their NC machines.

The operation and programming of NC machines is explained in detail to provide a basis for the discussion of the analysis of the various skill levels chosen by different companies.

A report comparing the structures chosen by matched pairs of British and German Companies is reviewed, and the enhanced depth of shop floor skills adopted by German companies is revealed.

Chapter 6, Organisation for NC

6.1 Company Organisation

Overall trends in the evolution of the structure of industry as it adopts more complex levels of technology can be summarised as below*.

There is a trend towards increasing:

- Mechanisation at Work
- Capital Intensity
- Division of Labour
- Polarisation of skills and qualifications
- Centralisation reducing shop floor autonomy
- Bureaucratisation - greater use of documentation

The role of N.C. Technology in the factory organisation is here being examined to determine whether it continues these trends or whether it permits a different approach to company organisation. C.N.C. techniques, in particular, offer a wide choice of factory organisation. The individual machines can be linked to become part of a DNC system, where workshop control is centralised onto a shop computer. Alternatively the computer on each machine can allow delegation of programming to the shop floor and allow the operator to exercise his skills in a way that N.C. precluded. Which route is adopted appears to depend upon the philosophy of the company (or country). American factories appear to aim for total shop floor control, whereas countries with a tradition of worker participation (e.g. Norway**) devolve far more decision making to the operator.

A study of the impact of N.C. upon the organisation of the company needs, however, to examine wider aspects than where the programming is done. It is convenient to consider three aspects of the organisation as a framework for analysis, there are technological, organisation and human factors:-

* Ref. 17 **Ref. 20

Technological Factors denote the state of the art sophistication of the products and of the manufacturing processes.

In terms of N.C. the below points are relevant:

- Tooling Costs
- Jig and Fixture Costs
- Machinery Costs
- Programme proving
- Inspection techniques
- Maintenance features
- Product Design

Organisational Factors refer to the structure of the organisation, as well as the workflow sequencing.

The below points are relevant to N.C:

- The costing of NC
- Delivery lead times
- Component prices
- Systems integration
- Production control
- Machine monitoring
- Program preparation
- System reliability
- Batch Quantities
- Shop layout
- The size of the company

Human Factors refer to the recruitment, training and use of people in the company. In relation to N.C. the below factors should be considered:

- The level of skill required to operate the machines
- The separation of skills e.g. programmers, setters, operators
- The distribution of skills in the company
- The training requirements
- The number of people required
- The degree of control delegated to each individual

6.2 Company Objectives

In a recent paper Buchanan* has recently examined the impact of technological change on organisations in Central Scotland, who ranged from biscuit manufacturers to shipyards and concluded that:-

(i) It is not possible to predict the organisational consequences of technological change from a knowledge of the technologies features and capabilities.

(ii) The impact of technical change depends upon why and how it is introduced.

(iii) Management has a choice of the uses to which technology is put.

(iv) These management choices should be identified and evaluated in advance of change being introduced.

The examination also showed that various levels of management had different expectations of new technology but overall their reasons for using it fell into three broad categories:-

(A) STRATEGIC OBJECTIVES these are objectives which will have a major impact on the company and largely driven by external customer related forces, market changes, and economic pressures. They are designed to significantly improve the running of the company.

(B) CONTROL OBJECTIVES are inward looking objectives seeking to improve the control of the factory by:-

  (i) reducing human intervention

  (ii) reducing dependence on operator control

  (iii) increasing the amount of production performance information

  (iv) making this information available more quickly.

(C) OPERATING OBJECTIVES are internal technical and cost saving objectives aimed at removing bottlenecks, reducing part cycle times, or reducing energy consumption.

*Ref. 22

These investment objectives are relevant to the use of NC machines, they can be used in any of the three ways outlined above. The company strategy can be modified by investments which are designed to dramatically reduce the lead time to make a product and thus to reduce W.I.P. costs. Management control can be enhanced, jobs can be deskilled, and NC machines can monitor the operating time, and they can be used to make parts in less time.

It should be noted here that Buchanan found that computerised systems which de-humanised the work lead to a bored and discontented workforce who were not able to develop their skills and gain opportunities for promotion. Factories which used the technology to provide operators with better information and designed workplaces to provide operators with the opportunity to develop their skills were the ones that achieved significant productivity improvements.

Two case studies of the organisational impact of NC have recently been completed in the Sheffield area during the period of this study of NC use in the North East.* In both cases the pursuit of control objectives contributed to inefficient use of the machines.

Case Study One A small company had invested £600,000 in the years 1978-83 in CNC machinery with the overall aims of:

(i) increased competitiveness (strategic objective)

(ii) the introduction of more productive machinery (operational objective)

(iii) CNC chosen to give close control of shop floor labour (control objective).

The owner's philosophy was that CNC would enable him to wrest control of the machining operations from the shop floor. Programming was done by the owner and by the production engineer, the production engineer's other tasks included estimating and scheduling, and he was only able to spend one third of his time on programming. This meant that program

*Ref 22

proving and development had to be left to the machinists. Other factors also made the programmer's job more difficult. He was not an ex-machinist and had to seek advice from the machinists on complex jobs, the nine machines needed five different languages between them, he worked office hours and the machinists worked shifts and weekends. This led to his job being very pressured, and the current programmer was the fourth one in five years, obviously his depth of experience and knowledge of the machinery was weak.

These factors combined to make the company depend upon much greater operator involvement in program development than envisaged by the owner, the operator's skills were essential for the successful running of the machines.

The owner's response to this was to purchase a small computerised NC tape preparation system. This was intended to prove out the programs remotely from the machines, and the use of only one language on the computer would simplify the programmer's job - hopefully to the extent that the production engineer could delegate some programming to a less skilled person.

Six months later the computer was not living up to expectations. It was found to be compatible with only four of the nine machines, the remaining five having to be programmed manually. It proved difficult to operate, the programmer often used manual methods of programming on the machines with which the computer was compatible. On programs produced from the computer operator intervention had not been reduced, the operators still needed to refine the sequence of operations and the speeds and feeds. The computer was unable to use the machines' built in canned cycles and thus produced longer tapes than manual ones, which took more proving. The pressures on the operators also led to a high labour turnover - during this six month study six of the nine original machinists left.

The pursuit of control objectives was thus reducing the overall efficiency of the company.

Case Study Two A large tool manufacturer wished to react to competitive pressures and also to raise the quality of one of its products by the introduction of an NC miller. The first machine was thus introduced for strategic and operational reasons. A production engineer was placed in overall control of programming and setting, but the machine setter was the person with the time available for the task. The machine worked successfully with few problems, the setter programmed and monitored the machine, while an operator was employed as a loader/ unloader for the relatively large batches of work (approx. 1000 parts per batch).

Two problems developed, however, over the 18 months initial phase. The operator complained of boredom, and of the inability to earn the 20% bonus available for increased output by the shopfloor workers. The setter had now become the only person in the company who could write and prove out programs. No one else knew if it should take four hours or four days to write a program, and supervision felt unable to manage the situation. A further complication was that the shop steward was negotiating a rise for the operator and the setter (and the shop steward was the setter!). There was no dispute that these rises were justified, but all these factors combined to give supervisors a desire to regain control.

The first machine had been successful, it had performed according to plan and quality and output had improved and a second machine was purchased to remedy a similar quality problem on another product. The company planned to buy a second identical machine, until they realised that they would be expected to operate it in the same way as the first machine. They thus deliberately chose a more expensive machine and to use a setter/operator to run it, with editing and programming to be done by the production engineer. The method of implementation of this machine was thus totally decided by control objectives.

The actual running of this machine is now, however, less efficient than of the first machine. Supervision now do have control, but the editing and development tasks are now performed by the production engineer, at a higher pay rate than the setter, and he has many other responsibilities. This second machine is more difficult to deal with than the original machine and actually needs more editing - but the production engineer is often not immediately available, so the machine frequently waits until he can attend to it. A further complication is that the second machine is less reliable than the first one, and jobs have had to be transferred to the first one as a back-up measure - needing the setter to write second programs for these jobs!

Both of these cases illustrate that shop floor control objectives have conflicted with efficient use of the machines. In engineering, technology has been seen as predictable and stable, while people have been regarded as the unstable part of the organisation. Machines have often been introduced "to reduce human error". This has led to managers putting a great deal of emphasis on the removal of discretion and skill from the shop floor in order to make it easier to predict and control the output from groups of workers. CNC can be used in this way if management so desire.

6.3 What Are Skills?

One dictionary definition* defines skill as "practical knowledge in combination with ability", this can be better expressed as "knowledgeable practise". Knowledge implies experience plus mental skills, and practise may or may not include manual skills. An alternative way of defining skills is to consider "conceptual" and "motor" skills as components of the whole. The acquisition of motor skills on their own would not be considered sufficient to demonstrate that a person was skilled. A worker screwing parts together repetitively on an assembly line would be using motor skills, but if the task did not involve using judgement he would not be considered to be exercising skill. It is generally accepted that skill must have some mental involvement. A blacksmith hammering red hot iron on the anvil is continually making decisions about where and how hard to hit the metal, and whether or not it is at the correct temperature. His actions will never be the same on two occasions and his continual adjustment of his actions to the prevailing conditions is a good example of the use of high level conceptual and motor skills.

The presence of motor skills is, however, less necessary, most people would agreed that a doctor exercises a high level of conceptual skills and knowledge, but his use of manual skills is quite limited.

The skills exercised by a skilled machinist are similar to those used by the blacksmith. The machinist is planning out the sequence of operations, choosing the tools to be used, and deciding the sequence of and the depth of the cuts to be taken, taking into account the required accuracy, the power available, and the strength of the tool and workpiece. He thus uses conceptual skills to plan out his actions, and he uses motor skills to a considerable extent to apply each cut, to measure the part, and to coordinate the controls. His major task is to predict the reactions of the machine and workpiece to the current cut. The machine slides

*Ref 24

and the drive screws deflect under load and the workpiece deflects similarly. This means that a cut of .5mm apparently applied via the machine controls will not result in exactly .5 mm removed from the workpiece. A large part of the machinist's skill lies in knowing what will actually happen to the workpiece when a cut is applied, and in coordinating the machine operation to produce precision components.

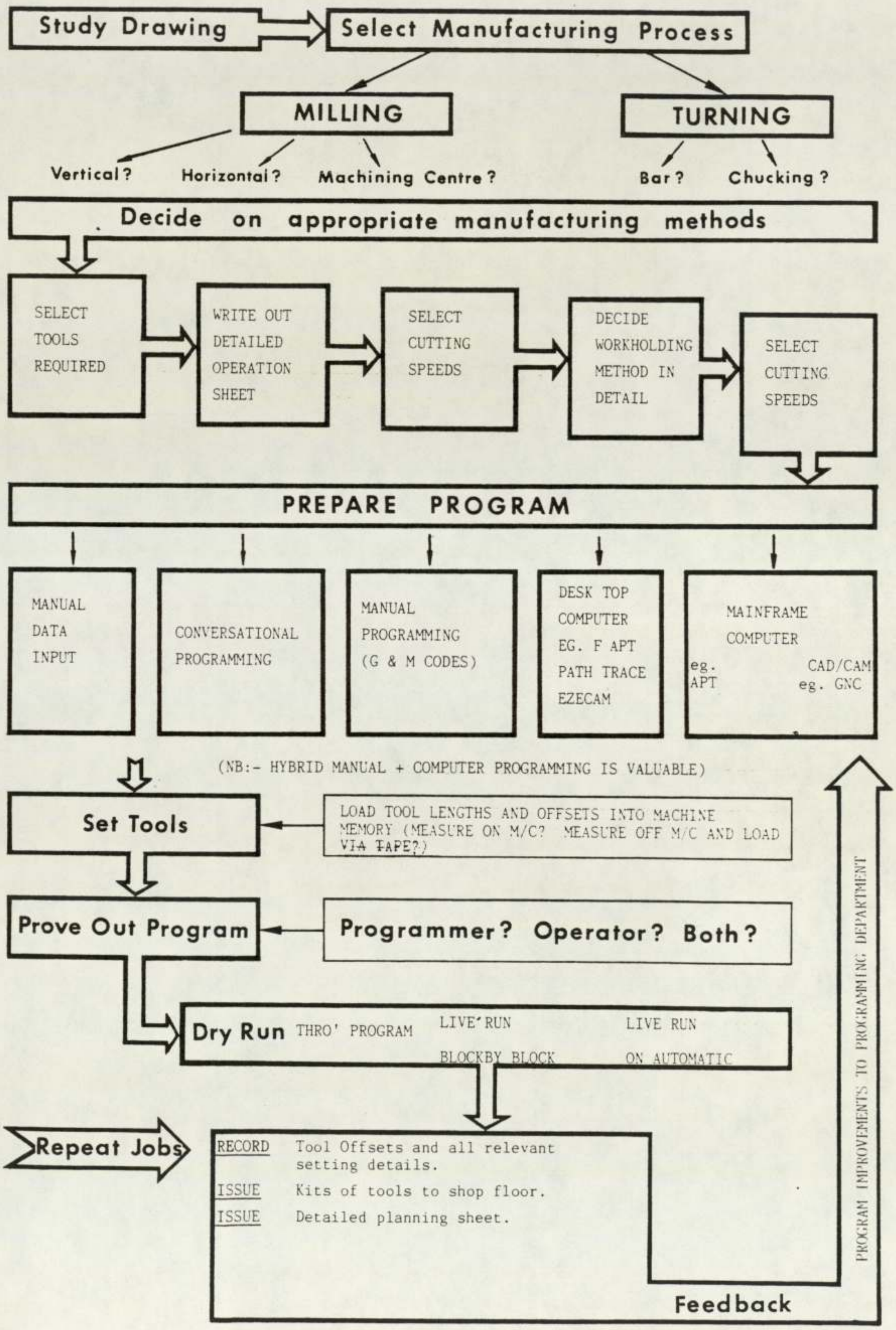
One aspect of skill has not yet been mentioned however, skill always contains some element which cannot be fully analysed and explained. A doctor in arriving at a diagnosis will use explicit rules which he has learnt or formulated, but he will also use other rules which he is not aware of knowing, and which he has never made explicit i.e. he knows more than he is aware of knowing. This has been referred to as "Tacit Knowledge"* and expressed as "we know more than we can tell".
Language is the way we learn to express our thoughts and to communicate with, but it is limited in its description of events. A machinist watching a job chatter will not express this in terms of nodes of vibration and resonance, terms with which the technical engineer will be familiar, but he will still observe the process and learn how to deal with it even though he is unable to use the "correct" technical jargon to describe what is happening. He will use his tacit knowledge of machining to guide his actions.

6.4 Operation of NC Machines

The full sequence of actions needed to organise a new job being introduced in the works will be explained in detail. This thesis examines the various organisational structures chosen by companies to run their numerical control machines in chapters seven and eight, and a detailed understanding of the necessary procedures is essential. Figure 15 summarises the sequence, and it will be described in terms of a "traditional" organisation i.e. the programming is being done by a

*Ref 25

Figure 15: Organisation for NC use



separate technical department, and the machine operation by shop floor personnel.

6.4 (I) The Programmer's Job

He will first have to study the drawings of the part to be machined and to select the appropriate machining processes. In general terms flat or cubic components are milled, and round components are turned, although there is growing competition between these two processes. The availability of orbital milling canned cycles means that short components can have round sections machined by milling. This can be particularly beneficial when a part would have to be turned and then milled since the two separate operations can be combined on a machining centre to produce a completed part at one set up with a consequent reduction in the lead time.

When he has decided upon the relevant process he has to choose the cutting tools to be used, preferably using those already available within the company. The use of each tool can now be specified on a detailed operation sheet, which should also show the relevant speeds and feeds for each tool. The workholding methods need to be fully defined before the program can be written to ensure that the cutter movements do not collide with the clamps.

During this process the programmer will be trying to achieve the high output rates now possible with modern cutting tools and he will be trying to run the machines to exploit their full theoretical capabilities. He has to keep in mind a clear mental image of the relative motions of the cutter as it moves around the workpiece in three dimensional space and at the same time to predict and avoid the use of undesirable cutting conditions. He has to judge when lack of workpiece or cutting tool rigidity will lead to vibration problems, and to try to use the full power available on the machine, but not overload the machine or the tool. When he is programming a lathe he must also ensure that he is using the "chipbreaking envelope" combination of speed, feed, and depth of cut so that the swarf forms chips or he will have the workpiece buried in a tangled mass of swarf, and possibly tool damage.

It can easily be seen that programming involves a high level of conceptual skills as well as knowledge and experience, but obviously no motor skills.

When the machining sequence has been determined as above the programmer has to translate this into the N.C. machine language.

Figure 15 shows six possible ways of producing an N.C. program, and the first two of these are designed specifically for shop floor use. It is relevant to explain all these methods at this stage:-

(i) Manaual Data Input There are several ranges of low cost N.C. machines which allow the operator to move the machine manually and to record the sequence of position required (Record/Playback - the original N.C. machine!). The machine will then repeat these moves, or the operator can insert simple commands, line by line, in the order requested by the controller.

(ii) Conversational Programming Recently several controls have been introduced with graphics facilities which show the workpiece contours on the screen and which ask the operator to respond to a "menu" of possible movements.

These greatly increase the power of shopfloor programming and have now been adopted as standard by the largest British manufacturer of NC milling machines, so customer reaction must be favourable. Some of these controls allow the operator to be programming the next job while the machine continues to produce the current job.

(iii) Manual Programming is used to describe programming in the original G and M codes. This can be done without any computer support, although it will involve a considerable amount of trigonometry since the cutter centre positions are often needed.

One major problem that the programmer inevitably faces at this stage is that virtually every machine uses its own unique coding system. The ISO codes are available but each manufacturer usually has some unique variation. The models of a particular machine produced during a given year may all use identical program formats, but the rate of development of controllers means that more features are being added all the time. Newer controllers will usually accept programs from their predecessors, but the reverse is not true.

This means that the programmer has to be familiar with many different languages and to remember which one to use at any time, this is obviously a very confusing and undesirable situation. It also means that interchangeability of jobs between similar machines can be severely limited unless duplicate programs are issued.

(iv) Micro Computer Programming Assistance There are now many "desk-top" computer packages which can reduce program preparation time. These are usually suitable to cope with straightforward workpieces (which are 90% of engineering parts) and have a range of post-processors available to translate the output data into the formats required for various machines. The benefit of these systems is that all calculations are done by the computer, so geometry errors should be eliminated and the computer will check the program to a large extent, usually giving some sort of graphical plot of the program.

Many of these systems are simplified versions of the original APT system, being able to cope with 2½ D work (i.e. any flat shape, but with only steps in thickness) compared with APT's capability to control 5 machine axes simultaneously.

(v) Main Frame Computer N.C. Programming APT is the original system for computer assisted NC programming. It was designed as a sophisticated means of guiding the cutter movements using normal "English" words so that it would be a "friendly" language. It has a dictionary of 400 words, and an APT word has at most six letters in it. These words are shortened versions of normal English words e.g. GORGT for Go Right and are thus relatively easy to remember. The first section of the program consists of the geometrical definitions needed to specify the component geometry, the second section will have cutting information - cutter size, feedrate, spindle speed etc., and some post-processor statements to call up machine canned cycles, and the third section contains the motion statements which guide the cutter around the part.

For many years APT has been run in batch mode on mainframe computers, the programmer would have to wait until the next day to find out his typing mistakes, but as computer power has developed the response time has been reduced. It is now possible to buy mini computer systems running APT interactively so that mistakes are checked as each line is entered.

The output from APT is a C.L. File - a cutter centre line path. This has to be run through a post-processor to suit each machine which strips out information which is redundant to that particular machine, and which translates the CL file format into the format required by the machine.

In recent years Computer Aided Design has become established in some larger companies. This means that the designer enters the information to specify the component shape into the computer as he designs it, so the geometry definition stage of APT can be by-passed if the design data can be passed over to a suitable N.C. programming system. This can simplify the N.C. programmers job considerably, he can use the files established by the designer and concentrate on the production engineering task of selecting appropriate tools, motions, and cutting conditions. He can also watch a 3D simulation of the program to see how many clamps he machines through!

The output from this still has to go through a post-processor to translate it into the correct format for the particular machine tool.

6.4 (2) The Operator's Job

We will start by considering the most complex case, an operator setting up a new job from a manually prepared program. In this case he has to detect any programming mistakes, as well as having to ensure that satisfactory cutting conditions are produced by the program. He will first read the tape into the machine memory, and then select the "test" mode, i.e. the controller can run through the program to check for spelling and format errors but the machine stays inactive. The degree of help available from the controller at this stage varies from a simple "fault present" message on basic controllers, to those where the cursor will stop at the offending line of the program and some related error message will be displayed.

When the program is acceptable to the machine, the operator can start to run the machine very cautiously under the control of the program. There is no need to have tools set in the machine at this stage. He just needs to check that none of the existing tools in the machine are likely to collide with the chuck or vice. The controller will be set to run "block by block" through the program (one line at a time). The main control used at this time is the feedrate override knob, which the operator will set to 0% until he has examined the next program instruction and checked the position of the tools to see whether that move is safe. If he is satisfied that it is safe he can move the feed override knob to say 20% to allow the machine to proceed slowly to the required position. He then examines the next line of the program and looks at the machine to see if that instruction is possible. Very often the movements are bringing rotating cutters close to the vice, or turning tools close to the chuck (or inside the jaws for hollow work). An error of a few millimetres in the program or the workpiece datum can easily mean that there is a collision.

At this stage the operator is not familiar with the required sequence of events, and is have to make continuous judgements about the safety of his next movement, and he is also conscious of expending valuable machine time. If he operates more than one machine he is also having to remember the position of the control buttons on this particular machine. This is particularly dangerous because we all use habitual movements and if our concentration flags slightly we automatically revert to the habitual action in that situation - and press the wrong button! N.C. controllers in general are extremely "unfriendly" and of widely varying panel layout, they thus take a lot of understanding and add to the stress of the situation.

The operator thus continues this sequence of events involving very close concentration for a long period of time until he gets through the program satisfactorily, or until he finds a mistake and then calls for a programmer to correct it, or corrects it himself.

The tools may be set before the program is proved, or they may be set afterwards. The operator must have a detailed list of tooling provided, showing which tools are to be used in each tool station. He then carefully and securely bolts the tools into the correct positions, and then has to enter the tool offsets into the machine memory.

These may be inserted by means of the program tape, or they may have to be inserted manually by the operator, in which case he has to move the machine using the manual control buttons to make the tools contact some datum position, at which point the slide position can be used to calculate the tool lengths or diameters. Once again any mistake at this stage can have disasterous results.

When the tools are all set the operator can now insert a part ready for a trial cutting operation, and he can run the job block by block using feed and speed overrides to make sure that the machine is not overloaded. At this stage he has proved that the program is safe from collision problems, but a rapid move in the wrong place, or too heavy a cut could rip the job out of the chuck and cause considerable damage so he is still under severe pressure. Once again a slight misjudgement could have dangerous and expensive consequences. When he has ensured that the program can go safely through the sequence of operation he can pay attention to tuning it up to satisfactory speeds and feeds, and finding out what vibration and surface finish problems arise. These often demand some modification of speeds and feeds and can, in extreme cases, cause some major program alterations - more rigid tool holders may be needed or the sequence of cuts may need drastic revision to reduce the magnitude of the forces exerted upon the workpiece.

When the part is being machined successfully the operator can now pay attention to machining it ot the exact sizes required by the drawing. The part needs to be measured carefully and errors need to be compensated for by corresponding alterations to the tool offsets.

At the end of all the above effort the machine should be running correctly and the operator will have to get it passed off by the inspector. The inspection department will pay particularly close attention to the first-off inspection of a new job from a new program, but subsequent inspections need to prove only that quality is being maintained. The first batch of parts will be watched carefully to ensure that the program provides adequate tool life, and hence reliable quality.

The operator should record carefully all the offsets used to produce the part, and all essential details of the set-up, so that the job can be quickly reset. It is obvious that the setting of a proven job will be much quicker, the uncertainty is absent, the tools and settings are known to work. Variations in workpiece material, or unnoticed damage to the tooling can cause some fine tuning to be necessary when each batch is set up, although the use of "qualified" (precision) tooling can greatly increase the speed of re-setting the job.

It can be clearly seen from the above that the operator is using a high level of conceptual skills, combined with close concentration and "delicate" motor skills - fine control of knobs rather than the coordination of muscle power in the example of the blacksmith.

The above description has been written around two tasks - programming and setting/operating. If long runs of work are being undertaken it is possible to subdivide the skills further and to employ operators who are merely machine loaders. N.C. machine operation is extremely repetitive and purely loading and unloading a machine many times an hour is a very boring job. The major problem the operator has to contend with are the problems caused by tool failures. N.C. machines are usually running at high speed and problems build up very quickly. The tool life of carbide tools is very unpredictable, they give little warning when they are about to fail, and they often fail catastrophically. The tool holders are expensive - e.g. a turning tool costs £40 and a boring bar or drill £70. Extremely quick responses are needed by the operator if a tool tip failure is to be prevented from becoming a tool shank failure as well. It is very unrealistic to expect an operator to stand by a machine and watch and listen for a possible tool failure at any time during a shift, and then to respond instantly. People cannot concentrate for such a length of time.

One extreme example of a solution to this problem is given below in an article from the American Machinist of July 1979*:-

"Four years ago, Roland Temme started his machine shop in Lincoln, Neb, with one $1100 lathe. This year, that shop, called TMCO, will do $250,000 in business, three-quarters of that on labour-only contracts.

"But perhaps even more important than the growth of the seven-employee shop is the way in which two young men, classified as mentally handicapped, have contributed to the company's success...

"Mike Bayless, 28 years old with a maximum intelligence level of a 12-year old, has become the company's NC-machining-centre operator because his limitations afford him the level of patience and persistence to carefully watch his machine and the work that it produces. Bayless was originally hired to do miscellaneous secondary operations, such as drilling and tapping ...

"Mike Bayless has been trained to know exactly what the Moog Hydra-Point machining centre does with each table of parts that he loads into it. 'His big plus, though,' says Temme, 'is that he will watch the machine go through each operation step by step, and he doesn't hesitate to hit the "Stop" button if it doesn't look right.' "That patience and watchfulness saved TMCO a bundle not too long ago, recalls Temme, because Bayless anticipated a problem before it could develop fully. 'If a so-called normal individual had been assigned to the machine, he would have been doing inspection work or deburring and would never have known what was happening until it was too late. Mike hit the button at the first hint of something wrong and saved us significant downtime and repair.'

"Mike's meticulous attention to the operation of the machining centre has also saved TMCO rework and reject costs. 'He loads every table the way he has been taught, watches the Moog operate, and then unloads. It's the kind of tedious work that some non-handicapped people might have difficulty coping with', Temme points out."

Chapter 4 pointed out however that NC machines are mostly being used to make small batches of parts, and thus it is common to employ a skilled operator who may spend an hour setting the machine. If only a small batch of parts is being produced it is not worthwhile organising a separate person to run the machine for another hour or so while the parts are made. The use of a skilled person to run the machine is beneficial at this stage because all jobs have teething troubles when a new batch is started, and the skilled person can be trouble-shooting the job as he runs the machine.

6.4 (3) Operators' Attitudes to CNC

Very few detailed studies of workforce attitudes to N.C. have been undertaken, but one recent survey* of the implementation of an FMS system in the USA analysed the attitudes of the 18 mechanics, tool setters, operators and loaders employed to run the system over two shifts. All jobs were found to be down on job responsibility (in comparison to other machinists) and down on task identification (the extent to which a job requires the completion of a whole task). Operations and loaders scored below the norm on skill variety, task significance, feedback and experience of "meaningfullness" of their jobs, and operators and toolsetters were below the norm for knowledge of the results of their actions. The mechanics had the most control over the results of their work and scored above the norm on seven out of the eight characteristics examined, the operators were below on all characteristics and the loaders below on all but one. Significantly sixteen out of the eighteen employees considered that they had skills they would like to use, but which they could not use.

This was in a large tractor manufacturing plant, where large company attitudes were enforcing task separation and use of de-skilling as far as possible. (The operators did some machine adjustments, but loaders purely loaded machines).

* Ref 27

6.5 Batch Quantities and Plant Size

These are independent variables, thus a major study of the use of N.C. in Britain and Germany* used the below company classification when examining the use of N.C.:-

		Plant Size	
		Small	Large
Batch size	Small		
	Large		

It was also considered that milling and turning could require different organisation features, so the same classification was adopted for both processes.

The study was conducted by carefully matching similar companies in these classifications in both countries, and examining their structure during a series of structured interviews.

6.5 (I) Small Batch - Small Plant

Organisations and demarcations were not so rigidly defined in the smaller companies, in one smaller German company two people did most of the programming, but often the operators were given contracts to write programmes at home. When the operator had written a programme he then set up the machine and proved the programme in the shop. Tape proving and machine setting were handled simultaneously by the operator. A programmer may be present if an entirely new program was being tried out, to offer assistance.

Although programming related functions were flexibly distributed among the planners and operators in all the plants, the German plants tried to build C.N.C. expertise into the production management hierarchy and wider organisation, whilst British plants located it in a specific

*Ref 17

segment of the workshop - possibly the group of operators, or the CNC Corner of the shop.

6.5 (2) Small Batch - Large Plant

Larger differences in company organisations existed when larger companies were examined, particularly for turning. The British company used a more traditional N.C. philosophy: programmes were written in the planning department, and proved on the machines with the programmer and the operator both present. Operators were supposed to 'advise' the programmer, but they set up and ran the machines by themselves. A second British company studied did not think that it was feasible for operators to produce their own programmes direct from drawings. The size of the company was probably relevant here - the overheads were so high that leaving a machine idle while a programme was written was not possible. This had influenced the programmer to believe that the operators were not capable of it. In the past operators had tried to improve programmes at this company, but the management response had been to "lock-off" the control systems. This demarcation had now been extended to the C.N.C. machines, and it exaggerated differences of opinion over suitable cutting speeds.

This demarcation was postively discouraged in the German companies where they deliberately tried to "make use of intelligence on the shop floor" to speed up jobs and reduce down time because of malfunction and bottlenecks, and to maintain quality. In one of the German companies the introduction of N.C. had caused a bottle neck in programming which had been solved by the extensive use of operators as programmers in the planning office, and by programmes being written at home by operators after working hours, and being paid overtime for this.

In the second German company operator familiarity with programming had been encouraged by deliberately rotating personnel between the office and the shop floor. About half of the operators on the shop floor had programming office experience, and about two thirds of the programming personnel in the office were graded as workers.

With milling both countries tended to separate programming from the shop floor, leaving a degree of control for the operators via variations in the feed rates set in the programmes.

The role of the foreman in C.N.C. operation was quite different in both countries. In Germany the foremen had adopted a new role as program trouble shooters. In Britain the foreman had been by-passed by programming, and the deskilling of the foreman's job was seen as a problem.

6.5 (3) Large Batch - Small Plant

Few differences were found between the countries in this area. Programming was clearly separated from operating, and operating became merely loading and unloading of the machine. Programming tended to be concentrated in the level of personnel above the operators, and to be closely linked to the machine setting expertise. Obviously competitive pressures mean that programmes will be more finely tuned for large batches of work, it is not worth tuning the programme so closely on a very short run job, and the price will reflect this.

6.5 (4) Large Batch - Large Plant

As would be anticipated the larger organisation will have a more bureaucratic organisation. One British company had a separate programming department, the machine setters then prepared the machines, and operators became mere loaders again. The same structure was present in the German company except in the turning shop where a supervisor with a forceful personality had managed to retain control of programming. It was still done off the machine, and setters commissioned each job.

Summary

In all the cases of comparison the British companies used C.N.C. in such a way as to maintain departmental and personnel functions separately from the shop floor, and to separate N.C. into a special programming department. In Germany C.N.C. organisation was so fashioned that it linked foreman, chargehands, workers and planners together into a team. This was particularly noticeable in regard to foremen, who were involved in C.N.C. expertise in Germany, but more by-passed in Britain.

These differences in the traditional organisation of each country are clearly demonstrated in the organisation charts from two of the companies studied (Fig. 16). It should be noted that the German companies were reluctant to write down organisation charts, since they could inhibit personal contacts if the organisation became too formal.

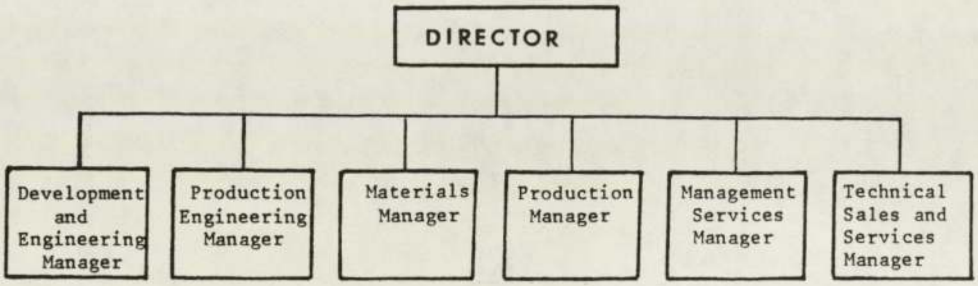
6.5 (5) Large Companies

One of the British companies started using semi-skilled operators for their N.C. machines, but found that this produced excessive down time and loss of quality, so they were moving towards having skilled operators.

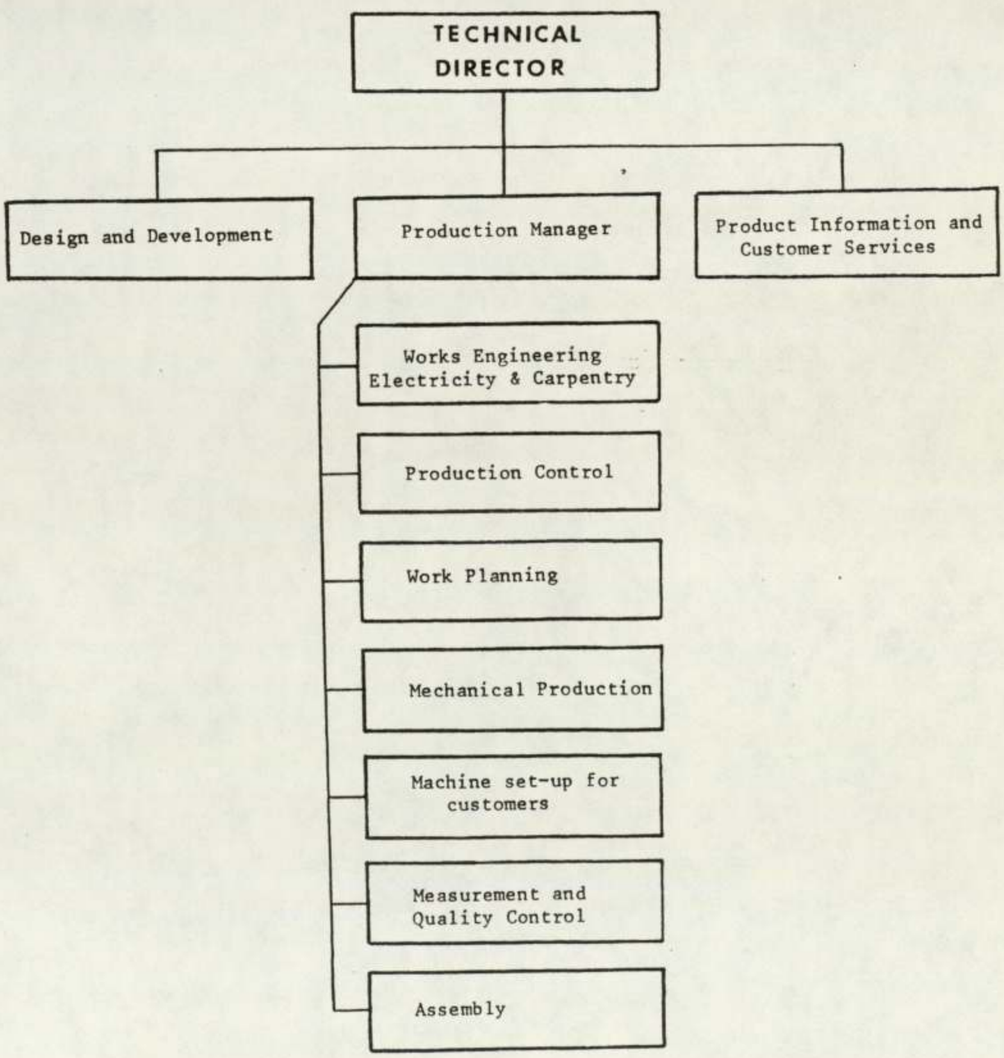
The German companies only put skilled workers on the machines, and thus are able to use shop floor programming more widely. British companies have tended to use the wage saving of semi-skilled operators as a justification for N.C. and are thus reluctant to change the precedent. British companies tended to feel that C.N.C. was de-skilling, while the German companies went out of their way to enhance the skills of the operator, and to enable him to contribute towards improved machine utilisation.

Figure 16: Company organisation for NC in Britain and Germany *

British Company



German Company



*Ref. 17

A major difference in the training between the two countries is the route into the planning office. In Britain craft apprentices are recruited separately from Technician apprentices, and are trained separately. In Germany all apprentices take an initial craft apprenticeship, and those who wish to become technicians must then undertake further training. The split between blue collar and white collar functions is not so rigidly maintained in Germany, where both types of workers can be working alongside each other in the planning office. This training difference has been mentioned earlier when considering the separation of programming into separate functional departments in Britain.

6.6 Training and Qualifications

6.6 (I) Small Companies in both countries tended to use practically experienced people and on site training to develop peoples skills, none of the people involved were graduates, although some had post apprenticeship part time training. The German companies placed far more emphasis on competent skilled people, and one of them had 5 pay grades to encourage people to learn N.C. skills., they were:-

1. able to operate according to instruction;
2. able to set machine with the aid of a setter for repeat runs;
3. able to set machine without help for repeat runs;
4. able to set machine for new jobs with help;
5. able to set machine for new jobs unaided.

This grading system reflected the manager's desire to develop the skills of all the operators. In Germany technical competence was more highly valued than status, in one company a supervisor had chosen to become an operator again because he got more job satisfaction. He was more highly qualified than the planner, and was the leading C.N.C. exponent in the company.

There is generally a lesser utilisation of formally qualified engineering personnel in Britain, particularly in small plants. Engineering qualifications of different types, from craft worker to technician or engineer, are to be found in all the German plants, but are sometimes entirely absent in Britain. Formal qualifications are thus less produced and achieved and are more limited to certain segments of the workforce and the economy in Britain.

6.6 (2) Large Companies

Qualification structures are more polarised in larger companies, Operators more frequently being semi-skilled, and craftsmen becoming setters. This trend is much stronger when larger batches of work are undertaken. Planners and programmers are expected to be either technician trained in Britian or Meister-craftsmen in Germany (craftsmen who have taken extended forms of study after their apprenticeship).

In both countries the perception of the skills needed for C.N.C. operation is that advanced machining skills are essential, and that the programming aids on the machine are seen to be tools for increasing the control of a process which has itself become more complex and demanding as the range of tools and power available has increased. Programming is seen as a necessary skill, but less taxing and satisfying than the actual planning of how to tackle the particular job.

These programming skills tend to belong to the production engineer or planner in Britain, whereas it is more often the craft worker who has these skills in Germany.

The above framework of N.C. skills suggested by the German company has been taken as a valuable method to assess the degree of skills used by particular companies, but local small companies are making considerable use of programmer/operators so a sixth grade of skill has been added to the list. The below grading of N.C. skills has been extensively used in the study of local industry discussed in Chapter 8:-

Table 5: A Classification of NC Operators' Skills

Grade 6	Programs sets and operates machine.
Grade 5	Sets machine unaided for new jobs and operates machine.
Grade 4	Sets machine for new jobs with help and operates machine.
Grade 3	Sets machine without help for existing jobs and operates machine
Grade 2	Sets machines with help for existing jobs and operates machine
Grade 1	Operates machine according to instructions.

A second survey* of the economic and social effects of the use of N.C. and F.M.S. in Germany derived a similar analysis of the tasks undertaken by N.C. operators, but divided the skills used into only four grades. This survey was undertaken in 1981 and, in line with the previously discussed survey, found the delegation of programming skills to the shopfloor to be present, although CNC was a relatively recent innovation at that time. This is further confirmation of German companies willingness to utilise shopfloor skills to a greater extent than in Britain. At that time 78% of operators were working on programs provided by a programming department, and 22% of operators were using programs prepared in the workshop. 14% prepared their own programs.

*Ref 21

6.7 Product Innovation

A frequent comment made by N.C. users was that companies* were keen to cater for smaller market sections in place of uniform mass markets. There was a trend towards increasing variations in the models of the product available to the customer, and market expansion was thought to be feasible only by this route.

In product and part design there was a tendency for increasing part complexity, and there was a noticeable increase in geometrically complex cuts. Thus enhanced capability was becoming a significant feature in the justification of N.C.

The trend to increasing variability of the product was exploiting the ease of changing a machine from one job to another, and was a symptom of reducing batch sizes. The speed of changeover meant that the large changeover cost of a conventional machine, which then caused the need to run the machine for several days to get a high utilisation, was a thing of the past. The need for fast changeover was however reinforced by the accelerated output rate of the machine! For example, if the machine could be reset in an hour, but then only took 2 hours to produce the batch, then the machine's productive utilisation was only 66%. This put increasing pressure on the designer to adopt a standard range of tools which, hopefully, always remained set on the machine, thus reducing the changeover to merely programme substitution, plus some fine tuning.

This increased variation in the product range encouraged the use of skilled operators, since the length of the run was being reduced, thus the opportunity to use semi-skilled operators was reduced.

*Ref. 17

Chapter 7, The Local Survey of NC Use (1982 - 85)

The results of an extended timescale survey of the use made of N.C. machines by a group of small to medium sized local companies are presented. The skill levels chosen are reviewed and high level shop floor skills are linked to expanding companies, whereas companies which used N.C. to de-skill the shop floor are shown to be vulnerable to major problems.

Chapter 7, The Local Survey of NC Use (1982 - 85)

7.1 Establishment of the Survey

A group of local companies who used N.C. machines and who would collaborate with Newcastle Polytechnic in an extended timescale study of their use of N.C. techniques was organised early in 1982. This study was intended to be an in depth study of the response of companies to the introduction of N.C. The previously mentioned national study (Ref. 14) which the author had helped to construct was being done simultaneously, and would produce an overall "snapshot" of the diffusion of N.C. This national study was unable to examine the implications of the adoption of N.C.by a particular company, so it was decided to concentrate the time available onto an extended study of a small group of companies.

This group of companies was chosen by local knowledge of industry in the area, with a deliberate policy of avoiding larger companies. It was felt that the impact of N.C. upon larger companies would be less apparent due to the scale of the organisation. The consequent lack of detailed knowledge of the overall functioning of the company by any one individual would mean that the impact of N.C. upon the company would be much more difficult to discern. It was considered that the most meaningful results would be obtained by talking directly to the production engineer responsible for operating or programming the N.C. machines in each company. By definition this would be a key person whose time is valuable to the company, so the interviews were structured round short questionnaires at each visit, to build up into a cummulative profile of the company and to allow for repeated short interviews which would enable developing trends in each company to be monitored.

7.2 Profile of Local Companies

Six small companies with between seventeen and sixty employees, and one medium sized company with approximately four hundred employees agreed to participate in this study. Their sales ranged from one third to one and one half million pounds, with the medium sized company having sales of approx. ten million pounds.

The figures related to sales should be treated with caution because several of the smaller companies were engaged in sub-contract engineering upon free issue materials. Thus their sales could include a large proportion of added value, but no material costs.

7.2. (1) Company Structure

Four of the companies were independent privately owned companies, and two of these had small local subsidiaries. The three remaining companies were subsidiary plants of larger groups, two of them were part of groups with their headquarters in the North East, and the medium sized company was a subsidiary of a major national British group.

Five of the companies were principally sub contract engineering companies, often to a high degree of precision, with local and national customers who demanded the highest standards of quality. Customers names were not sought during this study out of respect for confidentiality between local companies, who were obviously in competition with each other. Two customers who commonly occurred and can reasonably be mentioned are the Ministry of Defence and the Mining Industry, both of whom set extremely high standards and can be considered as typical of the quality of work undertaken by the companies. The other two companies were ones who have their own finished product, and who use N.C. techniques as one part of their whole manufacturing process.

Early in 1982 the number of N.C. and C.N.C. machines in use at all these companies was as below:

Millers	13
Lathes	22
Machining Centres	9
N.C. Inspection Machines	2
Total	46

The larger company had 13 of these machines, leaving 33 machines spread between 6 small companies, giving an average of 5½ machines, in companies with, an average, a total staff of 30. It is worth noting that the five companies who were purely sub contractors had much "leaner" organisations, with very small numbers of office staff in comparison to the companies with their own products. The sub contractors had on average one office worker per five shop floor workers, whilst the two companies with their own products had a ratio of 1:1.

One of the companies used only N.C. machines, but in most of them there was a mixture of conventional and N.C. machinery. In most of the companies the N.C. machines tended to be used either for longer hours or for two shifts, so that they produce a larger proportion of the company's output. Typically the N.C. machines formed 20-40% of the machines in the company, the proportion of output by N.C. is summarised below:-

proportion of output from N.C. machines	Number of companies
10% or less	2
20% - 40%	3
80%	1
100%	1

7.2 (2) Programming for NC Machines

Five of the companies were preparing programmes in N.C. machine language in 1982, and two of the companies used computer assisted programme preparation. One of these used the computerised programming system to issue a range of tapes for different lathes for the same job, so that the shop floor supervision could choose freely which lathe was to be used in view of the current workload when the job was actually being machined. Most programmes have to be written specifically for a particular machine.

Interestingly the programmes for the machining centres were deliberately prepared manually because the operators on the shop floor area were more able to get involved in improving the program. This was particularly important for the nightshift, when the programming department was not available for program development.

Programmes were written by shop floor machinists in two of the companies, in three of the companies programmes were prepared by owner/supervisor or machine setter, in one company they were prepared by the works manager, and one company had a separate programming department of 5 people.

7.2 (3) Computer Use in the Companies

Two of the companies had no computer on the premises. Three of the companies used computers for accounts type purposes only. Two of the companies used computers for N.C. programme preparation, and one of these had recently had an extensive shop floor job-logging terminal system installed. Job process sheets were prepared by the computer, but it was felt that the scheduling system was now in need of updating. The existing system assumed that two operations could be performed on each batch in a week, no account was taken on the elapsed time of each operation. This leads to some jobs taking far longer than planned, since it could often take more than a week to get a job through one operation. It also lead to the opposite situation where short cycle time jobs were left lying around the shop floor unnecessarily.

7.3 Workpiece Selection for NC

Companies were asked how they selected work suitable for N.C. machines. None of the companies had a formal decision making procedure for this, they all used "rule of thumb" instinctive judgements. Workpiece complexity was felt to be the critical factor in four of the seven companies, the batch quantity was also a limiting criteria in 3 companies. Batches of less than five parts being done by manual methods in one case, in another case batches less than 200 parts would not be considered for N.C. The amount of metal to be removed was quoted in one case as a major factor, the benefits of the high powered N.C. machines giving bigger gains where more metal had to be removed. One company in particular was involved in machining very tough materials and N.C. was found to be the only way of applying modern tooling technology to successfully machine the components.

One company expressed a realistic view - "if the job is worth £1000 we'll do it on the N.C. machine". Without taking any regard of the complexity of the workpiece, any job that provided one week's work for a machine was worth tackling.

Related to the machining of difficult materials is the choice of the type of tooling used on the machines. All the companies used disposable carbide tooling, two of the companies used ceramic tooling for high speed metal removal, and one company used diamond tooling to produce ultra-high quality finishes on components.

None of the companies use N.C. for the purpose it was originally designed for, i.e. machining complex 3D shapes. All the companies were using it for "conventional" machining operations, but doing them more efficiently than on conventional machines. Several companies were machining complex castings, but the operations involved were machining flat faces, machining bores, drilling and tapping patterns of holes etc. Some of the turning work was using blended curves on the part profiles, which are much easier by N.C. techniques, but not impossible using conventional machinery.

Workpiece accuracy was definitely an advantage of the use of N.C., companies were asked about the proportion of work they did involving tolerances .001" or less. The results are summarised below:-

Work with .001" tolerance	-	90%	- one company
" " " "	-	50%	- two companies
" " " "	-	25-50%	- four companies
" " " "	-	25%	- one company

One company machining large castings to close tolerance found, however, that in spite of purchasing "precision" machining centres they were unable to hold the required tolerances. They now resorted to machining the castings to leave a small amount of metal on the relevant bores, and then performing a manually operated finishing operation on a machine with digital readout equipment.

Two of the companies were using N.C. coordinate measuring machines to provide a high quality inspection system, but the other five companies had not found any need to enhance their existing inspection technique. One of the companies with the coordinate measuring machine was surprised by the errors they found with its help. They realised that their quality was not as good as they thought, and were making strenuous efforts to work to a higher standard now that they could measure to that standard. They are a company who pride themselves on their reputation for high quality and they saw the efforts as an investment in their reputation.

One company stated however that a major inspection problem as far as they were concerned was the output rate of N.C. machines compared to conventional machines. Parts were produced at a much higher rate which meant that if the machine or tooling went wrong, incorrect parts would be produced at a much higher rate. This company tended to produce large volume batches of work, and have patrol inspectors who regularly visited the machines. They now required their inspector to pay particularly close attention tothe N.C. bar lathe.

Batch Quantities

A feature of most of the firms involved in the survey were the small batch sizes involved in most cases. Milling work tended to have the smallest batch quantities, then chucking lathe work, with bar fed lathe work being done in larger batch quantities.

Batch Quantities for N.C. work

10-20	two companies
20-50	two companies
50-100	one company
100-250	two companies

One company stated that they expected to get about four different jobs on an N.C. lathe in a day in batches of 10-20 parts. Their parts were typically shafts 2-6" diameter by 1-2 ft long.

Changeover times

Lathe changeover times varied from ½ to 4 hours, changeover times for millers were typically 1½ hours, and for machining centres 4 hours was a typical time.

Three of the seven companies used preset tooling as an aid to quick machine resetting, one of these companies employed two people specifically to preset tools for various machines.

Maintenance of N.C. machines

One of the companies being studied has access to extremely highly specialised skills within its parent group, so it has been excluded from this summary as it would totally distort the results from this survey.

The six smaller companies were asked about the problems with N.C. maintenance during the last twelve months. They all felt that maintenance was a problem, but the overall picture is that N.C. machinery is extremely reliable. It can however be very expensive when problems do occur, and the companies are often dependent on outside help. It is estimated that the companies lost a total of 30 days production during the twelve month period. This is less than 1 day per machine on average, but the costs of solving problems were high, charges of £25 per hour for the service engineer being normal, giving £200 per day, plus the cost of replacement parts.

One company had to replace a ballscrew driving a machine slideway at a cost of £2,500, and another company was charged £1,400 for a replacement circuit board.

Two companies had taken advantage of maintenance training courses offered by the manufacturers, all the companies were pleased with the maintenance instructions provided by the makers, and all companies followed the preventactive maintenance schedules laid down by the manufacturers.

7.4 The Relevance of NC to the Company's Work

All the companies were asked the series of questions proposed by Putnam* (previously detailed in this report as tables 1 and 2). It is extremely interesting that the result was scores of:-

* Ref (16)

2 out of 7 - one company

3 out of 7 - two companies

4 out of 7 - three companies

5 out of 7 - one company

Putnam suggested that the average N.C. user in America scored 3 out of 7 on the system. This confirms that his method of identifying companies who use N.C. does apply in practice.

This particular group of companies have been selected for the study as being N.C. users, and it is interesting to examine the results to each question.

Table 6: Characteristics of NC Adopters - Local Companies Responses

1. More than 25% of parts can be grouped in families	Only one company had more than 25% of parts where this applied. 50% of their turned parts can be considered as families of parts. Since 5 of the companies are purely subcontractors, they obviously get a random assortment of parts to manufacture.
2. More than 25% of parts require 3 or more speed or feed changes in a single set-up?	All companies agreed with this.
3. Parts have contours defined by mathematical equations?	No company agreed with this.
4. Typical lot size is less than 50 pieces?	Four out of seven companies agreed with this, turning work was the exception.
5. More than 25% of parts contain contours that are not lines or circles?	None of the parts made by the companies fitted into this category. This again confirms that N.C. is not being used for the complex shapes for which it was invented.
6. Average set up time exceeds 3 hours?	Four out of seven companies agreed with this.
7. More than 25% of parts have tolerances of less than .001"?	Six out of seven companies agreed with this.
8. Typical part design is changed more than 5 times/year?	No company agreed with this.

The conventional view of N.C. being applied to complex parts grouped by families is not borne out at all by this particular group of companies. It must be remembered that five of these companies are subcontractors, and thus have no opportunity to organise families of parts. It also appears that many designers have not yet started realising that complex shapes can be made if they so wish (or that complex shapes are only made in big firms - e.g. NEI Parsons making turbine blades, to quote a local example).

Job Costing

Six out of the seven companies identified N.C. as a separate cost centre from the general machine shop costs, most of the companies identified individual machines as specific cost centres with appropriate hourly rates.

Human Aspects

Two companies had redeployed people with the introduction of N.C., and one of these companies said that it had reduced the need to recruit additional staff by four people.

Four of the companies had not had to reduce staff, and one had increased staff due to additional work caused by the introduction of N.C.

Four of the companies had sent operators and programmers to manufacturers training courses, whilst the other companies had done their own in-house training. There had been no opposition to the introduction of N.C. at any of the companies, only one company stated that there had been some initial suspicion.

Three companies paid N.C. operators a flat hourly rate, and four companies used a bonus scheme which gave some incentive increase on a flat hourly rate. In all cases N.C. operators were on the same pay structure as the rest of the operators in the workshop.

The companies involved in the study employed a total of 50 operators at the start of the study, their ages were typically 30 years old, and they were typically skilled ex-machinists. The range of ages was from 20 to 40 years old, with one person aged 50, who had started using N.C. machines when they were introduced at his company 15 years ago.

7.5 Changes with Time

N.C. programming

During this period one company had an equiry for a complex 3D shaped part to be machined, and had been seeking external programming of the part. This company subsequently leased a desk top computer programme preparation system to speed up their programming, the complex shape facilities were not however purchased at this stage.

A second company also installed a similar system for programme preparation and had recently been developing their use of this facility. They had also installed a small desk top computer to act as a programme storage and editing facility for several of their machines. This computer was connected directly to the machines and could transmit and retrieve programmes from the machines.

This company also has had an enquiry for machining complex 3D shapes, and has sought a price locally for preparing programmes for these parts. To date the customer has not found the price acceptable.

This does show that there was starting to be some interest by designers in the manufacture of complex shapes.

A third company investigated the purchase of a computer assisted programming system, but rejected it at this stage of their development.

Skill Developments

One company engaged a local college to provide an N.C. programming on-site course for its operators during the study, with a view to enhancing the companies skills, and of diffusing still further the programming skills through the company.

During the period of the study two companies introduced large machining centres for the first time. The first company manufactured complex machined parts from castings, these parts took ten separate operations to fully machine them from raw castings. A major part of the justification of the machining centre was the reduction in lead time for complex parts such as these by machining them at one set up. The original method took a total of 452 minutes to machine the parts over a period of approximately ten weeks, this time was reduced by nearly 50% on the machining centre, using a total of 30 tools, and machining the castings from one face first, then reclamping them for opposite end machining during the same machining cycle. This reduced the lead time to the set up time for the machining centre i.e. 1 day, which would improve as they gained familiarity with the machine. They had also found it worthwhile to introduce X-ray testing of the castings prior to N.C. machining, to avoid wasting expensive machining centre time due to casting porosity.

The second company was very quickly (within two weeks) machining large batches of angular castings using a variety of tools. In this time they had solved problems of thermal distortion of castings, causing problems with tight tolerances on the castings.

These are two examples of companies very quickly assimilating new complex machines, into their organisation, in the first case they effectively had good experience only on N.C. lathes before installing the machining centre, whilst the second company had 9 N.C. machines prior to the purchase of the machining centre.

Company changes

Three companies had remained static during the period of the study, one company expanded by 50% by means of a takeover and merger. A second company had a 33% redundancy early on during the study due to a decline in the market for their product, but had widened its market share by taking over the product range of another company in the same field.

Two companies expanded dramatically during the period, roughly doubling their turnovers, this has been by the attraction of new work onto their expanding range of N.C. machinery. This should be contrasted to the contraction of the North East Engineering Industry described later - an overall reduction of 44% of the number of exmployees between 1980 and 1985.

There had been an overall increase of nine in the number of N.C. machines used by the companies during this period, with an overall cost of £940,000. This is an increase of 20% in the number of N.C. machines in use, which is a considerable increase in the present state of the British economy. A significant point to be mentioned here is that 6 of the nine machines, to a value of £760,000 had been installed at two of the smallest companies being studied, the other machines being distributed among the other small companies. This illustrates further the point made above that two of the companies had expanded dramatically during this period.

All companies, except one who was not eligible, have taken advantage of the SEFIS1 and SEFIS2 grants available over this period which provide a grant of 1/3rd of the cost of a new machine, in addition to regional aid. This has meant that 6 out of 7 of these companies had an opportunity to purchase C.N.C. machines with a 50% total discount. The seventh company is outside the regional aid boundary and has installed a good but second hand machining centre as part of its expansion.

Product range changes

As mentioned above two companies had expanded their product range by take-overs, and both of the companies with their own products had moved into subcontracting to avoid problems of declining markets.

Three of the five subcontracting companies had conversely attempted to widen the scope of their activities by introducing their own products, they felt that this would be more profitable than pure sub-contracting.

Workpiece Design

Five of the companies had little or no control over the design since they were sub-contractors making components for assembly by the customer. They thus very rarely had the opportunity to see the whole assembly and to contribute to redesign and simplification. The two companies with their own product were finding a need to feed back shop floor problems to the design office. One company had recently started regular meetings between the process planning department and design to suggest improvements. Their recent new product had been subjected to intensive value analysis, which had eliminated many separate components, and reduced the price considerably.

The other company was finding that the installation of a machining centre highlighted drawing office inconsistencies, leading to the need for 30 tools on the first job they put onto the machine. They were certain that there was room for improvement in this area, and were already getting some modifications done to reduce the number of tools. Each operation had been done previously on a separate machine, with no requirement for an overall examination of the tools needed to machine the whole part by the original processes. They now needed to evolve a policy to deal with this new situation.

7.6 Problems Arising During the Study

Two of the companies, however, hit major problems during this period. One company's product was associated with the mining industry, and the recent lack of orders in that industry had caused the group to close that site with most of the workforce being made redundant. The machines have been transferred to another plant in the group.

This company had been rapidly increasing its N.C. skills by the addition of complex N.C. turning work to its range, and the introduction of a large machining centre with complex multi-tool machinery. These machines have been transferred to the new site.

The second company hit problems of a less expected kind. The owner had serious health problems in mid-83, he was obviously a central character in the company, being their N.C. technical expert, and the salesman. This left the company facing serious problems, and a new works manager was recruited with a wide experience of complex machining, but without N.C. programming skills. The situation was then that the company was running in a stable manner with the sales being done by telephone by the owner. Unfortunately lightning can strike twice, and the foreman, who was the second main N.C. programmer, then had a car crash, and was out of action for a period of months.

This left the company critically weakened, and they sought outside programming help, but cash flow problems lead to the closure of the company in December 1983.

A company which had not adopted N.C. technology would have needed considerably more staff to produce the same volume of work, and would thus have had more supervision and a larger reservoir of skills. The loss of any one or two people would have been a smaller reduction in the manpower of the company, and would have had less impact on the organisation. The added complications was that these two key people had "captured" most of the technical skills of the company because of new technology, and now it could not manage without them. If traditional skills had still been in use they would have been evenly diffused throughout the company and it would have been far less vulnerable to the loss of any one person.

Another company had a different problem, but with similar implications. During 1982 they had introduced an N.C. lathe to do first operation work on parts currently being machined on centre lathes, this lathe took them six months to learn to use effectively and then replaced the group of centre lathes. It then broke down, but by then the company was geared up to a fast turnaround of turned parts, feeding onto their N.C. millers. The company found itself with 4 N.C. millers very short of work, and a lot of unhappy customers. The lathe took seven days to recommission, during which time the company experienced a major crisis. This was a crisis which had been unable to happen to them before the introduction of the lathe, the loss of one centre lathe out of four for a week would have been a nuisance, but not a nightmare! They have since installed a second N.C. lathe to reduce their dependence upon one machine. Once again the introduction of a new high speed machine had concentrated the flow of work into a potential bottleneck, and Murphy's law is infallible:- if things can go wrong - then they will! The rapid throughput of work by the lathe and the millers meant that the company could indeed offer much quicker deliveries, but that any problems turned into a crisis much more quickly than before. The overall reliability of N.C. machines in this survey was very high, but all the companies thought that N.C. maintenance was a problem. This is not surprising now that they can lose money at a much faster rate than ever before when things do go wrong!

The same company has since introduced two machining centres in very quick succession. They would have been even more vulnerable if they had only introduced one, so even though this was a massive investment for a small company, the only safe method of entry into that market was to purchase both machines. It is worth commenting that this company had adopted shop floor programming with all its operators doing N.C. programming, so they had considerably reduced the risk of depending upon key people, and they did not depend critically upon any one key machine.

Another one of the companies involved in the study experienced a decline in orders, and, in spite of launching a new product, was subject to a reduction in overall numbers of staff. The number of employees remaining in the machining division shrank to thirteen people, and unfortunately the N.C. programmer and an N.C. operator were two of the key people to leave. This left the company in the position where it was able to repeat existing N.C. jobs, on its lathes, but unable to produce new programs for any N.C. machine or even to set up the machining centre. A repeat order for the machining centre justified flying up a machinist from the manufacturers to the North East to re-commission the machining centre. The level of work remaining was inadequate to justify the recruitment of the necessary skills to re-enter the N.C. market.

Subsequently two N.C. machines have been sold off.

Of the seven companies in this study, four companies are very dependent upon key programming people. Two companies have operator/programmers, and the seventh company has several programmers in the programming department. Thus four companies were vulnerable to the loss of a programmer, and it happened with disastrous consequences in one instance, and with severe consequences in the second instance.

Chapter 8, The Extended Survey of NC Use in the North East (1985)

The extended timescale study reviewed in chapter seven was followed by a wider survey of 34 local companies during January-June 1986 to determine the relevance of the lessons learnt in the initial survey to industry at large.

It is shown that smaller subcontract companies have adopted flexible working practises and a high level of shop floor skills, whilst larger companies have tended to reduce the scope for shop floor initiative.

Chapter 8, The Extended Survey of NC Use in the North East (1985)

8.1 Derivation of Survey Objectives

8.1 (1) "NC Philosophy"

The preceeding local survey revealed that the use of N.C. was almost exclusively confined to "conventional" machining operations i.e. it was being used to turn or mill parts which had previously been made by conventional means, but to do it more quickly by virtue of the superior performance of the machines. In no case was it being used as an opportunity to rethink the manufacturing system and to introduce revolutionary changes into the company. The classic and well publicised case of this strategic use of N.C. is Ferranti, where Charles Allen* the Engineering Director has pursued a policy of switching from castings to solid blocks of aluminium and of "forcing" the designers to produce finished components in one set up on the N.C. machining centres and thus reducing new part lead times from up to 24 months to one month.

The extent of the rethinking of product design to enhance the effective use of N.C. was thus considered to be of major importance in demonstrating the impact of N.C. upon the organisation of the company. Hypotheses one and two relate to this.

8.1 (2) Skill Structures

The use of N.C. to either enhance operator's skills and to delegate responsibility to the shop floor or to de-skill the shop floor and to extend managerial control over the machinists has been discussed in depth. Hypothesis four relates to this.

8.1 (3) Own-Product Versus Sub-Contract Companies

Differences in the organisation adopted by companies with their own product compared to sub-contract companies were found in the extended timescale local survey. It is to be expected that companies manufacturing a product will develop their production techniques over-

*Presentation to Newcastle Polytechnic CADCAM forum, June 1985 time to reduce costs as they extend their experience of making the product. Sub-contract companies do not have the opportunity to develop techniques overtime, as their order book is totally unpredictable. Hypothesis five relates to this.

8.1 (4) Use of Capital Intensive Machines

N.C. machines are two to three times more expensive than the machines they replace, and produce two to three times more rapidly. Consequently the issuing of tooling and program, and the component handling systems need to be more tightly organised in order to maintain high utilisation of the machines. Hypothesis six summarised this.

8.1 (5) Company Vulnerability

It has been clearly demonstrated during the extended local survey of N.C. use that N.C. can introduce hidden dangers into a company, and it is an item of major interest to determine the extent of this problem, and the extent to which companies have planned back-up systems to avoid critical dependencies upon key people or machines.

Hypothesis seven refers to this.

8.2 Objectives of NC Questionnaire

8.2 (1) Hypotheses

The below hypotheses are suggested as relevant to the impact of N.C. upon company organisation:-

1. CNC is mostly being used to manufacture conventional parts more cheaply, rather than for the manufacture of complex 3D parts for which it was invented.
2. Major savings can be made by strengthening the Design/Production links e.g.

   by using parametric programmes or CAD/CAM links.

   To what extent is this exploited by manufacturers with their own products? How can it be exploited by subcontractors?

3. CNC can reduce product leadtimes - to what extent is this happening?

4. Skill structures chosen for the use of CNC machines are company determined.

   (i) large companies will tend to bureaucratise their use of CNC and consequently reduce their operators' initiative and the skill levels required.

   (ii) small companies will delegate additional skills to machine operators and exploit their initiative by demanding higher skill levels.

5. (a) Companies manufacturing their own products will be expecting to use their programmes over a long time cycle and will refine them carefully.

   (b) Subcontract companies need a flexible response - they will tend to delegate skills to operators and use less refined programmes.

6. CNC is more expensive and produces at a higher rate, it therefore demands tighter company organisation to maximise the benefits arising from its use.

7. CNC can introduce excessive dependency upon particular machines or people.

8.2 (2) The Use of the Questionnaire

The use of short interviews with senior people in the companies had proved successful over the initial three year examination of N.C. use, and this was now to be extended over a wider range of companies to examine as many issues relevant to the use of N.C. as possible within the limited time available at each company. The intention was to interview the person responsible for N.C. operation in each company. This varied from the shop foreman or owner in a small company, to the machineshop supervisor in a mediumsized company, or to the senior N.C. programmer in a large company. These people are all key people whose time is valuable and the questionnaire was thus designed to be answered in around 45 mins, since this was found to be the amount of time that senior people would spare. People contacted for interview were initially cautious and, if they did agree to be interviewed, they only agreed to be interviewed for the minimum time intially.

Open ended questions were used at the end of the questionnaire to draw out the person once mutual confidence had been established.

It was frequently found that the person had little opportunity to discuss the development of N.C. in their company and sometimes the total interview expanded to over two hours with the questionnaire being dealt with initially, then a tour of the firm taking place to demonstrate the company's achievements in its use of N.C. The fact that the interviewer was a mature person and experienced in N.C. use was a major contributing factor in establishing a rapport with the person being interviewed and in obtaining this extension of the interview.

8.2c Chc (3) Choice of Companies for Interview

A representative range of small, medium, and large companies was selected by reference to the Kompass guide, local trade directories, and word of mouth. The area covered was the North East of England (comprising Durham, Tyne and Wear, and Northumberland). Industry here, as elsewhere in Britain, has been in a state of flux in recent years. A major contraction of the Engineering Industry has taken place in this region during the period of this project. This contraction meant that the data that was available was highly suspect. The Kompass guide is usually taken as the most convenient handbook, giving a summary of the size and products of companies analysed down to county level. This study has tried to cover a typical sample of British industry, where the majority of companies have fewer than 100 employees. Only sixteen out of the thirty four companies participating in the survey are actually mentioned in the Kompass register, and of these sixteen only two had below one hundred employees. Illustrative of the decline in the industry is the fact that these sixteen companies employed 4,305 people according to their 1984 entries in the register, whilst the visits revealed that they actually employed 2,377 people. It is not claimed that this 45% reduction in manpower accurately reflects the decline of the local engineering industry. The figures are quoted here to illustrate the difficulty encountered in obtaining any accurate data regarding the current trends and the current structure of industry in the region. (Four of the thirty four companies are known to have closed since this survey was completed).

Frequently companies when contacted had no N.C. equipment and were thus not eligible for the survey, and a significant number of companies were too busy to spare any time. This necessitated continuous revision of the list of companies, and close attention was paid to covering the whole range of company sizes. There is no information available regarding the adoption rate of N.C. by company size in the region and it was considered that the derivation of this information was a completely separate task not central to the theme of this research project. The time available was spent contacting and interviewing as many companies as possible. This was found to be a time consuming task, contacting the relevant person in each company and arranging an appointment often took several phone calls over a period of a few days. Larger companies frequently required formal approval of the visit at management level, the person contacted was usually quite amenable, but time consuming protocol had to be complied with to assure the company that confidentiality would be complete. In a few cases this took several months.

Use was made of personal contacts wherever possible, or via suggestions from representatives whose local knowledge was invaluable.

8.3 Design of the Questionnaire

The initial information sought by the questionnaire was to determine the size of the company, and whether the company was an independent company or whether the company was part of a larger group, and if so to determine the role of the company within the group.

The company's products were then defined in order to determine initially whether the company had its own product, or had control over design, or to what extent the company engaged in sub-contract work.

The hours worked by the company on its conventional and N.C. machines were covered by question four, and the extent of computer use in relation to N.C. was examined by question five.

The extent of the use made of N.C. by the company was covered by question six, which also addressed any differences in the scheduling of work for N.C. machines, and whether group technology was being exploited.

The company's choice of skills to operate N.C. machines was covered by question seven, which also examined the foreman's role in relation to N.C. The previously defined classification of six skill levels for N.C. machine operators was used as a basis for the questionnaire and four levels of skill were considered for the foremen. These were:-

Table 7: Foremen's Skill Levels

(1)	Foreman purely organises work for N.C. machines.
(2)	Foreman liaises with programming dept. over problems.
(3)	Foreman tunes up programs himself.
(4)	Foreman writes programs himself.

The type of N.C. program preparation used by the company was examined by questions eight and nine, together with an open ended question about the future plans for N.C. program preparation. Question ten determined any developments in the inspection system consequent upon the use of N.C.

and question eleven attempted to estimate the batch quantities for which the N.C. machines were used.

The relationship between product design and N.C. use was explored by question twelve which was designed to reveal the extent to which N.C. use had allowed designers to release themselves from the constraints of conventional machining and to exploit the design freedom now available to them. An open ended question was again used to examine the development of links (if any) between the production engineers using the N.C. machines and the designers.

The degree of change in stock levels brought about by the use of N.C. was examined by question thirteen.

The final part of the questionnaire was more open ended and examined the problems arising from the use of N.C., and the related actions taken by the company to avoid dependance upon key machines or people.

The distribution of the N.C. skills in the organisation was examined by asking for an organisation chart identifying the location of the N.C. skills within the hierarchy of the company.

The company's future plans for N.C. use were addressed by a final open ended question designed to draw out the extent to which the company planned to utilise N.C. It was hoped that this question would reveal the appreciation by the company of the potential for change introduced by the adoption of N.C.

The number of employees in the company was left until last because it was felt that this may lead to a referral to the personnel department, and the aim was to have an uninterrupted interview.

A draft questionnaire was drawn up as above and then several meetings were held with the Centre for Urban and Regional Development Studies at Newcastle University to review the structure of the questions and the validity of the objectives in view of their long experience in this type of survey work, and also to benefit from their experience of the interviewing of companies across the country in relation to the diffusion of N.C. and other technologies.

8.4 Questionnaire Results

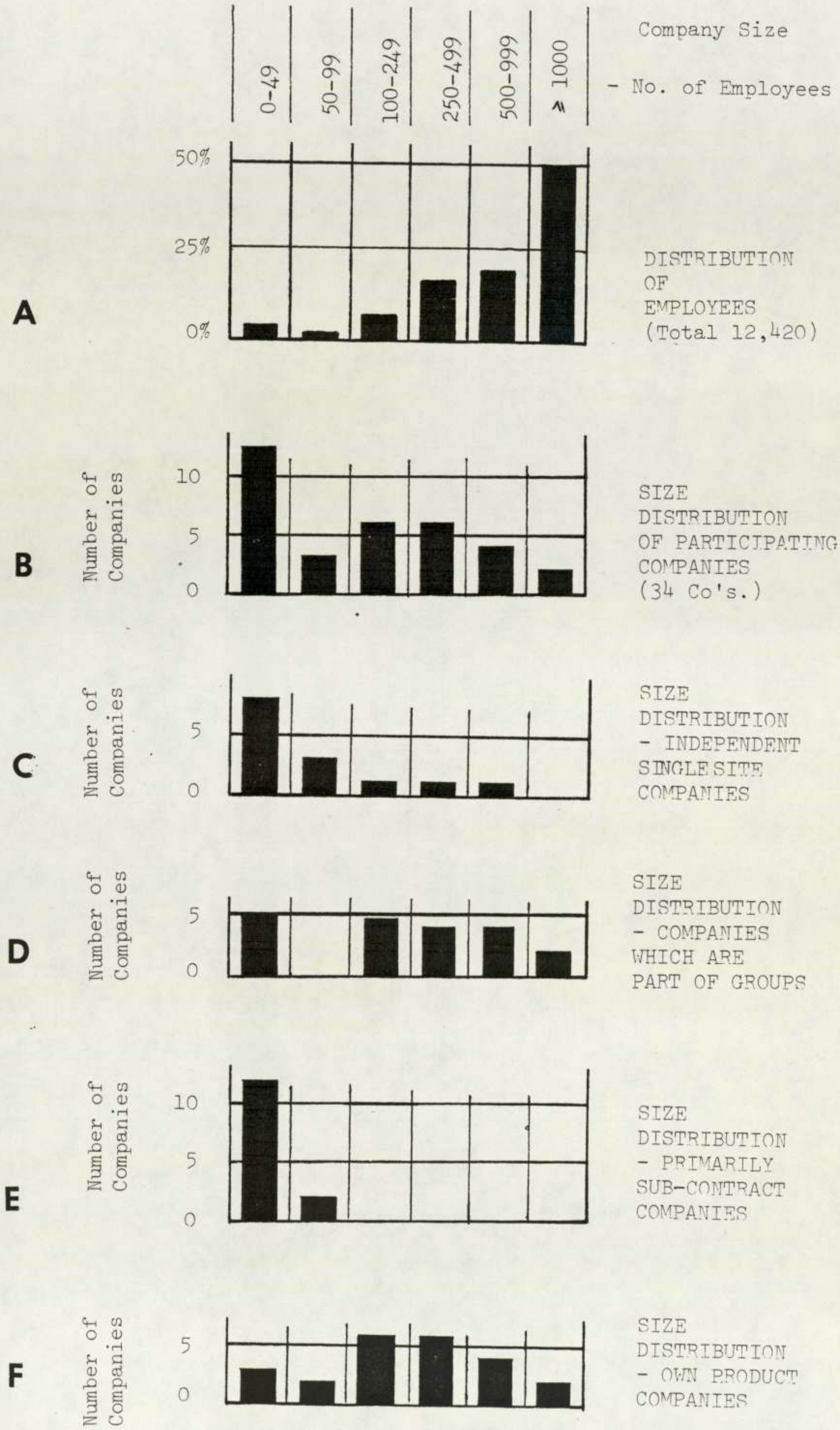
8.4.(1) Company Profiles

Figure 17 summarises the distribution of the thirty four companies visited classified by numbers of employees. The companies chosen for interview were active users of N.C. metal cutting machinery within the general description of mechanical Engineering, and ranged in size from five to several thousand employees. Twelve companies had more than 250 employees, and all manufactured their own product ranges, although some did a proportion of subcontract work also. The remaining twenty two companies had less than 250 employees, and fourteen of these were primarily subcontractors, whilst seven manufactured their own products.

Figure 17A shows the predominance of the two larger companies have in the total number of employees covered by the survey.

Figure 17C shows the distribution of independent companies, who not surprisingly, turn out to be the majority of the smaller companies surveyed. Figure 17D shows the distribution of companies which are a part of a larger group. Figure 17E shows that twelve of the thirteen small companies are primarily subcontractors, although a significant proportion of the larger companies undertake some subcontract work. Figure 17F shows that twenty three of the companies produce their own products. In all but three of these companies their own product forms the major part of their workload.

Figure 17: A profile of the participating companies



8.4 (2) Hours of Work

It was suspected that companies would tend to use N.C. machines more intensively than conventional machines (hypothesis 6) and Figure 18 confirms this. There is less difference in the hours worked by smaller companies, but larger companies are often running their N.C. machines for two shifts. One company in the 50-99 employee size group ran its machines continuously from Monday morning to Friday night, and the two largest companies in the survey had recently introduced three shifts working on their N.C. machines. One of these two companies had also just introduced two shift working for its N.C. programmers to improve the back up to the machines.

The overall average hours worked on conventional machines were 52 hours per week, and 69 hours per week for the N.C. machines.

Figure 18: Hours worked by conventional and NC machines

8.4 (3) Computer Use

The extent of computer useage by the participating companies is presented in Figure 19. It is to be expected that larger companies will make

Figure 19: Extent of computer use in companies

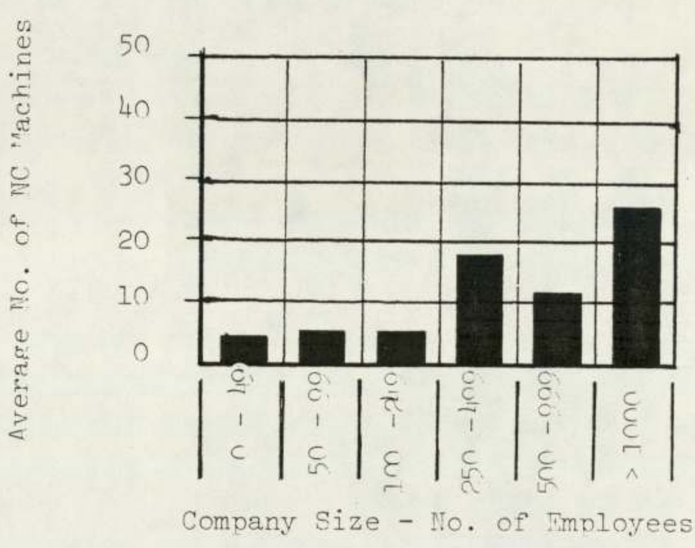
Company Size - Numbers of Employees	Company No.	Commercial Use	Production Control	Design Analysis	C.A.D.	NC Program Preparation	D.N.C.
0-49	1					●	
	2	●	●			●	
	3						
	4						
	5						
	6						
	7	●					
	8						
	9	●	●				
	10						
	11						
	12	●	●				
	13						
50-99	14	●				●	
	15	●	●			●	●
	16	●					
100-249	17	●	●			●	
	18	●					
	19	●	●				
	20	●	●			●	
	21	●	●				
	22	●		●			
250-499	23	●		●		●	
	24	●	●			●	
	25	●	●	●		●	
	26	●	●		●	●	
	27	●	●				
	28	●	●			●	
500-999	29	●	●		●	●	
	30	●	●		●	●	
	31	●	●	●	●		
	32	●	●		●	●	
≥ 1000	33	●		●	●	●	
	34	●	●	●			

considerably more use of computers, and this is shown to be true. The smaller companies involved only made limited use of computers, and computers were used for N.C. program preparation by fifteen of the thirty four companies. Computer Aided Design was used by six of the larger companies. It would have been expected that computer use for design analysis would have been more widespread than C.A.D. which is a more recent innovation, but in fact only six companies claimed to be using computers for this purpose.

8.4 (4) Distribution of NC Machines

The numbers of N.C. machines per company are shown by Figure 20 which starts to show one of the main results arising from this survey - the disproportionately high uptake of N.C. by the small subcontract companies. On average they have 3.6 machines per company, and this is in companies with an average of 22 employees.

Figure 20: Distribution of NC machines by company size

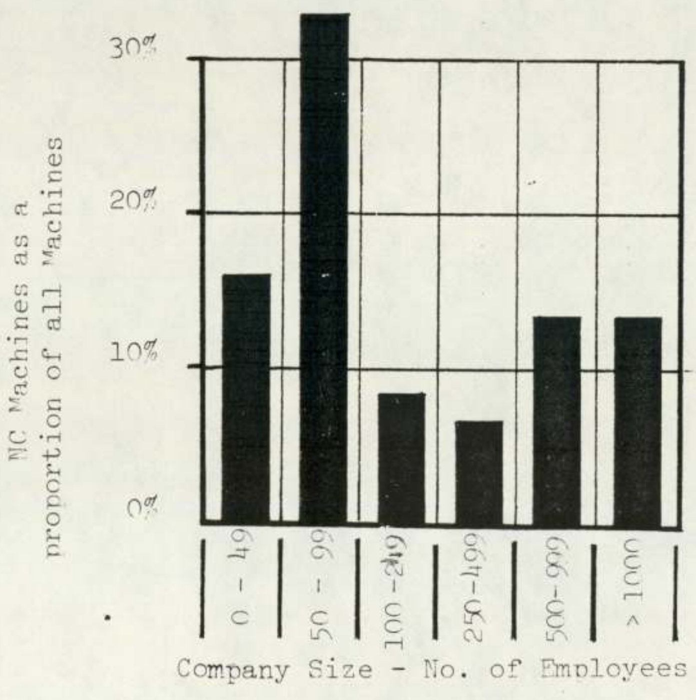


The actual number of N.C. machines in these small companies varied from one to ten machines, but the details have not been tabulated in order to maintain anonymity of the companies. As expected the larger companies have more N.C. machines, but in spite of being up to one hundred times larger than the smaller companies they only have up to ten times as many N.C. machines.

The overall average proportion of N.C. machines to conventional machines was found to be 8%. This can be compared to the latest available estimate of the proportion of N.C. machines in industry* which showed the national overall figure to be 3.32% in 1982. The Northern region in which this study is based, however, only had 2.7% of N.C. machines. The current survey was taken in 1985, and thus more N.C. machines have been sold over the three year period, but the level of 8% is higher than the national average. This is obviously to be expected since companies not using N.C. have been excluded from this survey.

Figure 21 shows the proportion of N.C. machines found in the different sized companies, but the 33% value for companies with 50-99 employees is untypical. There were only three companies within this classification and one of these three had 75% of its machine tools with N.C. controls.

Figure 21: The proportions of NC machines used by differently sized companies

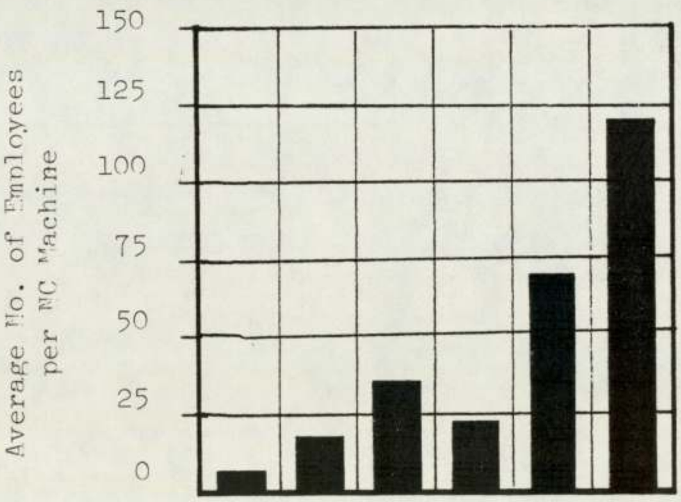


*Ref 28

8.4 (5) Employees per NC Machine

The ratio of the total number of employees to each N.C. machine again highlights the intensive use made of N.C. by the small subcontract companies. On average they have 6.3 employees per N.C. machine, whilst the very large companies have 122 employees per N.C. machine (see Figure 21). One of the small companies had twenty employees including office staff, with a total of ten N.C. machines. It will be argued later that this factor enables all the staff of these small companies to become much more aware of the capabilities of the machines, than the staff of large companies and thus enables them to exploit the machines more effectively.

Figure 22: The ratios of employees to NC machines

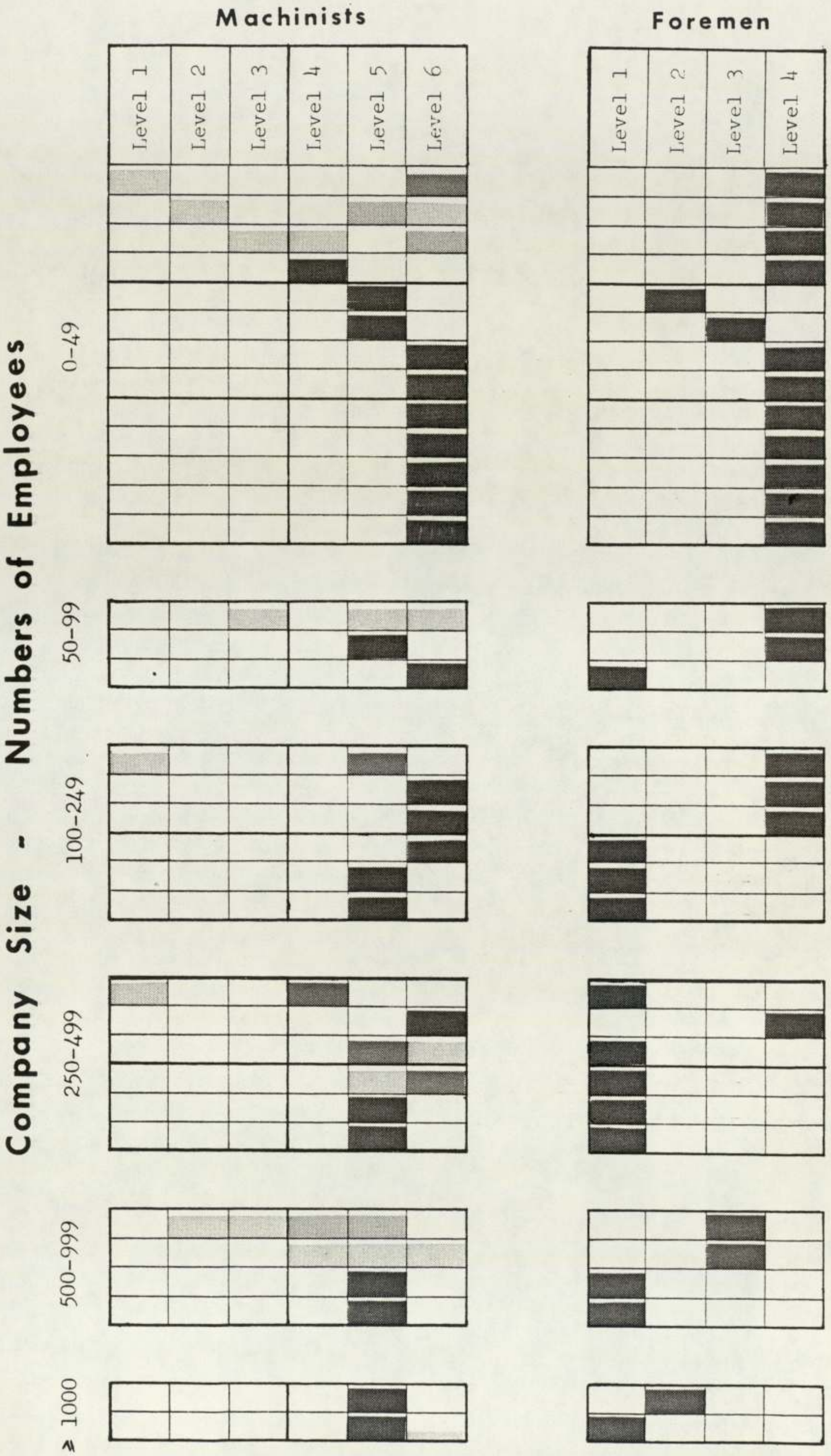


Note: Total NC machines in survey = 281
Av. No. of NC machines per company = 8.3

8.4 (6) Skill Levels

The classification of the skill levels of the N.C. machine operators was defined in section 6.5 (table 7), and the foreman's skill classification was defined in section 8.2 (Table 8). Figure 23 summarises the skill levels adopted by the different company sizes. It is immediately apparent that ten of the thirteen small companies chose to have operators who were able to write their own programs, and also that

Figure 23: The distribution of NC skills



eleven of these companies had supervisors who were also able to write programs. This is a marked contrast to the larger companies, where the supervisors are largely unskilled in N.C. programming, and the operators are not expected to program the machines.

Figure 24 present a slightly different perspective of the skill levels. In this diagram the total numbers of operators with each skill level are shown and obviously Level 5 skills predominate. In this case the few larger companies outweigh the significantly different skill distributions of the smaller companies.

Figure 24: The distribution of skills of NC operators

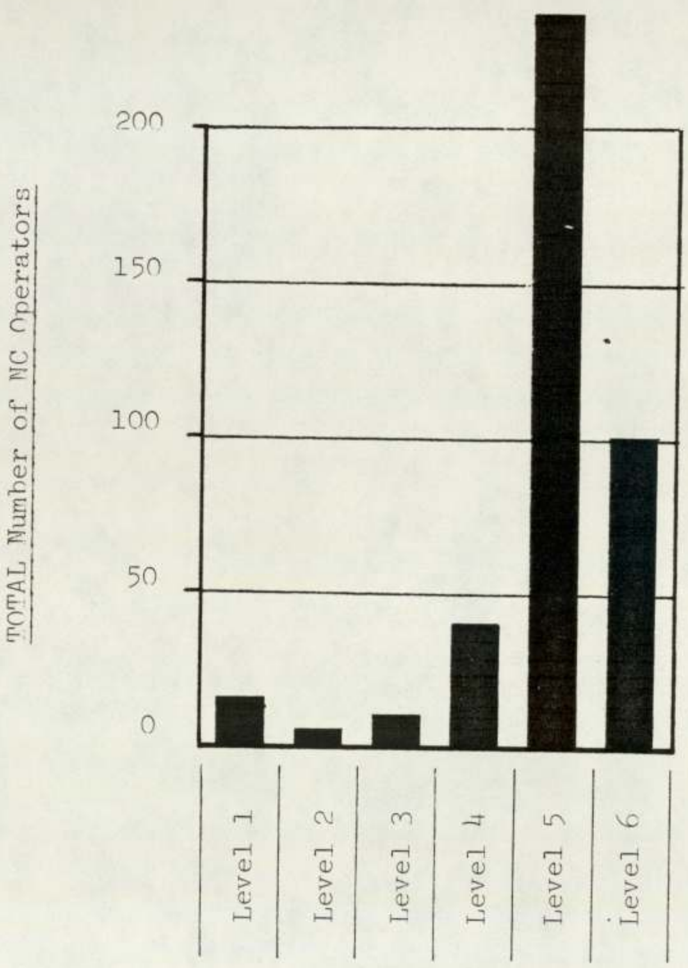
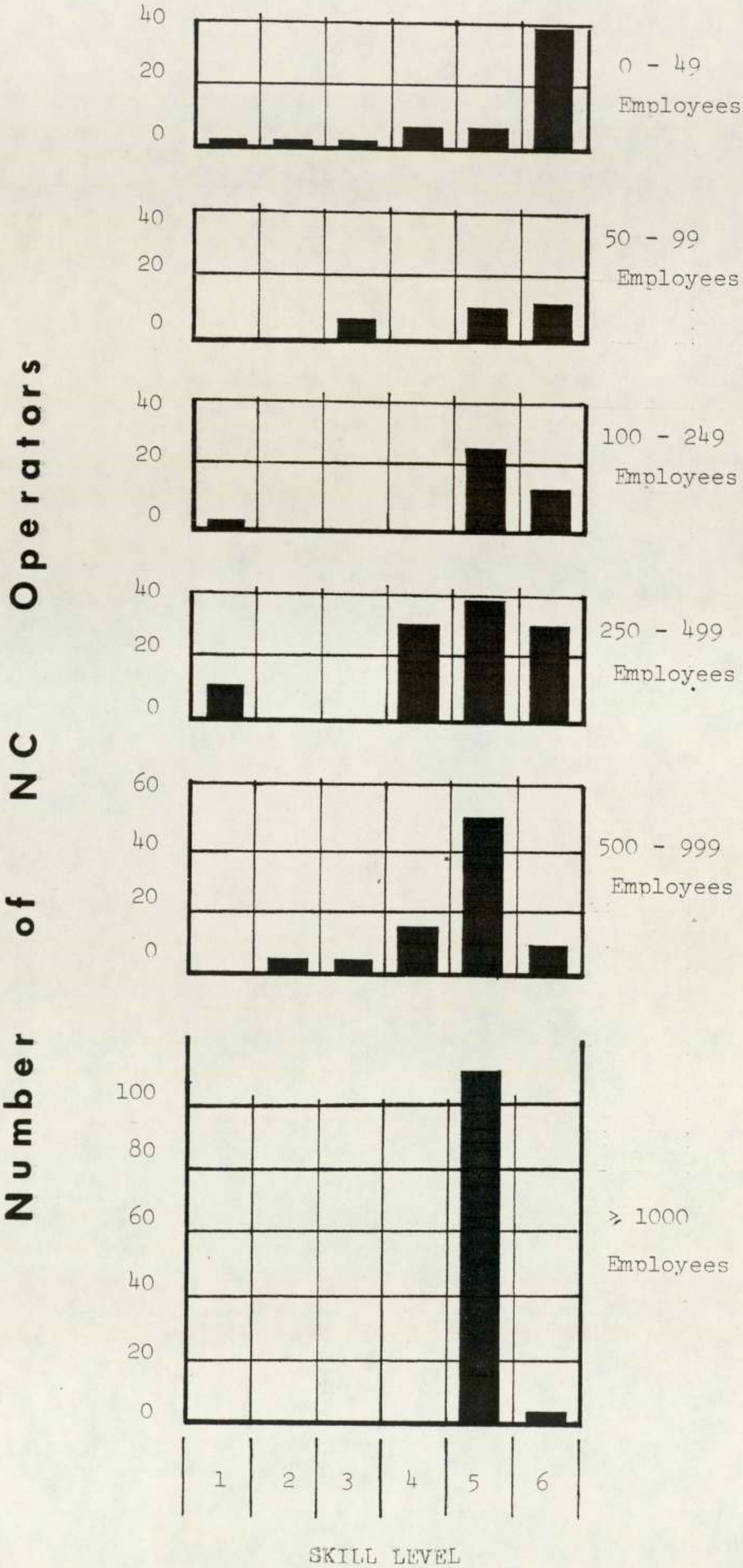


Figure 25, however, breaks down the overall picture to show the skills adopted by the different company sizes. This shows that, whilst level 5 skills predominate, they do so only in the larger companies, even the medium sized companies use shop floor programming skills to a large extent. One of these companies had recently introduced a range of conversational programming lathes on to the shop floor, a move which significantly reduced the size of the programming department.

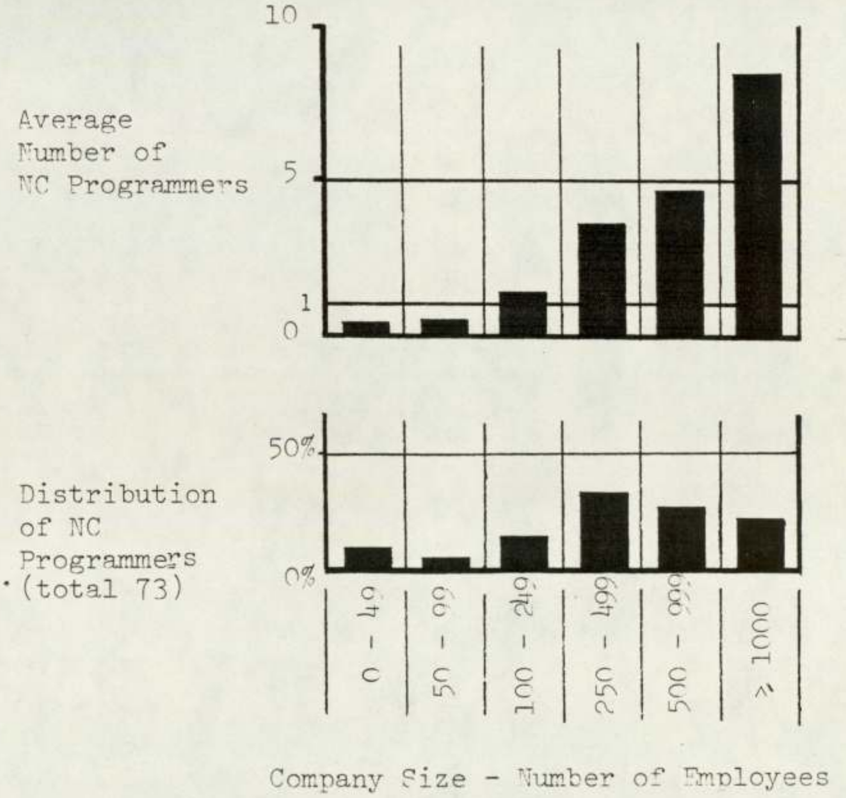
Figure 25: The distribution of operators skills according to company size



8.4 (7) Distribution of NC Programmers

The distribution of N.C. programmers is shown in Figure 26, and obviously the larger companies employ more programmers. Notice, however, that companies with less than one hundred employees were well below one programmer per company i.e. the majority of them did not employ a person specifically to be a programmer.

Figure 26: The distribution of NC programmers



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8.4 (8) NC Program Preparation Techniques

The program preparation techniques used by the companies are shown by Figure 27, and as would be expected the larger companies are making more use of computers for N.C. program preparation. In only one case, however, were complex 3D shaped parts being produced by N.C. techniques, and this task was a small part of that particular company's workload. This was the task for which so much effort and money was expended in the early days of N.C. and which lead to the barriers to its adoption by the average company - the need to have a large computer and the relevant skills to operate the whole system. The active use of CAD/CAM links to produce N.C. programs only occurred at two companies. The predominant programming method is still manual programming, with a strong move into conversational programming by both small and large companies. The lack of a serious move into group technology is highlighted by only three companies preparing programs for part families.

Figure 27: A perspective of NC program preparation techniques

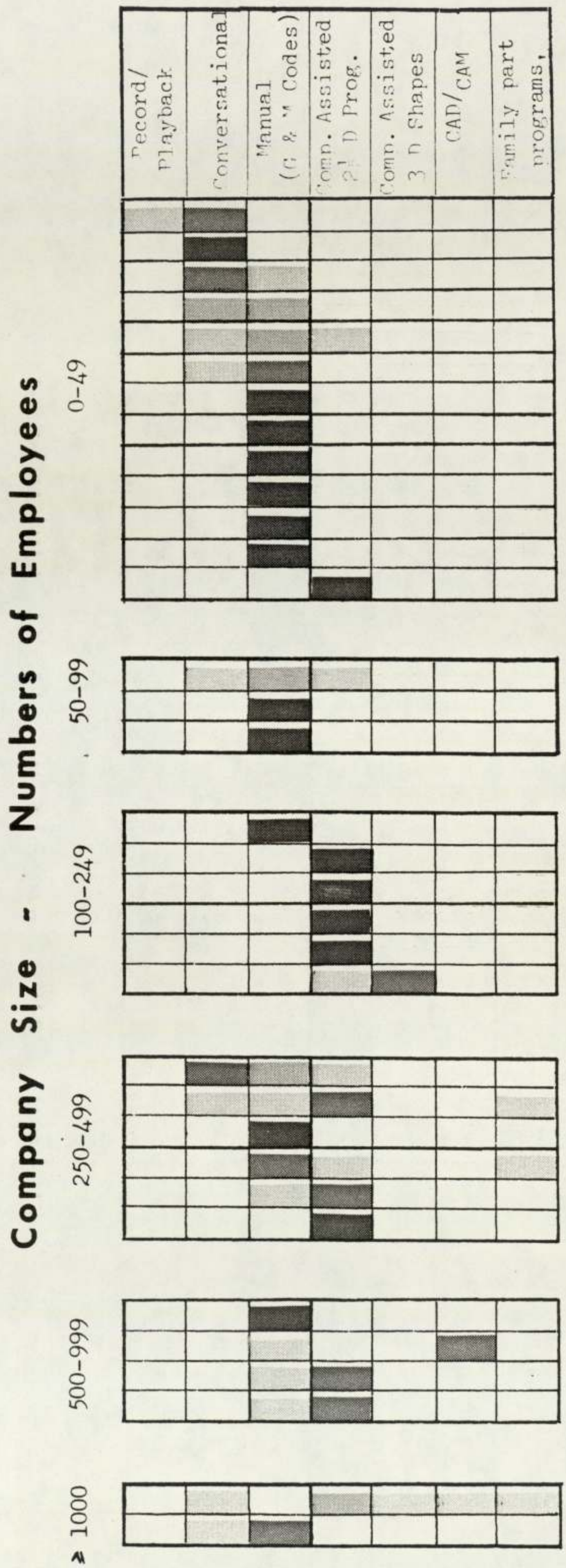
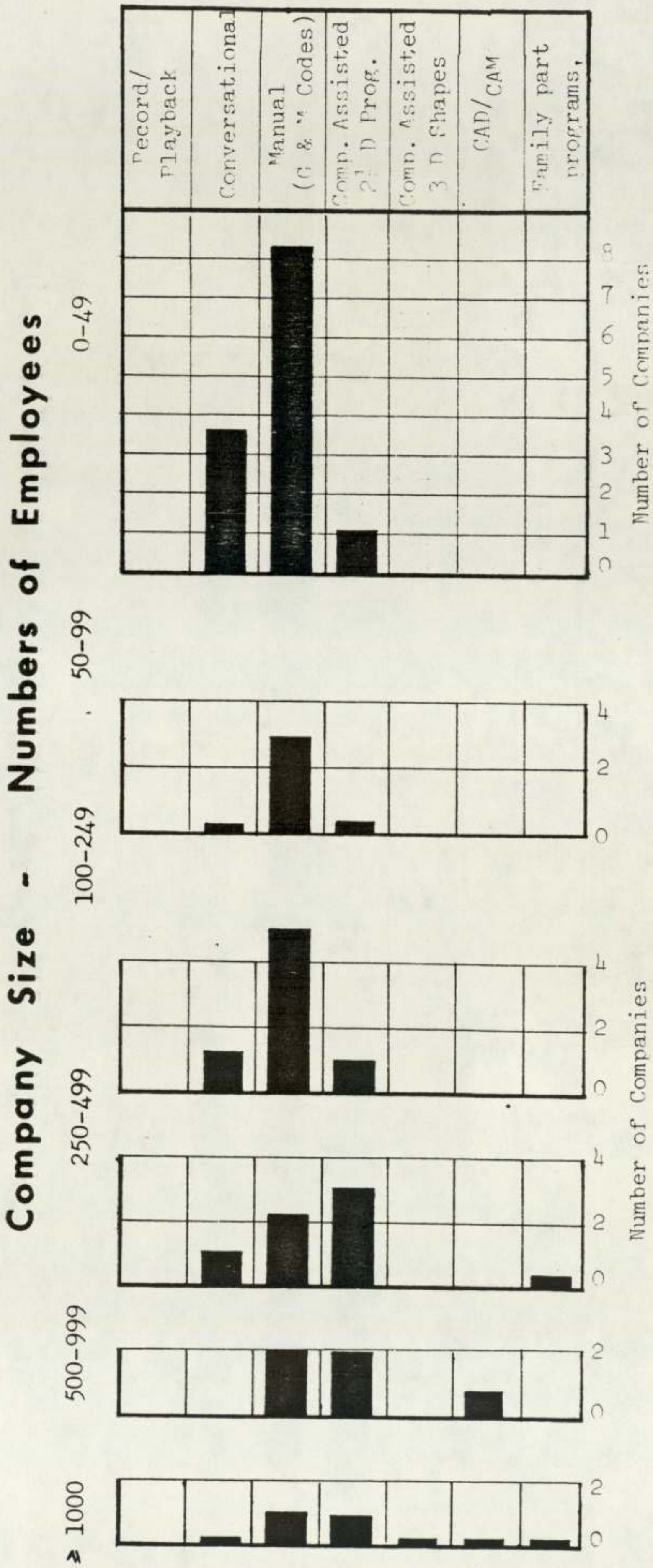


Figure 28: NC program preparation techniques versus company size classes



The distribution of program preparation methods is shown by Figure 29. This shows again the predominance of operator programming in small companies - but note that it is not totally absent from the largest companies.

Figure 29: Proportions of companies using shop floor programming

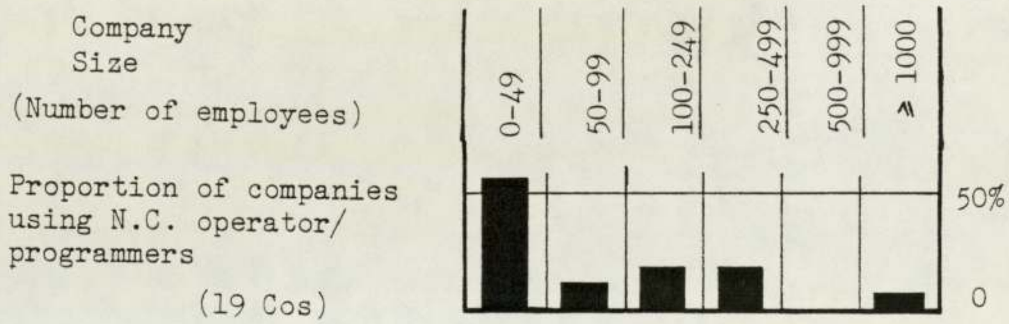


Figure 30 shows the distribution of separate programming departments according to company size. The concentration of programming into separate departments remote from the shop floor is becoming to be acknowledged as undesirable, one of the larger companies had recently reorganised its programming department into three smaller units attached to the three machining sections that they serviced.

Figure 30: Proportions of companies using separate programming departments

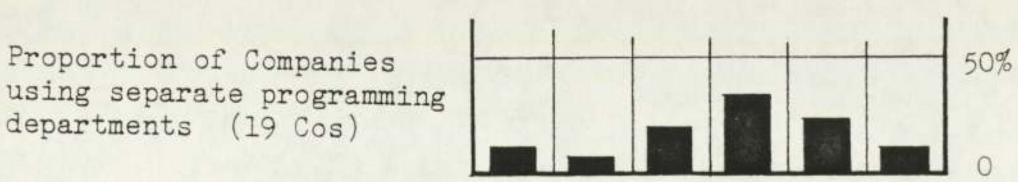


Figure 31 shows the concentration of computer assisted N.C. programming in the medium to larger companies - but it was used in only eleven of the thirty four companies. Manual programming was used by 28 of the companies, and while it predominates in the smaller companies (Figure 32) it is by no means absent from the larger companies. One of the larger companies specifically used manual programming for machining centres because their computer system produced complex program structures since it used the systems "canned-cycles" in place of the machines' own canned cycles. This made the programs unintelligible to the operators, and prevented them from solving problems on the shop floor, this then meant that a machine could be stopped all night until the programmers came in the next day to sort out the problem.

Figure 31: Proportions of companies using computer assisted NC programming

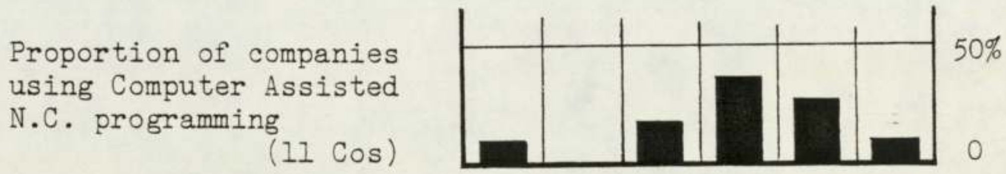


Figure 32: Proportions of companies using manual programming

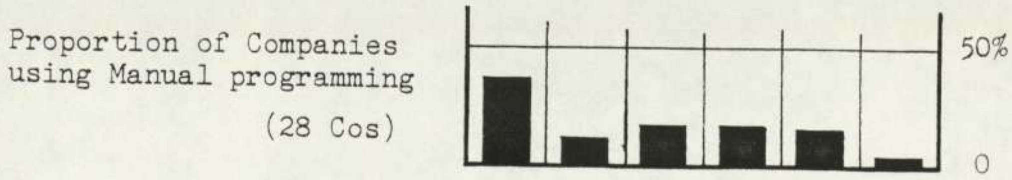


Figure 33 shows that the 185 operators who worked from manually prepared programs were evenly spread across all the company size classes, whilst Figure 34 shows that the 174 operators worked from programs prepared with computer assistance (fewer than those working from manually prepared programs) were concentrated in the larger companies.

Figure 33: Proportions of NC operators working from manual programming

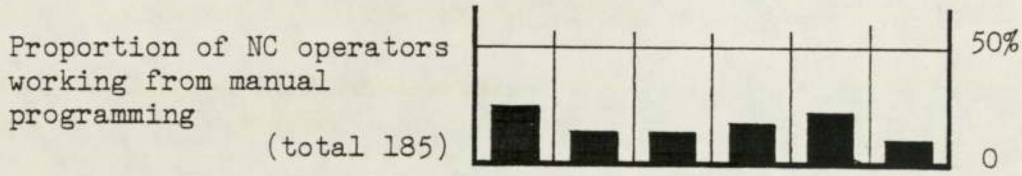
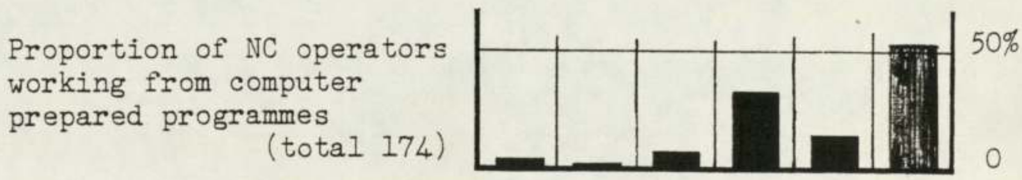


Figure 34: Proportions of NC operators working from computer prepared programs



8.4 (9) Designer's Links with NC Skills

Companies with 1-49 Employees Contacts between the companies and the designers were classified as "very rare", "slight contact", and only one company claimed to have good contacts between the production engineers and the designers - and this was the company which produced its own product. The other twelve companies were subcontract companies who were able to see design improvements sometimes in their work, but they usually only saw individual components rather than the whole assembly. Their usual contact was with the buyer of their customer, which diminished their opportunities to offer constructive suggestions.

The one company with its own product had, however, taken the opportunity of purchasing a machining centre to re-structure the company. They found that they needed to offer a quick delivery to customers - and the typical two week delivery period was much shorter than the lead time needed to make batches of parts in order to assemble the particular customer's order. The purchase of the machining centre meant that they were now able to produce the family of parts necessary for a particular customer's order in the sequence required for assembly, and thus to reduce the lead time to one week. This enabled them to change the company policy - stocks of raw material were now held instead of stocks of finished parts, and their work in progress investment had reduced considerably.

They also found that the speed of N.C. machining enabled them to offer features which had previously been expensive options on their products as standard features on all products at no extra cost. This change also meant that routing of individual specific orders was not essential - since components were now interchangeable rather than specifically tied to a particular customer.

Companies with 50-99 Employees Two of the companies had some contact with the customers designers but little influence over the component design details. The third company, however, specialised in long running, high value, complex jobs for a small number of customers. They deliberately sought work which was to demanding high standards of accuracy and in which they expected to invest a considerable time developing machining techniques. Their customers were not in the traditional engineering field, and this meant that they deliberately cultivated a "special relationship" with their customers to improve on the prototype drawings.

One of the companies claimed that there was a significant improvement in the quality and performance of cone clutch components produced by them on N.C. lathes. The compatability of parts was much improved by the consistency of the taper angles on the mating clutch faces produced from different batches of parts.

Companies with 100-249 Employees Three of the six companies had "some contacts" or "improving contacts" with the design office, whilst three said they had close links between the N.C. programmers and the design office. One of these three companies had introduced N.C. machines relatively recently and, whilst the shopfloor had programming skills, the post of "Industrial Engineer" had been created for the N.C. programmer, and he was placed in the design office. This contact with the design office then lead to the re-evaluation of some components which had been brazed together from separate components prior to the introduction of N.C. machines. It had become possible to machine the assembly from a single forging with a significant saving in cost and in lead time.

A second company was finding that it had more freedom to modify parts when necessary, since N.C. did not need complex fixturing redesign for minor component modifications.

Companies with 250-499 Employees Three of these companies had "some" or "few" links between the N.C. programmers and their design offices, but the other three companies had structured their organisations so as to create deliberate interaction between the programmers and the designers.

One of these companies had deliberately positioned the N.C. programmers among the designers, so that there was an interaction between the designers and the programmers at the design concept stage, and a second company had recently merged the design and planning departments in order to obtain the same interaction. The third company was structured so that one person was totally responsible for a particular product, from design, to manufacture, and to commissioning on site. This structure was for the purpose of ensuring feedback of customer and manufacturing problems to the designers.

One of these companies had installed production lines for their products in which the first machine was an N.C. machine. The designers had been constrained to redesign the components made on these lines so that all products on that line could be made with the set of tooling with which the machine was equipped, and so that all products fitted into the same fixturing.

The programming was also standardised so that only dimensions relevant to each particular part needed editing by the operator for the machines to be ready to produce the next batch of components.

This tight discipline over the allowed variations between components meant that there was no need to reset the machines to produce a large variety of parts. The batch sizes that were made were then chosen according to the needs of the assembly line, instead of economic batch quantities being forced onto the factory by the need to recover lost time due to machine downtime to reset the machines between batches of parts. This then meant that parts were not made for stock but only to orders received, and the company found that this was of significant benefit when tailoring products to suit a customer's need for a non-standard product.

Companies with 500-999 Employees Two of these companies did not have local control over design and felt strongly that this was a major disadvantage, but the other two companies had design offices on the same sites and were developing good links with the designers. One company had regular product review meetings between designers and shop floor production engineers. They had also undertaken extensive value analysis exercises when new products were introduced, which they claimed have halved the manufacturing cost of one of their recent new products. The second company was the one company making extensive use of CAD/CAM links, and the very use of this method forced the establishment of a database of each machine tool's facilities and tightened the links between the design and production engineering departments. The designers were constrained by CAD to adopt company standards and had very much less freedom to create parts which were incomptabible with the manufacturing resources.

Companies with > 1000 Employees In one of these companies the interview was interrupted by urgent business and no information was obtained about design/production links. The second company however had undertaken a large investment in CAD/CAM and was devoting much effort to generating N.C. programs from the CAD data. This was forcing much more interaction between the production engineers and the designers than had ever occurred previously.

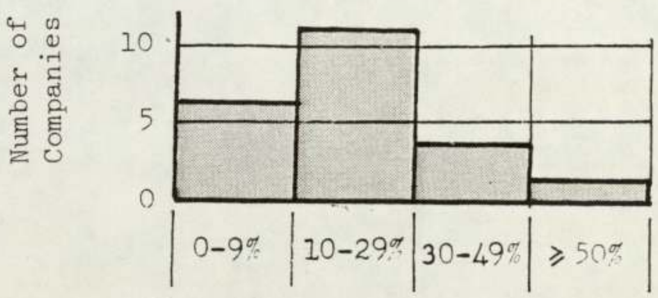
Design Links - Subcontract Versus Own Product Companies Thirteen of the fourteen subcontracting companies were virtually totally divorced from the designers who worked at the customers' companies. In only one case had the company developed a 'special' relationship with its customers. This was a deliberate policy to reduce the possibility of losing jobs once the expensive teething stage of developing a new order had been accomplished. The other companies were undertaking much more "general" subcontracting on less complex work.

In two of the own-product companies investment decisions had been taken which were designed to restructure the company's organisation. In these cases the purchase of the machine tool was taken as an opportunity to re-think and to re-organise the flow of work through the factory.

In four companies the N.C. machines were being used to reduce work-in progress levels by merging operations where possible, but in 17 of the 23 companies N.C. machines were largely being used to produce existing parts in less time. The opportunity to use the same investment to review the companies' structures was largely not appreciated.

8.4 (10) Work in Progress Changes in Companies

Figure 35: Summary of work-in-progress changes due to NC adoption

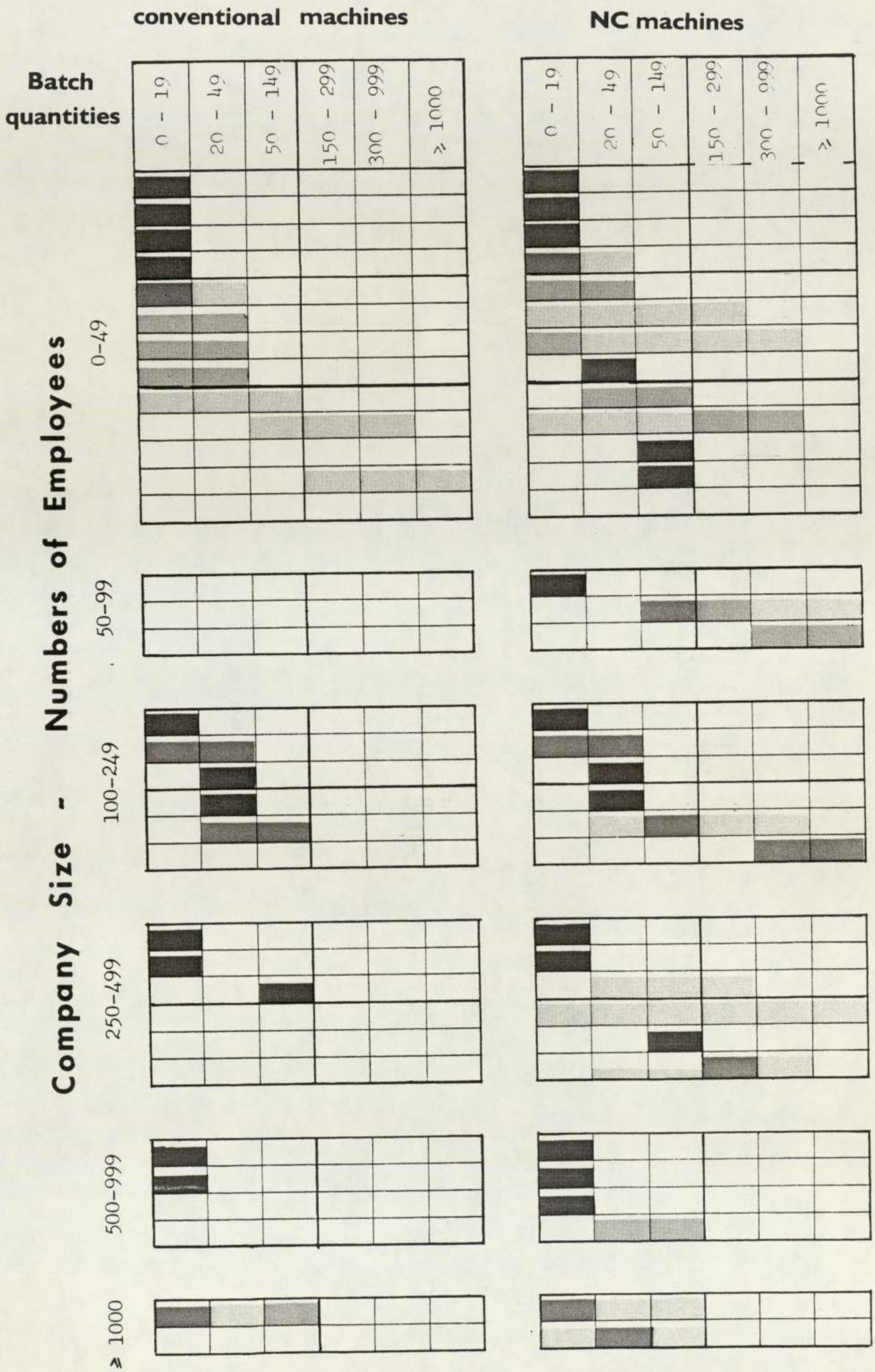


Companies were asked to estimate the effect that the adoption of N.C. had had on the values of work in progress in the company. Many of the subcontract companies said that this question was irrelevant to them since they handled components only, rather than building up sets of parts towards completed assemblies. Most companies agreed that there had been some reduction in work in progress, and six companies as previously mentioned stated that they were deliberately using N.C. techniques as a means of reducing the product leadtimes and hence work in progress levels.

8.4 (II) Batch Quantities

Each company was asked to estimate the typical batch quantities of work undertaken on the conventional and N.C. machines. This was a difficult question to answer in one or two minutes, since obviously there were many different batch sizes in progress at any one time. Fig. 36 summarises the replies obtained, and provides at least a rough picture of the type of batch sizes undertaken by the companies in the survey. It is evident that the majority of the work on both types of machinery is in very small batches, and that very few of the companies were engaged in the manufacture of high volume work. Many of the subcontract companies were using N.C. machines for one-off components, the operators being given the customer's drawing and developing a program as they made the one component.

Figure 36: Batch quantities produced on conventional and NC machines



8.4 (12) Company Organisation and NC Skills

Companies were asked to sketch the organisation structure and to identify the areas where N.C. skills were used in the organisation. It would be highly repetitive to present thirty four organisation charts, so a selection of nine charts have been chosen as representative of the distributions of N.C. skills found in survey.

Figure 37 shows the typical small company structure found in the survey. The owner, the supervisor and the machinists were all able to program and operate the N.C. machines.

Figure 37: Typical small company organisation (10 - 25 employees)

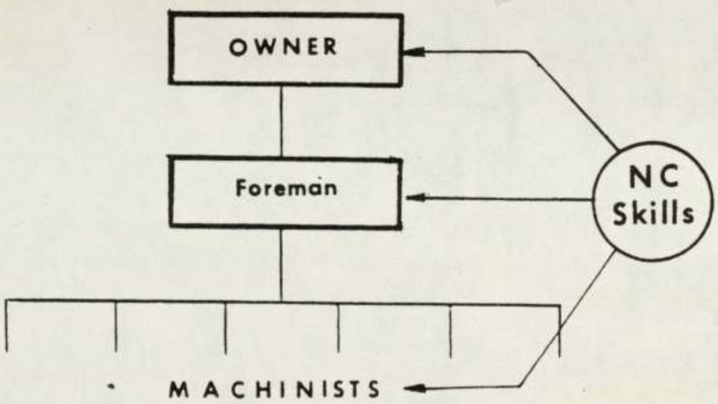


Figure 38 shows an untypical small company structure, this is a company previously mentioned which had contracted considerably. It had previously employed an N.C. programmer, but his departure had left the company unable to initiate new N.C. jobs. Probably because this company had been used to relying upon the services of a programmer, it was now unable to conceive of the idea of training its machinists to write their own programs. It may be that the machinists were incapable of undertaking N.C. programming, but the only solution to the dilemma that the company would consider was to recruit a replacement programmer. This could only happen however when a large increase in the workload was obtained, and this must have been an unlikely event until the programmer was in post. The company still had the option of recruiting machinists either able to program, or able to learn programming, but again these options were not within the imagination of the company.

Figure 38: Untypical small company organisation (10 - 25 employees)

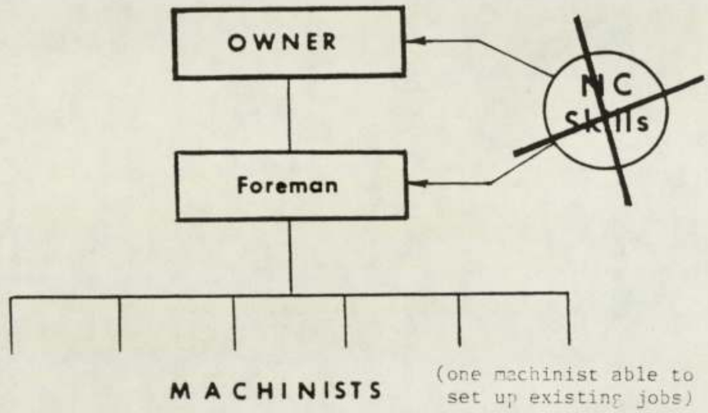


Figure 39 shows a slightly more complex small company organisation. In this case the company had some own product work which meant that the machine shop was one part only of the structure. Once again, however, all the people with responsibility for the machine shop were able to write N.C. programs and to fully comprehend the opportunities to exploit the potential of N.C. machines.

Figure 39: Small company organisation (10 - 25 employees)

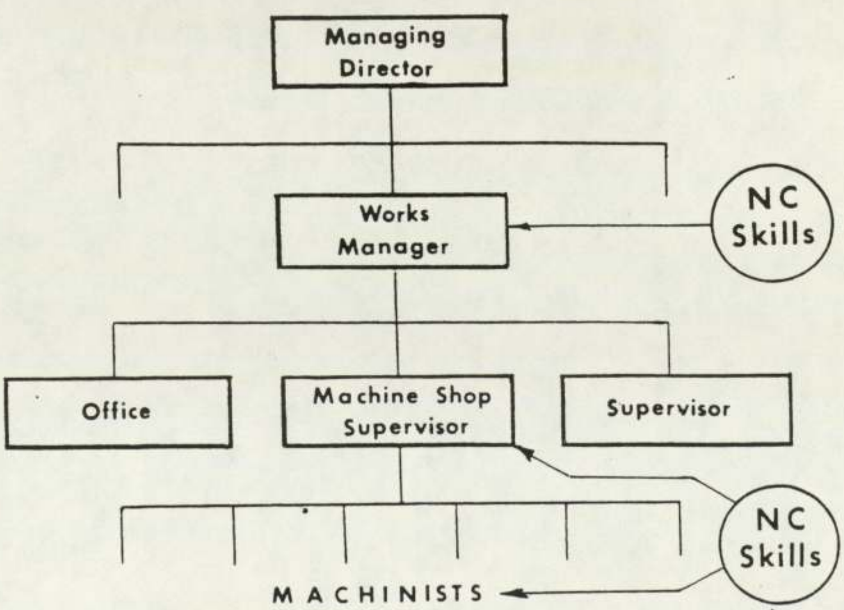


Figure 40 shows the organisation of a small company which was making intensive use of N.C. machines, with an expanding N.C. section. In this case the company had recruited a person with N.C. experience from one of the larger companies, and he had successfully expanded its use. The company did not realise, however, how dependent it had become upon the one person, he was the foreman responsible for running the N.C. machine section, but he was the only person in the company with the full knowledge of the machines.

Figure 40: Small company organisation (25 - 49 employees)

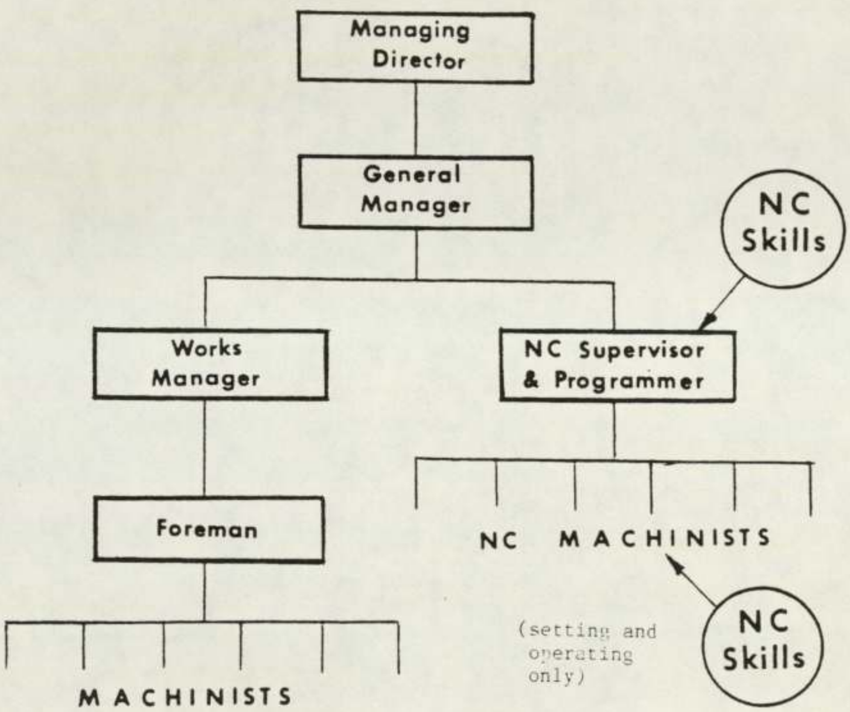


Figure 41 shows a comparable company to the one shown in figure 40. Both had similar numbers of employees and both were engaged in precision subcontract work for customers who were well known to set exacting quality standards. Both companies have had some years experience of N.C. use and are expanding their range of machinery.

In the second case however the Managing Director was very enthusiastic about N.C., and he acted as troubleshooter for the more complex N.C.

programs. More routine programming was delgated to various levels of the company.

Figure 41: Small company organisation (25 - 49 employees)

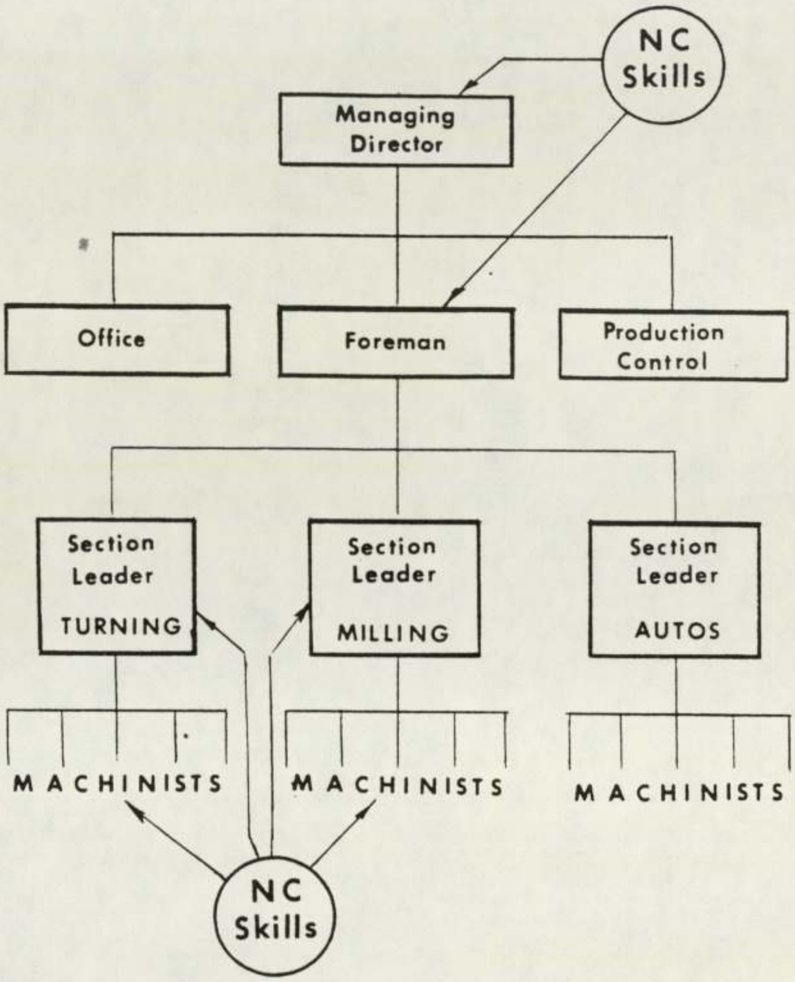


Figure 42 shows the organisation structure of a medium sized family business. The company was making sophisticated heavy fabrications which required precision machining to exacting standards. The company purchased two small N.C. machines in 1982, and the operators were sent on programming courses. The N.C. machines were not in use at the time of the visit and seem to be used for "odd jobs", the N.C. skills were isolated in one corner of the machine shop, and N.C. was not seen as relevant to the company. They prided themselves as offering high quality at a high price. This company was difficult to approach, and the minimum time possible was spared for the visit. (It should be mentioned that this company has expanded slightly between 1980 and 1985, so it has done better than many other companies in this survey.)

Figure 42: Medium sized company organisation (150 - 250 employees)

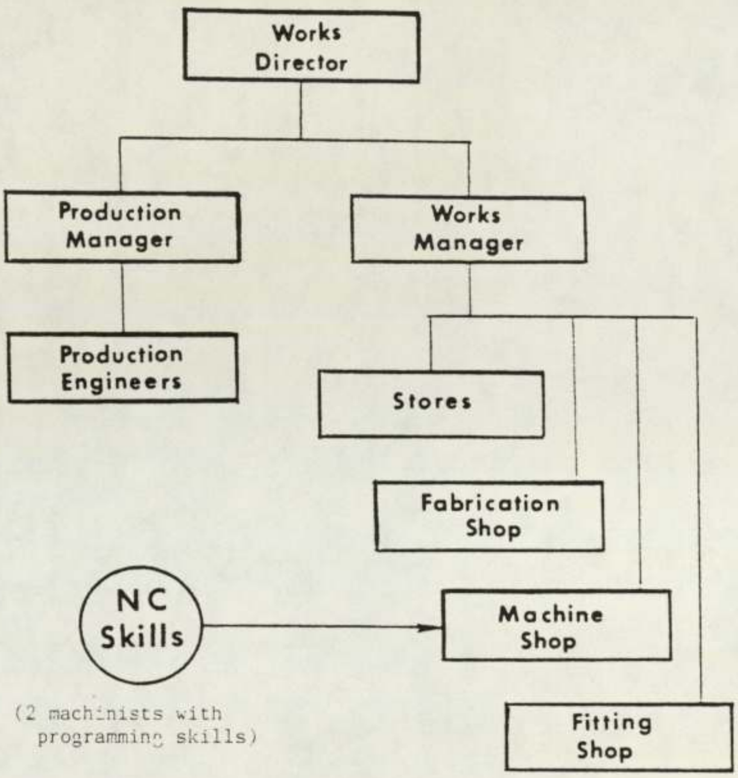


Figure 43 shows a similar sized company which introduced three N.C. lathes in 1984. The company had distributed the N.C skills through the organisation, and had given a lot of thought to N.C. use in relation to product design and cost saving. In this company the machineshop manager and the foreman had learnt N.C. programming as had the machinists. An "industrial engineer" had been appointed with the specific responsibility for N.C. programming, but he had been deliberately placed in the design office.

This lead to redesign of components to suit the lathe's capabilities, and demonstrated an example of a company positively integrating N.C. into the company's structure.

Figure 43: Medium sized company organisation (150 - 250 employees)

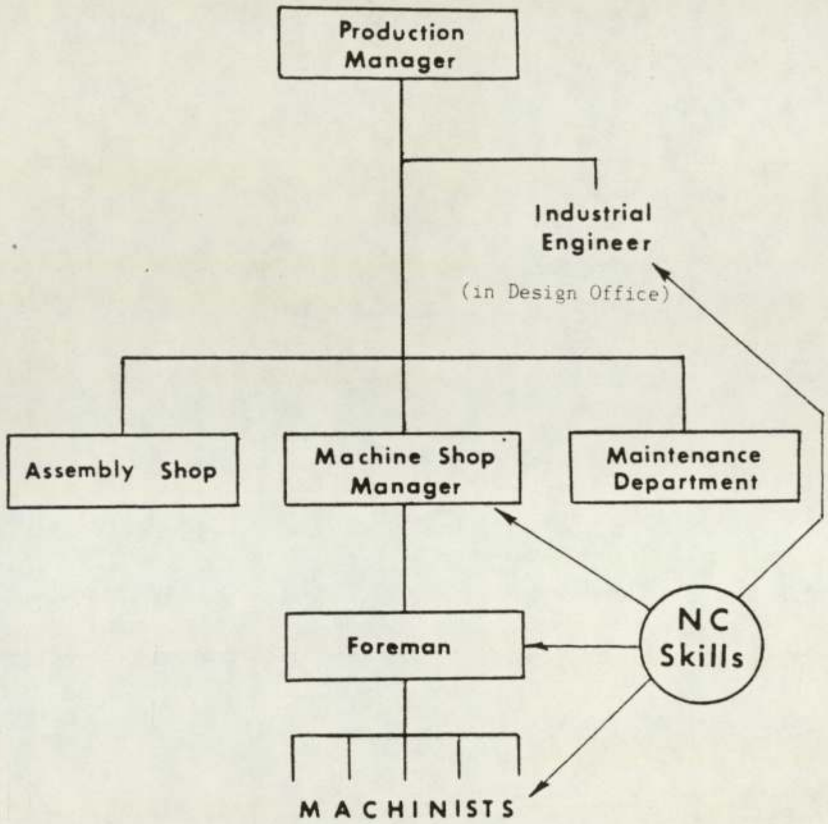


Figure 44 shows the structure of a medium sized company which installed its first N.C. machine in 1971 (which is still in use) and then had an injection of new management in 1981 who introduced 12 N.C. machines between 1981 and 1985. This had been seen to be highly successful and a further reorganisation and investment program for N.C. machine tools was being implemented. So far there had been little impact upon the component designs. The N.C. skills were concentrated in the manufacturing departments.

Figure 44: Medium sized company organisation (150 - 250 employees)

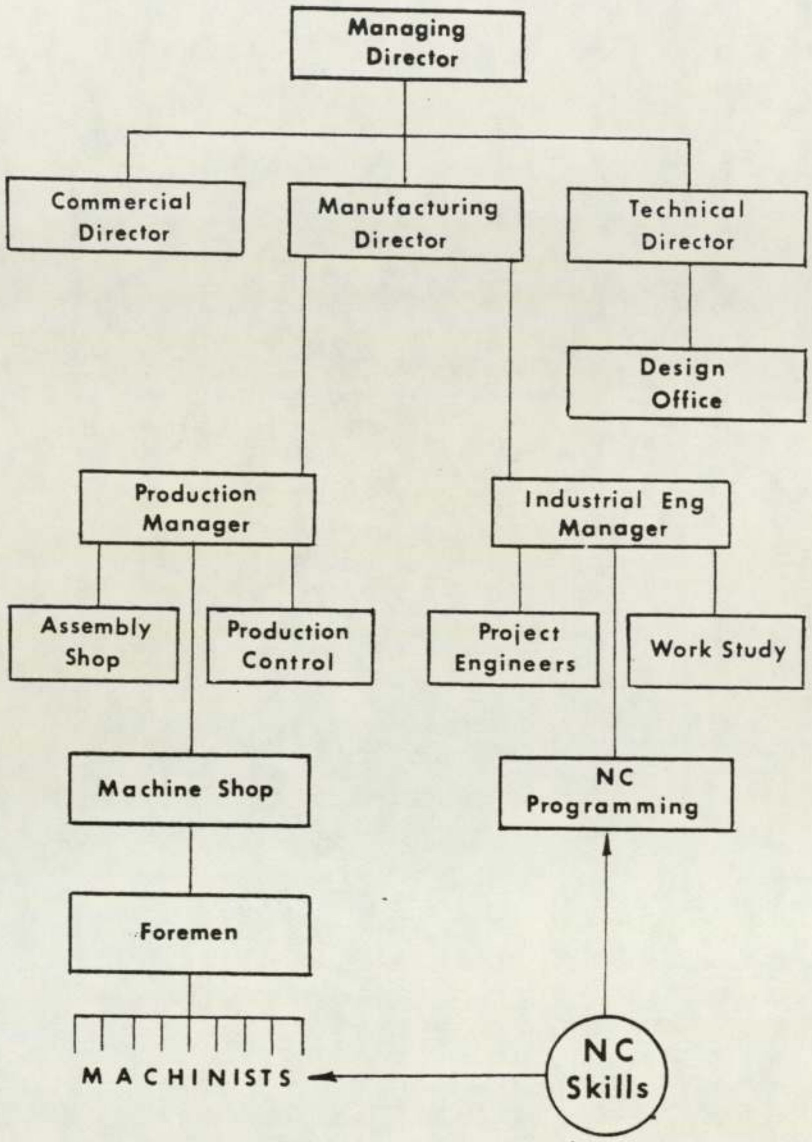
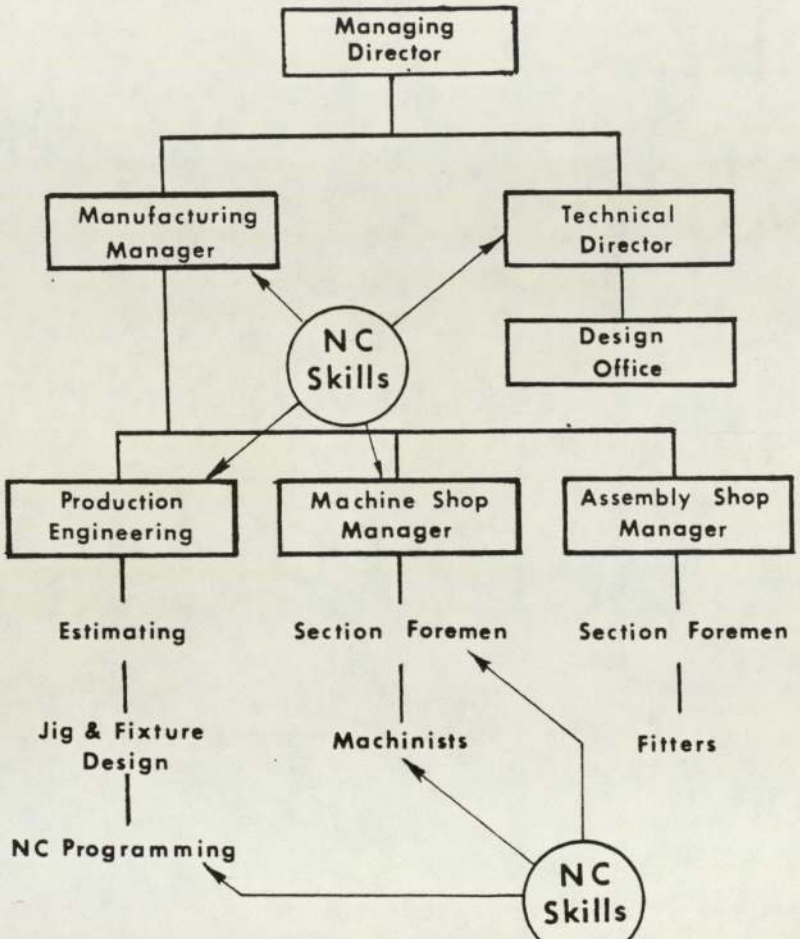


Figure 45 shows a large company which introduced its first N.C. machines in 1965-1968 and these machines were still on site for making some replacement parts. Further N.C. machines were introduced in 1973, 1974, 1978 and 1984, so that the company then had 12 machines in active use. The machines had been well integrated into the company, with all work being put onto N.C. machines whenever possible and the machines being run for two shifts. N.C. skills were well distributed through the company and the shop floor were positively encouraged to gain skills. N.C. machine operators spent two weeks working in the programming department as part of their training, and the programming department collected revised tapes from the shop floor after the operators had developed programs more fully.

Figure 45: Large company organisation (500 - 1000 employees)



8.4 (13) Company Vulnerability Due to NC Adoption

Twenty seven of the companies had considered the possible implications of the failure of a key N.C. machine, and all the larger companies had duplicate machines, or had deliberately retained some of the old machines and tooling as an insurance policy against possible N.C. stoppages. Five of the small companies, however, were vulnerable to N.C. problems, by having one key machine, or possibly more dangerously, by depending upon one key person. In one company there was a supervisor specifically for the N.C. machines - but he did all the setting and programming for several machines. If he were to leave, or to have an accident, or if he were ill, the machinery would become unusable very rapidly. In another company the decline in the general order book had led to people leaving - but one of them was the N.C. programmer. This left the company unable to take on new jobs, and N.C. machines were being disposed of. The company was unable to visualise the possibility of training the shop floor workers to do programming, and was hoping that an upturn in work would allow them to recruit a replacement programmer. The other three companies were dependent upon key people - but recognised this and planned to train other staff as back-up people in case key people were absent.

Other larger companies had experienced significant problems with N.C. - one company had to replace a leadscrew on an N.C. machine, but they had to wait six weeks for the new part. A second company had experienced a major machine breakdown and had undertaken extensive reprogramming to route work onto other N.C. machines. A third company had a break in, and a pile of "tape cassettes" were taken. Unfortunately these cassettes were not much use to the vandals - but the tapes represented one year's work on program development for the N.C. machines!

8.4 (14) Companies Future NC Plans

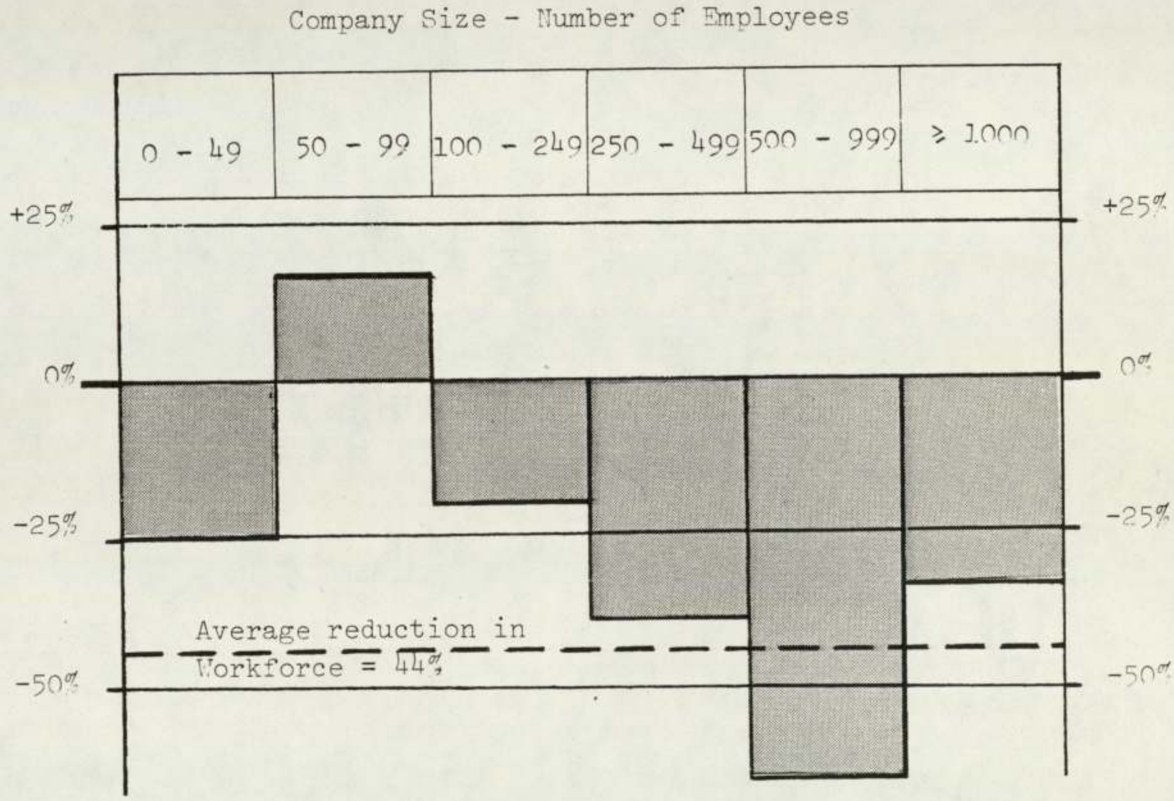
The small companies in the survey were keen to upgrade their utilisation of N.C. Four companies were expected to enhance their skills by further staff development, four were hoping to buy some form of simple computer assisted program preparation system. One company was keen to develop unmanned machining, and obviously they wanted more machinery when their workload could justify it.

One of the medium sized companies was engaged in a substantial investment program in N.C. and was making positive plans to enhance its support systems for N.C. machinery. They were introducing "Tool Kitting" (issuing all tooling for a job in a made-up kit from the stores), tool presetting, and considering the use of DNC systems to monitor machine utilisation. A second medium sized company was very pleased with the benefits from redesigning parts to suit N.C. and intended to exploit the merging of operations much further. Two companies were seriously considering robot operated machining cells or FMS systems. One of the larger companies was about to introduce N.C. lathes with conversational programming into the machine shops for the first time.

8.4 (15) Growth Pattern of Companies

The thirty four companies in this survey have suffered a forty four percent drop in their combined workforce between 1980 and 1985. A few of the smaller companies have shown dramatic growth, from twelve to sixty five employees in one case, but others have shown equally dramatic reductions in the workforce. Figure 46 shows the overall perspective of the workforce changes,

Figure 46: Changes in total employment 1980 - 85



Nine of the twenty two companies with less than 250 employees have increased their numbers of employees, whilst all of the companies with over 250 employees have reduced their workforces. Figure 46 shows that the major area of job losses has been in the large companies (500-999 employees), three of these four companies had workforces of several thousand employees in 1980.

Companies were also asked if their output had increased, and seventeen companies claimed to have significantly improved their output over this period. They had still experienced a 25% job loss over this time. One small company claimed to have increased its output by 500% over this period, but its workforce had only increased by 25%, and some of the larger companies had halved their workforces, but still increased their output.

The companies who were part of groups had experienced a 46% drop in their workforces, whilst the independent companies had only experienced a 19% drop in their workforces. The subcontracting companies showed the smallest overall drop in their workforce - 12%, whilst the own-product companies experienced a 45% decrease in employment.

The overall 46% job loss figure is inevitably an understatement of the change in the workforce of this sector of the manufacturing industry in this region, since companies which closed during the 1980-1985 survey period had obviously excluded themselves from this survey. Two of the companies involved in the initial study did close during the survey period, and it is known that four of these thirty four companies have ceased trading since the survey was completed.

Ten of the thirteen small companies were well established N.C. users with N.C. skills spread throughout the company, whilst the other three companies had more recently adopted N.C., had isolated the N.C. skills, or had lost the N.C. skills. These ten companies had maintained precisely the same total number of employees over the five year period, whilst the other three companies had suffered a 47% reduction in workforce.

Chapter 9, Discussion

The benefits (or disadvantages) arising from N.C. use are discussed, and the impact of N.C. upon the company's performance is assessed. The scope for dramatic change in a company offered by reviewing the product design in relation to the flexibility of N.C. machinery is examined.

Recommendations are made for the organisational structures for effective N.C. use which are most suited to small, medium, and large companies. The training needs to implement these organisational changes are discussed.

Chapter 9, Discussion

9.1 CNC is mostly being used to manufacture conventional parts more cheaply?

As has been stated only one of the thirty four companies was using N.C. to make complex 3D shaped parts, although personal experience is that some other companies are beginning to show interest in die making applications, and two of the companies in the extended timescale survey had sought external quotations for programming complex shapes. N.C. was invented for this purpose, but very little aerospace work was undertaken by the companies in the survey of N.E. industry, and N.C. is being almost wholly applied to machining cubic or rotational components. Obviously complex 3D shapes are expensive to produce, and are usually avoided by designers, but surprisingly little use was made of the capability of N.C. to enhance design of simpler components. Two examples of companies producing complex 2D shapes (e.g. cams) were found, and it was expected that more evidence of the design freedom offered by N.C. would have been found in this survey. This points to a lack of knowledge by designers of the potential for N.C. techniques to offer manufacture of the components that they would like to design in place of the ones they have been previously forced to design.

9.2 Major savings can be made by strengthening the design-production links?

Only three of the companies visited had consciously evaluated the benefits arising from either tailoring the designs to the constraints imposed by the production system, or from installing N.C. equipment which enabled the parts for an assembly to be produced in the sequence required for the assembly process. In most companies the N.C. machines had been installed to produce existing components in a shorter cycle time.

Designers tend to consider each component in isolation, for example say a special nut, bolt, and washer is required, each would be considered on the merits and drawn separately. These would be needed on the assembly line as a family of parts - so they should be made as a family of parts. It is possible to turn the bolt, the nut, and the washer from the same hexagonal bar in that order using an N.C. lathe. Conventionally these would be made as a batch of washers, a batch of nuts, and a batch of bolts. This means that the manufacturing process has to start well before the parts are required and three job cards are issued, three jobs are processed through the factory, three operators are booked on and off the job etc. Multi-start threads can be made just as easily as single start threads on N.C. machines, and there are major advantages in standardising upon a particular thread form (and hence threading tool) and then insisting that the designers change the number of pitches as they use varying diameter threads. This means that tool changing for different thread forms is eliminated and hence the lathe machining the hypothetical family of nuts/bolts/ washers can now machine a range of sizes without the need for tool changes.

N.C. machines are also capable of machining much harder workpieces, and the heat treatment and grinding stages can be frequently avoided by using pre-hardened steel.

The introduction of CAD/CAM systems necessitates the derivation and imposition of a framework of company design and manufacture rules which automatically integrates the production engineers into the design phase of the products. This however was only happening at six of the companies visited, and obviously the full potential benefits at the other companies are not being realised. The time necessary to develop a suite of CAD routines to suit a particular product range means that its use is restricted to companies which manufacture a suitable product range. The use of CAD was seen as totally irrelevant by the majority of companies visited, particularly the subcontract companies.

Links between the subcontract companies and their customers were such that most of the N.C. programs were prepared by the sub-contractors. One or two cases were mentioned where the customers had supplied an N.C. tape with the order for a part, and this must be a method which could be exploited by the customers. If they were to prepare N.C. programs and tapes for the subcontractors they would know much more precisely the estimated costs of their designs, and they would presumably be able to get a quicker turnaround of orders. The major barrier to this is obviously the non-interchangeability of tapes between N.C. machines, but even if the customer were to supply post-processed programs for the major N.C. controls (say G.E. and FANUC) these would soon be edited by a subcontract company to suit a similar capacity machine with a different control.

The new EIA-RS494 data interchange standard* is a move towards this interchangeability but obviously another ten years will elapse before industry even becomes aware of it!

An alternative structure of a sub-contract company introducing group technology cells and specialising for example, in shafts, keyways, splines etc. could possibly offer an opportunity for a company to gain an edge on its competitors, but no example of this type was discovered.

9.3 CNC can reduce product lead times?

As mentioned in 9.2 above only three companies had systematically exploited this from the design stage. Figure thirty five demonstrated that the majority of companies were claiming to have reduced work in progress levels to some extent by virtue of the more rapid output

*Ref 12

from N.C. machines. The use of the N.C. machines for longer hours than conventional equipment must help to move work through the factory more quickly, particularly the three shift systems recently adopted by some of the larger companies.

The opportunity offered by the potential flexibility of N.C. machines was rarely appreciated by the companies visited during this survey. A major reappraisal of the company's investment strategy is required to enable these benefits to be realised. Many cases were seen of N.C. machines making the existing components just a bit faster. The same machine and the same investment could have been used to move towards "Just in Time" production. The Ferranti example previously mentioned is an excellent example of what is possible providing that the investment is treated as an opportunity to review the production sequences of the company, rather than approaching it as a conventional cost-benefit analysis of the savings from replacing three existing machines by one N.C. machine.

Buchanan's classification of investment objectives* into strategic, Control, or Operational classes is extremely pertinent here. Many of the larger companies have used N.C. to enhance their <u>control</u> of the shop floor, and many companies have installed N.C. for <u>operational</u> reasons - to reduce costs in a particular area. The three companies mentioned above who have revised their organisations by the introduction of N.C. have consciously evaluated the <u>strategic</u> objectives for the introduction of N.C. It is felt that this classification of company objective provides the key to effective implementation of N.C. The possible implications of N.C. use should be very carefully evaluated in order to demolish all arguments which

*Ref 22

prevent the machines from being used for "Just in Time" manufacture. This impacts considerably upon the designers as well as the production engineers. The example quoted of a company installing a line on which all products could be made on the fixtures already on the machines and by using the range of tools on the machines shows that it is possible to achieve this without installing an expensive FMS system.

Ferranti's philosophy was that the designer must use the range of standard materials kept in stock, and that the parts must be completed in one machining operation. This leads apparently to much waste metal when a complex structure was machined from solid material, but it was cheap standard material in place of special castings unique to a particular component.

Any machine investment is thus an opportunity to review the strategic objectives of the company, and a method study questioning approach must be applied to the investment proposals:-

WHAT are we doing with this machine?

What should we be doing with this machine?

WHEN do we use this machine in the manufacturing sequence?

When should we use this machine?

WHERE is this machine sited?

Where should it be sited?

WHY are we doing this operation?

Should we do it at all?

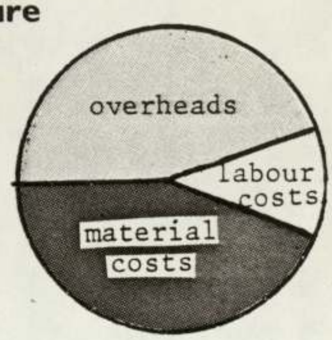
HOW are we machining this part?

How should it be machined?

In addition the form of the raw material must be reviewed - the part must be made from material that can be bought ex-stock from any supplier. Either standard material shapes should be bought, or flame cut blanks used. If flame cut blanks are used - then the designer must make all the parts from one sheet from which all the surplus metal has been flame cut, but which is left as one complete sheet for subsequent separation into individual parts as they are removed from the machining centre. In this way all the separate parts can be processed and set-up as one "assembly". None are missing, and all are ready at once.

A cost-benefit framework needs to be established to enable this approach to be appreciated by the company. Conventional costings take the machine cycle time as a basis and add overhead to this time i.e.

Figure 47: Conventional company costing structure



In fact the labour costs are usually the smallest part of the costs, and yet they are used to allocate overheads to the product. The technique of making families of parts discussed above removes the need for stores for batches of parts, for forktrucks to move the parts to and from the stores, for progress chasers to find out why the individual parts required are not in the stores, for clerks to cost each separate operation and for setters to set up machines for individual parts. It is obvious that family part manufacture transforms the company structure, and the existing company procedures cannot evaluate its benefits. May be that is why only three companies were adopting this approach.

A company which has adopted this approach is Flymo, who (although it is a very different industry) have costed the interest rate incurred on work in progress at 33%.* This is well above conventional interest rates, but it allows for the existence of the storage space and personnel necessary to manage parts storage.

*Ref 29

The companies who did employ N.C. machinery for strategic purposes were those where influential people had the depth of N.C. knowledge which allowed them to envisage these possibilities. This is obviously more likely to happen in smaller companies where the chain of command is much smaller and therefore communication barriers are less. Some of the larger companies had appreciated the benefits possible from the flexibility of N.C. and had deliberately structured the organisation to obtain these benefits by positioning the N.C. programmers in the design office. The companies who were just using the N.C. machines for operational purposes were those where the N.C. skills were isolated into local departments, and thus the knowledge of the machine's capacities was restricted to a few people who were probably also unaware of the strategic possibilities offered by the machines.

9.4 Skill structures:

(1) Large companies tend to use NC to control operators?

(2) Small companies tend to enhance operator's skills?

Figures 23 and 24 demonstrated that in general the large companies used N.C. operators as setter/operators, and retained programming skills in the relevant department, but the "bureaucratisation" of N.C. meant that programming skills were rarely available in the workshop supervision staff of the larger companies. This confirms the findings of the German/British N.C. survey mentioned previously that British companies adopt a "traditional" and "Tayloristic" approach to shop floor staff. This is in complete contrast to the situation found in the small companies where the operators are mostly programmers/ operators, but surprisingly the foremen are also programmers, and so is the manager. The small companies have thus deliberately enhanced their shop floor skills in order to get the most effective utilisation of the N.C. machines. The large companies try to become organised so that the machines are supplied with sets of tools, jigs. and materials, but they have not tried to motivate the shopfloor staff to enhance the machine utilisation by their own efforts. In one case a large company was having trouble finding volunteers to operate a new N.C. machine because the piecework system meant that the person moving onto the machine could lose money. On conventional machines the operator's efforts could have an impact on the output, and he could thus earn a satisfactory bonus.

This is a problem of the organisational structure of larger companies, but when it was mentioned to large companies that other companies expected operators to be programmers, this was treated as an unbelievable statement.

The managers of such large companies are thus accepting the straight-jacket of tradition, and an important result of this survey is the evidence that shopfloor people can be key people in enhancing the utilisation of the N.C. machines, when they are allowed to do so. The one outstanding small company who had achieved 500% growth had not only organised special courses on site in programming for their operators, but they took them to the races for the day (all expenses paid), and had installed a gymnasium for the operators.

The framework of gradings of N.C. skills developed during this study of N.C. use is considered to be one of the most important results of this study. It shows that companies do have a real choice about the skill structures they adopt for new technology, and it provides a framework for them to make a considered decision as to the best course of action, rather than continuing with the existing structure because it just happens to be there. The one larger company shown in figure 45 has consciously enhanced the shopfloor skills and designed its systems to encourage operators to improve on N.C. programs, and then the programmers are expected to learn from these improved programs. Obviously the work done in the larger companies is usually more complex than that done by the smaller companies, and this creates the need for a production engineering department to decide the machining techniques and programs to be used, but it does not prevent operators from building upon the production engineers initial efforts.

A few of the larger companies are introducing conversational programming for lathework, where the programs required will not be as complex as for machining centres, but very few of the larger companies were involving the supervisors or managers in the organisation of N.C. skills.

9.5 (1) Own product companies will refine their programs more carefully?

(2) Sub-contract companies will utilise operator initiative by delegating programming to the shop floor?

The own product companies tended to be the larger companies who invested more in computerisation of program preparation and controlled the machining conditions from the office (see figure 29), whilst the sub contract companies generally did delegate programming to the machinists. The smaller companies were able by this method to produce one-off components on the N.C. machines, and the queue of jobs awaiting programming was avoided if all the operators were able to be programmers.

The effectiveness of shop floor programming in comparison to office programming is a factor which could not be studied without spending a considerable amount of time in many companies, and the meaning of "effectiveness" would have to be carefully defined before it could be studied. Fast response to customers requirements may be more important than saving every possible second in the cycle time by the development of a "perfect" program.

Subjective evidence of the Polytechnic's technicians use of N.C. machines suggests that traditional machinists leave a lot to be desired in their exploitation of the N.C. machines capabilities for rapid metal cutting. The circumstantial evidence of the lack of job loss at the companies using shopfloor programming suggests that the possible loss in metal cutting efficiency is fully compensated for by the job satisfaction and hence motivation gained by trusting people on the shopfloor.

9.6 CNC demands tighter organisation to maximise its utilisation?

There was no evidence found that companies were actually scheduling work for N.C. machines differently to conventional machines in order to enhance its utilisation, but the larger companies were using techniques such as tool presetting and tool kitting to reduce machine downtime. One company had implemented a DNC system to enhance its monitoring of N.C. utilisation, and two were implementing DNC systems. The implementation of DNC must be regarded as a control objective of new technology, but the smaller companies relied upon personal control systems rather than bureaucratic systems. The most telling comment from the owner of one small company was that he thought of his machining centre as "clocking-up" costs just like a taxi cab meter:- One pound every two minutes! He thus ensured that the machine did not wait for anything.

The interpretation of this hypothesis can however be widened out by considering the meaning of "tighter organisation".

The objective is efficient and continuous use of the machinery, and as discussed the larger companies assign responsibilities for various functions to the relevant departments - programming, tool preparation etc. The smaller companies have devolved a higher level of skills and thus responsibility onto the operator, and benefit by better motivation.

One small company responded to next weeks gaps in the machine utilisation by seeking work for that machine from customers. This level of flexible response to daily situations is not likely to be realised by larger more bureaucratic companies.

9.7 CNC machines can introduce excessive dependency upon key machines or people?

This was initially found in the extended timescale survey, which was planned to discover situations such as this as they developed over time. Several companies have been identified which are still vulnerable. Many of these problems of vulnerability seem very obvious in retrospect, but they are new problems outside the experience of the people concerned. These are people learning to adapt to new skills and finding that quite time consuming, and they can easily drift into a situation where the unique skills of one particular person or a few tape cassettes are absolutely vital to the company. Murphy's law is such that that person will leave, or the tapes will get dropped in the coolant tank and the company suddenly finds it has a very dangerous situation on its hands.

It is easy to state that companies should avoid these situation, but smaller companies will inevitably have fewer staff or resources available to duplicate critical facilities, and larger companies will often find that a certain high cost machine cannot be duplicated.

Larger companies are more likely to organise back-up systems for computer files - but they need to ensure that all engineering files are fully duplicated. The spread of desk top computers and local data storage means that each user has to be extremely systematic about duplicating data, and about keeping those spare floppy discs in a separate building where even a fire will not destroy five years development. It is suspected that most small companies (and many medium sized companies) are not sufficiently self disciplined to avoid these critical dependencies, even if they are aware that they exist.

It is extremely important to realise that while the machine may be costed at £30 or £50 per hour, the repercussions of a stoppage can very rapidly be costing possibly £1000 per hour if a following assembly line is stopped by the knock-on effect.

In this discussion it has been argued that N.C. offers the potential to review the production system and make parts in the order required by the assembly line. This charges the factory from a batch production system to a Just in Time system. The long lead times for batch production, however, acted as a reservoir of stocks and allowed for remedial action to be taken (overtime?) to recover from a machine breakdown or someone having a day off ill. Moving to family part manufacture however means that the N.C. machine should be feeding directly onto the production line - and if that machine can only be operated by one individual, or if it has a major breakdown (- broken leadscrew - 6 weeks?) then the lost sales are immediately impacting upon the company. Companies who are entirely dependent upon one machine could negotiate in advance with another company with an identical machine to give themselves some insurance against catastrophies.

The non-standardisation of the machine control systems is another factor introducing vulnerability, the training of operators to cover each other's machines can be important, and the failure of a machine can cause the need for extensive programming to permit re-routing of work.

9.8 Company growth patterns.

Since the survey has concentrated specifically upon companies using N.C. machines for metal cutting, the data gathered cannot be related to any other published data for company size trends. Comparisons have thus been made between companies within the survey, and the area of strong growth (or at least No job loss) is the group of small subcontracting companies found during the survey. The national survey of N.C. use undertaken by the Centre for Urban and Regional Development studies at Newcastle University* had concluded that there was a threshold size of approximately 20 employees below which very few companies adopted N.C. This survey has shown, however that those small companies that do adopt N.C. make very good use of it. The 1982 survey of machine tool distribution by Metalworking Production* found that while subcontract companies had 14.3% of the total machine tool population in Britain, they had 21.7% of the N.C. machine tools installed in the country. This again confirms that smaller companies are making better use of N.C. machinery than the larger companies.

The difference in job losses between the own product companies and the sub-contract companies could be due to a growth in the proportion of work subcontracted from the own-product companies, but it would be dangerous to generalise without considerable further study of this topic. One of the own product companies had recently realised that half of its turnover now consisted merely of handling parts produced by subcontractors. This turnover (£2 million) was being used to justify the installation of the company's own CNC machines, with the aim of pulling back in all the subcontract work and regaining a large portion of the £2 million as an enhanced contribution to overheads.

While many of the companies have experienced large job losses over the period of the study, it is quite surprising how many of these companies have actually increased their output. The phrase "Jobless growth"

*Ref 30 *Ref 28

seems to need revising to "Job Loss growth". Two of the owners of the small companies had visited Japan to study the competition and had returned quite pleased with their own companies. They did not consider that they were behind the supposed world leading nation. One of these people did however comment that he considered that full employment would never return, further investment would lead to fewer jobs. The 1982 survey mentioned above also made the point that Britain's N.C. machines formed 3.32% of the total machine tool population, while they were only 2.84% of Japan's machine tool population.

It is very difficult to assess whether the "success" of these small subcontracting companies is consequent upon their use of N.C. machines. No comparable study has been made of a similar group of companies who have not adopted N.C. machines, and it may be that their success is due to other factors such as the flair of the owners.

9.9 "Ideal" organisation for NC:

9.9 (1) Small companies

The successful small companies encountered during these surveys were the ones who had delegated skills and responsibility to the machinists. The two companies who centralised the skills either closed or sold off the N.C. machines. This demonstrates the avoidance of vulnerability by the successful companies, and the benefits arising from enhancing the skills and participation of the shop floor staff.

It is thus concluded that the companies depicted by figures 37 and 39 (N.C. skills at all levels of the organisation) demonstrate an ideal structure for such small companies.

9.9 (2) Medium sized companies

Many of these companies had adopted a mixture of shopfloor programming and some "office based" programming. Obviously more complex workpieces can demand many hours of analysis to write a suitable program, and this is more easily undertaken in an office situation. None of the companies visited had tried the organisation discussed in the study of the German Companies, where the demarcations between the shopfloor and office staff were virtually non existent (and this is despite the German system of different state benefits for office and shop floor staff). This enabled programmers and machinists to be interchangeable according to the current workload.

This is considered to be an ideal structure, whereby, say, five people are employed to program and operate four N.C. machines between them. This provides the time for concentration upon difficult workpieces and, much more importantly, provides cover against absence or departure of any of the people. These people would ideally all be able to program and operate all the machines, but no doubt each would demonstrate a flair in one particular area, so he could tend to use those skills when possible.

Naturally the traditional organisational attitudes would all be used to raise reasons why this structure could not possibly work - but the most rigid thinking usually comes from the older managers who would never consider attempting to introduce this structure.

This structure is put forward as the ideal model for a medium sized company to adopt. The shop managers and foremen should also have N.C. training, and so should some senior design staff. Also the desk available for the programmer/machinist must be placed in the design office. Assuming that this medium sized company has its own product, it has the opportunity to review its design in relation to the N.C. facilities as discussed in section 9.3. It should design its products so that particular ranges of milled parts can be machined in "part families" on machining centres. These parts should be machined in kits equal to the set of parts required to make one finished assembly.

Most engineering products have rotational parts which fit into the cubic parts from the machining centres. These rotational parts should be designed so that they can be made in similar "part families" wherever possible.

This "part family" scheduling should allow delivery of a set of parts to the assembly shop in, say seven days. This type of short lead time is being achieved by companies using FMS systems - but there is no reason why the same approach cannot be applied at many factories where the heavy investment required for an FMS could never be justified. The problem of FMS investment justification is a particularly difficult one for small companies to overcome, and the approach suggested here is a way of allowing "FMS techniques" to be used in many smaller companies.

It is quite likely that many of the medium sized companies subcontract much of their work - but the design of the product to permit 'part family' machining would enable their suppliers to provide very rapid deliveries.

9.9 (3) Large companies

Large companies are much more likely to have a separate programming department, whose existence is justified by the specialised computer systems used to generate N.C. programs. They are, however, the companies who tend to constrain the skills of the machinists to just operating and setting the N.C. machines. The company shown in figure 45 is extremely unusual in its depth of N.C. skills, but the main organisation technique adopted of benefit in N.C. operation is considered to be the enlightened approach to enhancing the machinists programming skills. The systematic collection and reviewing of programs revised by the machinists in view of the problems they experience when machining a particular job is an extremely important way of providing feedback to the programmers. This not only provides the machinists with a chance to contribute their knowledge, but also helps systematically to educate the programmers about the realities of shop floor problems.

The proposed introduction of a DNC system to encourage this interchange of ideas and skills is an unusual example of the use of technology in a large company to enhance people's skills. DNC is also a monitoring and control system over the shop floor, but its "Big Brother" aspect is only one of the objectives of its proposed use in this instance.

It is unlikely that the above interchange of skills between the shop floor and the programming department can be realistically improved upon in large companies. It is thus suggested that the above example shows an "ideal" structure for N.C. use.

The product design suggestions above obviously can be just as relevant to large companies as to any other companies.

9.10 Training requirements for eficient CNC use:

9.10 (1) Machine operators

Companies involved in these surveys all claim to be satisfied with the machine tool manufacturer's training provision for operating and programming N.C. machines. It is thus recommended that these courses are used by companies - but with the addition that the machinists all undertake programming courses. The provision of one place on a programming course and one place on an operating course is usually included in the purchase price of the machine, but extra places are expensive, and also involve losing staff from production time. It is thus suggested that use is made of local technical college resources for additional training requirements. It has been mentioned that one small company arranged to have an N.C. programming course run in the plant immediately following theend of the working day, and obviously this method is effective in getting full participation where several operators and other staff need training.

9.10 (2) Shop foremen

The foremen will probably not need to have operator training courses, the operating skills can be easily acquired from the operators who have been on courses, but they should take the same programming courses as the operators.

9.10 (3) Programmers

There are two levels of machine tool programming and, whilst the majority of operators are working from manually prepared programmes, the majority of N.C. programmers are using some sort of computer assistance. It is recommended that programmers should be competent to operate the machines in smaller companies, but obviously larger and more complex machines need a longer learning period, and it is unlikely that programmers in larger companies would be able (or allowed) to operate N.C. machines. Obviously the programmers need training in the particular languages relevant to each company, but it is strongly recommended that they also take an operating course. This will enable them to understand advice given to them by the machinists, and thus will improve their programming skills.

9.10 (4) Designers

A representative number of design staff should take N.C. programming courses to enable them to gain a clear insight into the design possibilities offered by N.C. machines. Courses for designers should include seminars which cover the possibility of redesigning products to use standardised tooling kits and standardised workholding arrangements, as previously discussed.

9.10 (5) Shop managers and directors

It is essential that they have a good appreciation of the possibilities offered by N.C. machines, but they will not usually need to know the details of programming or operating N.C. machines. Special courses need to be mounted to demonstrate the design freedom possible with N.C. machines, and to drive home the message that N.C. offers an opportunity to completely rethink the traditional batch manufacturing process. "Part Family" manufacture is only possible if the designers are constrained to design within the limited freedom offered by a standardised kit of tooling and by the use of standardised raw materials which do not require special complex fixtures.

The ability to stand back and re-think the whole manufacturing system is limited by the presence of existing products, and obviously the best opportunity arises when a new generation of products is being launched.

The constraints of the existing costing systems inhibit the justification of proposals which restructure the company. A complete re-costing of any proposal needs to be undertaken which takes account of all the savings arising from removing work-in-progress, from releasing factory storage space and from reduced shop control activities. This should also take into account the benefits arising from a speedier response to customer's needs, and to the new market opportunities so created. This will involve retraining of senior staff, and some of the financial staff need to be involved in this training if they are going to comprehend the scale of the changes which are being suggested.

It is suggested that this type of training is best undertaken by a case study approach, i.e. a one or two day seminar off-site with several senior management and engineering staff who know their product intimately.

The one or two external people leading the seminar should start off by introducing Buchanan's investment objectives i.e.

(i) Strategic purposes

(ii) Control purposes

(iii) Operational purposes

and then lead the company staff into a strategic review of the manufacturing systems used by the company. They should adopt a method study questioning approach to lead the company staff in a complete review of the product to identify the separate components which may be brought together into part families for processing by milling or turning (or other N.C. processes). The objective is to reduce the separate new material types and shapes to as few distinct varieties as possible. This enables kits of parts to be made at one set-up from readily available raw materials in the shortest leadtime possible. When a consensus has been arrived at forthe proposed redesign the machine tools required to produce the product can be defined, and a detailed costing performed on the basis of providing all the required services, floor space, machinery, storage facilities etc in an empty workshop. This will allow the building up a new cost structure to suit the new produced production system. The sales department should be asked forestimates of the sales benefits that would arise from dramatically reduced delivery times (and lower costs). This approach is necessary for two reasons:-

(a) The existing cost structure cannot measure the benefits of the proposal.

(b) The participation by the senior people is essential if they are to accept the validity of a revolutionary proposal which breaks all the rules of their previous experience. If the proposal has been produced by the company personnel using their knowledge and experience they will have confidence in the result. It is unlikely that any external agency could sell a similar proposal to the company.

9.11 Recommendations for further work:

(1) Design for NC   One of the major findings from this research is that a close linkage between the production engineers and the designers can revolutionise the typical batch production factory. It is therefore recommended that the major research topic arising is an analysis of the scale of changes that are possible by the exploitation of this linkage.

This analysis should be undertaken by a detailed review of the production practises, at, say, ten own-product companies and the redesign of typical products from those companies in light of the "Part Family' approach previously described. The cost benefits would need to be carefully quantified to enable the potential benefits from this survey to be fully assessed. A very careful analysis of the redesign process could need to be conducted with a view to derivation of guidelines which would enable other companies to apply the lessons drawn form the study. These design guidelines would need to cover two main areas:-

(i) the design "freedom" available from the use of N.C. machines

(ii) the tooling and workholding contraints within which the designers must work in order to obtain the flexibility required to run different products through the N.C. machines without the need for re-setting the machines.

(2) Costing guidelines   In parallel with the derivation of the above design guidelines a review of the company costing procedures should be conducted to enable the derivation of a framework to enable companies to fully quantify the potential benefits of "part family" manufacture.

(3) Customer - sub-contractor relationships It is quite probable that the above study would involve some contact with subcontractors, but it is considered that a separate study be conducted of the potential

benefits arising from narrowing the communication gap between the customers and their suppliers. This study could be conducted by examining the benefits that would accrue to both the customer companies and their suppliers from the suppliers being able to feedback production engineering improvements to the customers. Several customer companies and their respective sub-contracting companies should be studied to provide an overall perspective of the potential benefits.

A second factor which could also be examined would be the benefits that could arise from customers being able to supply standardised N.C. programs and hence cycle times to their suppliers. What reduction in lead times would be possible, and what cost savings would there be to the customers?

(4) The effectiveness of shop floor programming

An emerging trend to shop floor programming has been revealed by this survey. The efficiency of the use of the N.C. machines under these circumstances is an important matter. Is there room for improvement in the programs being produced by shop floor programming? What cutting speeds and feeds are being used?

The definition and measurement of the "effective" use of N.C. machines in those circumstances is seen as an important task with major implications for the training requirements of shop floor and supervisory staff. In what areas are the shop floor staff making good/bad use of N.C. machines and how should these good/bad habits be encouraged or eliminated?

9.12 An overall perspective.

The average reduction of 46% in total employment by the companies involved in this survey is an alarming figure which has worrying social implications if it is a true picture of what is happening to industry nationally. The vision of a divided society was very effectively portrayed in the excerpt from "The Piano Player" and it is to be hoped that we can avoid that situation. Several local factors may have caused the contraction of the sector of the engineering industry studied in this report to be untypical of industry as a whole across the country. Only companies using N.C. machinery have been visited, and the mining and shipbuilding industries have had a troubled time recently. Several of the companies visited were directly affected as suppliers to the NCB, and shipbuilding is a major source of subcontract work. Interestingly though, the subcontract companies were the ones who had done best over the period of the survey, and several of them thought that the Nissan car factory project was creating local work towards the end of the study. The own-product companies however, were the companies whose markets were national and international, and thus they ought to be less dependent upon the local economy. It is these companies who have contracted most, whilst the subcontract companies would be expected to have a local customer base, and to be more dependent upon the local economy.

Several of the medium to large sized companies claimed to have increased their output whilst halving their workforces, and this confirms the general trend to displace labour by the increasing use of capital intensive machinery. N.C. machines are a continuation of (and an acceleration of) this long established trend. Chapter two showed the results of an intensive effort to improve productivity at a local factory making consumer products, and other examples abound.

This report has clearly demonstrated the benefits to be gained by fully involving trained personnel in the operation of the equipment - and also its critical dependency upon key personnel. The human factor is, however, ignored by conventional appraisal routines for plant replacement proposals. Surely the training or "replacement" costs of key people should be an essential consideration in the planning of advanced technology systems. The effective utilisation of such equipment is totally dependent upon well trained and well motivated shopfloor staff. German industry and, so we are told, Japanese industry have learnt these lessons, but the small companies in this survey are the ones who are moving significantly in this direction.

There was a strong feeling from the engineers interviewed that unemployment is here to stay, especially for those people who are lower down the skills scale. The "part-family" approach advocated in this report can be highly economic precisely because it displaces the workpiece handling and part storage operations typically found in batch manufacture. These types of jobs are now not necessary in well planned factories.

It is desirable to run the N.C. machines for longer hours, and generally the smaller companies used overtime for this purpose. The introduction of CAD into drawing offices has caused a revolution for draughtsmen's hours, and it is possible that the same approach of flexible working hours could create two jobs for each N.C. machine in small companies without the need for a nightshift. This could be used to considerable advantage if the operator's excess hours overlapped with other operators, and released people to prepare programs or tools for the next job.

Would this more intensive use of N.C. machines create or destroy jobs? If this approach were used to just make existing jobs more cheaply, there would be large scale job losses, unless these products can now reach a new expanding market because they are more competitive. Once again we see the strategic implications of effective N.C. use.affecting the operation of the company.

The sales department would need to explore the marketing opportunities created by lower prices, and to gear themselves up to exploit the new capacity and flexibility now available to them.

Chapter 10, Conclusions

- Complex 3D shapes form a very small part of the current workload on N.C. machines.
- Computer aided programme preparation was only used in one third of the companies surveyed, and some who did use it limited its use deliberately to avoid shop-floor editing problems.
- CAD/CAM links are only being developed by a very small minority of companies.
- N.C. can introduce vulnerability into an organisation and care needs to be taken to avoid dependence upon either critical machines or key personnel.
- Companies who isolate the N.C. skills into small compartments in the company are unlikely to fully exploit the potential of N.C. use.
- There is a need for management retraining on the benefits to be gained from the redesign of the product in order to enhance the efficient use of N.C.
- Small companies will appreciate and assimilate N.C. use more rapidly and more effectively than large companies.
- N.C. does not impose one particular organisational structure. It can be used to reinforce control of the shop-floor, or to delegate additional responsibility to the shop-floor in order to use more fully the operator's experience.
- Companies have a wide choice over the skill patterns they can choose to adopt for N.C. use. They should undertake a systematic analysis of the most relevant skill patterns to their particular situation, paying special attention to avoiding dependency upon key people.
- The major benefits potentially available from N.C. use arise from rethinking the product design to concentrate manufacture so that the workpiece is machined in one machining cycle.
- The objectives guiding any particular investment plan should be identified by reference to the below objectives:

(a) Strategic

(b) Control

(c) Operational

This enables a clear view to be taken of the implications of the investment, and to maximise the potential benefits of that investment.

- Introduction of N.C. machines should be seen as an opportunity to review the workflow patterns of a company.

From the research work done to date it is apparent that if industry is to be successful in adopting new technology is must consider this adoption as a totally integrated feature.

It must not only consider the new hardware (or software as the case may be) but also the interface with existing resources, which may be human.

Resistance to change can be the result of failure to inform all concerned of the benefits of new technology. Sub-optimum results can be obtained if the company leaves itself vulnerable to failure of a key resource.

Companies are still not achieving the full potential of new technology by their approach of using this to replace existing technology rather than as a means of generating new products of better performance, cost, or appearance.

APPENDICES

1. "The Piano Player"

Extract from "The Piano Player" by Kurt Vonnegut

"The group, five ranks of ten machines each, swept their tools in unison across steel bars, kicked out finished shafts onto continuous belts, stopped while raw bars dropped between their chucks and tailstocks, clampled down, and swept their tools across the bars, kicked out the finished shafts onto ...

Paul unlocked the box containing the tape recording that controlled them all. The tape was a small loop that fed continuously between magnetic pickups. On it were recorded the movements of a master machinist turning out a shaft for a fractional horsepower motor. Paul counted back - eleven, twelve, thirteen years ago, he'd been in on the making of the tape, the master from which this one had been made ...

He and Finnerty and Shepherd, with the ink hardly dry on their doctorates, had been sent to one of the machine shops to make the recording. The foreman had pointed out his best man - what was his name? - and, joking with the puzzled machinist, the three bright young men had hooked up the recording apparatus to the lathe controls. Hertz! That had been the machinist's name - Rudy Hertz, an old-timer, who had been about ready to retire. Paul remembered the name now, and remembered the deference the old man had shown the bright young men.

Afterward, they'd got Rudy's foreman to let him off, and, in a boisterous, whimsical spirit of industrial democracy, they'd taken him across the street for a beer. Rudy hadn't understood quite what the recording instruments were all about, but what he had understood, he'd liked: that he, out of thousands of machinists, had been chosen to have his motions immortalized on tape.

And here, now, this little loop in the box before Paul, here was Rudy as Rudy had been to his machine that afternoon - Rudy, the turner-on of power, the setter of speeds, the controller of the cutting tool. This was the essence of Rudy as far as his machine was concerned, as far as the economy was concerned, as far as the war effort had been concerned. The tape with the essence distilled from the small, polite man with the big hands and black fingernails; from the man who thought the world could be saved if everyone read a verse from the Bible every night; from the man who adored a collie for want of children; from the man who ....

... What else had Rudy said that afternoon? Paul supposed the old man was dead now - or in his second childhood in Homestead.

Now, by switching in lathes on a master panel and feeding them signals from the tape, Paul could make the essence of Rudy Hertz produce one, ten, a hundred, or a thousand of the shafts.

Paul closed the box's door. The tape seemed in good condition, and so were the pickups. Everything, in fact, was as shipshape as could be expected, considering the antiquity of the machines. There were just going to have to be rejects, and that was that. The whole group belonged in a museum, not a production setup. Even the box was archaic - a vault like affair bolted to the floor, with a steel door and lock. At the time of the riots, right after the war, the master tapes had all been locked up in this way. Now, with the antisabotage laws as rigidly enforced as they were, the only protection the controls needed was from dust, cockroaches, and mice."

2. CURDS questionnaire

UNIVERSITY OF NEWCASTLE UPON TYNE

CENTRE FOR URBAN AND REGIONAL DEVELOPMENT STUDIES

Name of Company ....

Address of Factory .... **Postal Code** ....

Name of Respondent .... **Position of Respondent** .... **Tel No** .... **Ext No** ......

1. IS THE COMPANY NAMED ABOVE;

		share capital held by another company	tick one box
1.	Wholly owned subsidiary	100%	
2.	Majority owned subsidiary	51% - 99%	
3.	Associate company	10% - 50%	
4.	Joint venture	equal shares	
5.	Independent	less than 10%	

2. IS THE FACTORY NAMED AT THE ABOVE ADDRESS;

(a) the only manufacturing unit of a single plant company ☐

or (b) part of a multiplant company group ☐

IF YOU HAVE TICKED 'b';

(i) WHAT IS THE NAME AND ADDRESS OF YOUR COMPANY GROUP HEADQUARTERS.

Name ....

Address .... Postcode ......

(ii) Please estimate the number of manufacturing establishments and the number of people employed in your TOTAL company group:

Establishments ☐ Employees ☐

How many establishments and employees located elsewhere are controlled from this site

Establishments ☐ Employees ☐

(iii) IS THIS FACTORY;

(please tick one box)

(a) The group headquarters ☐

(b) A regional headquarters ☐

(c) A product division headquarters ☐

(d) Part of a larger product division ☐

(e) Part of a larger regional division ☐

(f) Other (please specify) .... ☐

3. PLEASE ESTIMATE THE CURRENT NUMBER OF STAFF AND PRODUCTION WORKERS EMPLOYED IN THIS FACTORY

Total Employment	Office Staff inc. Management	Works Staff and Operatives	
		Male	Female

4. WHAT ARE THE MAIN PRODUCTS PRODUCED IN THIS FACTORY AND WHAT PROPORTION OF YOUR TURNOVER DOES EACH CONTRIBUTE

	Products	% of turnover (by value)
1.		
2.		
3.		

5. DO YOU CARRY OUT RESEARCH AND DEVELOPMENT WORK AT THIS FACTORY (ie work designed to produce new or improved products and processes)

YES ☐ NO ☐

IF 'YES';

(i) HOW MANY PEOPLE ARE ENGAGED FULL TIME, DIRECTLY ON THESE TASKS IN THIS FACTORY ..... number of people

(ii) PLEASE ESTIMATE THE PROPORTION OF RESEARCH DONE AT THIS SITE WHICH IS;

(a) applied (translating knowledge into commercial invention) ..... %

(b) development (translating inventions into commercial applications and further development of existing products) ..... %

(c) quality control (monitoring production) ..... %

100 %

IF YOU ARE PART OF A LARGER GROUP;

(a) DOES YOUR GROUP HAVE A CENTRALISED RESEARCH ESTABLISHMENT

YES ☐ NO ☐

(b) WHAT IS THE ADDRESS OF THE RESEARCH ESTABLISHMENT

Address ....

6. WHAT PROPORTION OF THE TOTAL INPUTS OF YOUR FACTORY ARE SUPPLIED BY EACH OF YOUR THREE MAIN SUPPLIERS, UNDER WHAT ARRANGEMENTS DO YOU DEAL WITH THEM, ARE THEY MEMBERS OF THE SAME GROUP AS YOURSELF AND ARE THEY MERCHANTS OR NOT

	% of inputs (by value)	principal purchasing arrangement (tick one box only)			member of same group		merchant, factor or wholesaler	
		bought from stock (off the shelf)	made to your specific order	made to your order with draw-off arrangements				
Supplier 1					yes	no	yes	no
Supplier 2					yes	no	yes	no
Supplier 3					yes	no	yes	no

7. DO YOU MAKE PRODUCTS OR EQUIPMENT UNDER FRANCHISE OR LICENSE TO ANOTHER COMPANY

YES ☐ NO ☐

8. WHAT PROPORTION OF THE TOTAL OUTPUT OF YOUR FACTORY IS SOLD TO EACH OF YOUR THREE MAIN CUSTOMERS, UNDER WHAT ARRANGEMENTS DO YOU DEAL WITH THEM AND ARE THEY MEMBERS OF THE SAME GROUP AS YOURSELF

	% of output (by value)	principal sales arrangement (tick one box only)			Member of same group	
		Sold from stock (off the shelf)	Made to specific customer order	Customer order with draw-off arrangements		
Customer 1					yes	no
Customer 2					yes	no
Customer 3					yes	no

THE FOLLOWING SECTION EXAMINES THE MANUFACTURING OPERATIONS CURRENTLY IN USE AT THIS FACTORY AND THE UTILISATION OF NUMERICAL CONTROL (NC) AND COMPUTERIZED NUMERICAL CONTROL (CNC) SYSTEMS

9. PLEASE INDICATE THOSE OPERATIONS YOU USE, ACCORDING TO THE TYPE OF CONTROL(S) CURRENTLY IN USE AT THIS FACTORY (Where a particular operation is not used, please leave blank)

	Method Other than NC or CNC	NC	CNC (incl. retrofit)		Method Other than NC or CNC	NC	CNC (incl. retrofit)
METAL CUTTING							
Boring	☐	☐	☐	Broaching	☐	☐	☐
Drilling	☐	☐	☐	Electro-chemical machining	☐	☐	☐
Grinding	☐	☐	☐	Electron Beam cutting	☐	☐	☐
Honing and lapping	☐	☐	☐	Laser cutting	☐	☐	☐
Milling	☐	☐	☐	Flame cutting	☐	☐	☐
Turning	☐	☐	☐	Spark erosion (EDM)	☐	☐	☐
Planing, slotting & shaping	☐	☐	☐	Other (please specify)	☐	☐	☐
Sawing & cutting off	☐	☐	☐	....			
Threading & Screwing	☐	☐	☐	....			
METAL FORMING							
Bending & Forming	☐	☐	☐	Punching	☐	☐	☐
Forging & Swaging	☐	☐	☐	Shearing	☐	☐	☐
Drawing	☐	☐	☐	Other (please specify)	☐	☐	☐
Extrusion	☐	☐	☐	....			
METAL JOINING							
Bolting or rivetting	☐	☐	☐	Explosive welding	☐	☐	☐
Soldering or brazing	☐	☐	☐	Electron beam welding	☐	☐	☐
Electric Arc Welding	☐	☐	☐	Laser welding	☐	☐	☐
Stud Arc Welding	☐	☐	☐	Adhesives	☐	☐	☐
Gas Welding	☐	☐	☐	Other (please specify)	☐	☐	☐
Friction Welding	☐	☐	☐	....			

10. WHAT PERCENTAGE (IF ANY) OF THE FOLLOWING OPERATIONS ARE CURRENTLY UNDERTAKEN BY NC AND/OR CNC CONTROLLED MACHINERY

	NUMERICAL CONTROL	COMPUTERIZED NUMERICAL CONTROL (including retrofit)
Metal Cutting	____%	____%
Metal Forming	____%	____%
Metal Joining	____%	____%

11. IN THE FOLLOWING TABLE, WE SEEK YOUR BEST ESTIMATE OF THE YEARS IN WHICH VARIOUS TYPES OF MACHINE CONTROL WERE FIRST INTRODUCED IN THIS FACTORY (Regardless of whether or not they are all in current use)

TYPE OF OPERATION	YEAR OF INTRODUCTION							
	MANUAL	SEMI AUTOMATIC	AUTOMATIC	COPY	PLUG-BOARD	NC	CNC (incl. retrofit)	OTHER TYPES OF CONTROL (Please specify)
Metal Cutting								
Metal Joining								
Metal Forming								

12. IF YOU USE SPARK EROSION (ELECTRICAL DISCHARGE MACHINING) PLEASE INDICATE:

(i) THE PROPORTION OF METAL CUTTING UNDERTAKEN AT THIS FACTORY WHICH IS DONE BY SPARK EROSION:

.... % of total metal cutting

(ii) THE YEARS IN WHICH VARIOUS TYPES OF EDM MACHINE CONTROL WERE INTRODUCED IN THIS FACTORY

	MANUAL	NUMERICAL CONTROL	COMPUTERIZED NUMERICAL CONTROL
YEAR			

13. IN WHICH YEAR DID YOU INTRODUCE TOOLS OR INSERTS OF THE MATERIALS LISTED BELOW IN THIS FACTORY

		PREMIUM CARBIDES	COATED CARBIDE	CERAMICS CERMETS
YEAR OF INTRODUCTION	Tools			
	Inserts			

14. PLEASE INDICATE THE YEAR IN WHICH YOU INTRODUCED ANY OF THE FOLLOWING SUBCOMPONENT (not raw material) FEEDING SYSTEMS INTO THIS FACTORY

	YEAR		YEAR
Manual	☐	Non programmable pick and place devices	☐
Manually loaded magazine feeds	☐	Numerically controlled pick and place devices	☐
Vibratory Bowls	☐	Programmable robots	☐

15. DOES THIS FACTORY USE COMPUTER BASED EQUIPMENT IN ITS:

		YES	NO
(i)	COMMERCIAL ACTIVITY (eg invoicing, stock control, wages or accounts)	☐	☐
(ii)	DESIGN AND DRAFTING	☐	☐
(iii)	MANUFACTURING ACTIVITY - not including CNC-controlled systems noted previously (eg monitoring and control of process, safety and environmental equipment)	☐	☐

IF 'YES'

WHICH OF THESE ACTIVITIES (IF ANY) ARE CARRIED OUT ON COMPUTER FACILITIES AVAILABLE TO YOU AS (please tick appropriate boxes)

		COMMERCIAL ACTIVITIES	DESIGN ACTIVITIES	MANUFACTURING ACTIVITIES
(a)	time purchased from an agency outside your company or company group	☐	☐	☐
(b)	shared time within your company group with hardware located elsewhere	☐	☐	☐
(c)	Other (please specify)	☐	☐	☐

16. EXCLUDING THOSE CONTROL FUNCTIONS ALREADY MENTIONED IN PREVIOUS QUESTIONS, HAVE YOU INCORPORATED MICRO-PROCESSORS INTO YOUR MANUFACTURING PROCESSES IN THIS FACTORY (ie to monitor, control or for safety and inspection etc.)

YES ☐ NO ☐

IF 'YES':

IN WHICH YEAR DID YOU INTRODUCE THESE INNOVATIONS INTO YOUR FACTORY .... year

17. DO ANY OF THE PRODUCTS MANUFACTURING IN THIS FACTORY INCORPORATE ANY OF THE FOLLOWING COMPONENTS AND, IF SO, IN WHAT YEAR WERE THEY INTRODUCED

	Incorporation		Year of Introduction
Maintenance free bearings	Yes	No	
Recirculating ball screws	Yes	No	
Mini computer microcomputer	Yes	No	
Microprocessors	Yes	No	

3. Newcastle upon Tyne Polytechnic questionnaire

Survey of the use of N.C. metalcutting in the North East

Newcastle upon Tyne Polytechnic

Note: ALL INFORMATION WILL BE TREATED AS STRICTLY CONFIDENTIAL

1. NAME OF COMPANY .... Name of Respondent ....
   Address .... Tel. Number .... Ext ....

2. COMPANY PROFILE
   (a) Approximate sales produced at this site ....
   (b) Is this factory the only manufacturing unit of a single plant company? .... Yes No
   or (c) Is this the parent company? .... Yes No
   (d) If not, what is the location of the company's HQ? ....
   (e) Please give an estimate of group's sales in the U.K. ....
   (f) Plase give an estimate of the number of employees on this site ....
   (g) Please give an estimate of the group's total number of employees in the U.K. ....
   (h) Please describe the group's products ....

3. COMPANY PRODUCTS

Please describe briefly the main products from this site, and the proportion of sales of each product.

	PRODUCT	% of Sales
1		
2		
3		

4. HOURS OF WORK

Please give an indication of the hours worked by the company.

	CONVENTIONAL MACHINES	N.C. MACHINES
Days		
2 Shifts		
3 Shifts		
Other?		

5. COMPUTER USE

Please describe the extent of computer applications in the company.

(a) Commercial, i.e. wages, invoicing? .... Yes No
(b) Production Control? .... Yes No
(c) Design Analysis? .... Yes No
(d) Computer Aided Design and Drafting? .... Yes No
(e) Preparation of N.C. programmes? .... Yes No
(f) Direct Numerical Control? .... Yes No
(g) Other? ....

6. N.C. MACHINERY Please describe the extent of the use of NC and CNC machinery in the Company.

	Number in Jan 1985	Dates of introduction of NC and Numbers of machines	% of total machines
N.C. Millers			
N.C. Bar Lathes			
N.C. Chucking Lathes			
N.C. Machining Centres			
Others (specify)			

(a) Are N.C. machines treated as separate cost centres? .... Yes No
(b) Is N.C. work scheduling separated from general shop scheduling? .... Yes No
(c) Number of operations per week planned when routing work through conventional machines? ....
(d) Number of operations per week planned when routing work through N.C. machines? ....
(e) Are parts planned to move through the factory in families? .... Yes No

7. ORGANISATION FOR N.C.

A. What level of skill is expected by the company for NC operators:

	Number of Operators	ages	Qualifications
(i) operators are able to operate according to instructions?			
(ii) operators are able to set machines with help for repeat jobs?			
(iii) operators are able to set machines without help for repeat jobs?			
(iv) operators are able to set machines with help for new jobs?			
(v) operators are able to set up new jobs without help?			
(vi) operators write programmes from part drawings?			

B. What N.C. training have your operators received? ....

C. (i) are skilled setters used specifically for machine setting? .... Yes No

(ii) are tools preset away from the machines? .... Yes No

D. (i) does the foreman purely organise work for N.C. machines? .... Yes No

(ii) does the foreman liaise with programmers on problems? .... Yes No

(iii) does the foreman tune-up programmes when necessary? .... Yes No

(iv) does the foreman write programmes from part drawings? .... Yes No

8. PROGRAMME PREPARATION

(a) How many programmers do you employ? ....

(b) What are their ages? ....

(c) What are their qualifications? ....

(d) Do you have a separate programming department? .... Yes No

9. PROGRAMME COMPLEXITY

	Please give %
(a) Programmes are created by record/playback techniques?	%
(b) Programmes are created by converstational programming?	%
(c) Programmes are written in N.C. machine code only?	%
(d) 2D programmes are written using computer assistance?	%
(e) 3D programmes are written using computer assistance?	%
(f) Programmes are prepared using CAD/CAM links?	%
(g) Programmes are prepared for families of parts?	%
(h) Programmes are prepared externally to the company?	%

(i) How do you see programming developing in your company? ....

....

....

10. INSPECTION TECHNIQUES

(a) Operators inspect their own work? .... Yes No

(b) Patrol inspectors are used? .... Yes No

(c) Automatic gauging is used with the N.C. machines? .... Yes No

(d) Coordinate measuring machines are used? .... Yes No

(e) Any other comments? ....

....

11. BATCH QUANTITIES

Please give an indication of the typical batch size produced in your factory.

NUMERICAL CONTROL MACHINES		
Batch size	% of work	
	Millers	Lathes
0-19		
20-49		
50-149		
150-299		
300-999		
1000 +		

CONVENTIONAL MACHINES		
Batch size	% of work	
	Millers	Lathes
0-19		
20-49		
50-149		
150-299		
300-999		
1000 +		

12. IMPACT OF N.C. UPON DESIGN

(a) What proportion of parts do you make that are only technically possible by N.C? .... %

(b) What proportion of parts do you make that are only economical by N.C.? .... %

(c) What proportion of parts do you make that designed to exploit N.C. techniques? .... %

(d) What proportion of part shapes use complex 2D machining - e.g. ellipses? .... %

(e) What proportion of part shapes use complex 3D machining? .... %

(f) Are products more customised now because of N.C.? .... Yes No

(g) Has design flexibility been enhanced by the use of N.C.? .... Yes No

(h) What links are there between design and production because of the use of N.C.? ....

....

....

13. IMPACT OF N.C. UPON YOUR FACTORY

(a) Product lead times have been cut by 0-9% 10-29% 30-49% 50% +

(b) To what extent have W.I.P. levels been affected by the use of N.C.? ....

(c) What is company policy towards W.I.P. levels in view of N.C.? ....

14. PURCHASE OF NEW MACHINERY

(a) Is there a formal procedure to justify the purchase of new machinery? .... Yes No

(b) - please give brief details of this procedure ....

(c) What cost justification procedure do you use? .... Payback (how long)? .... DCF? ....

(d) How do you finance new machinery? .... Internal cash? .... Bank Loan? ....

Leasing? .... Grants? .... Other? ....

(e) Does Group Policy restrict your purchases of new machinery? - how? ....

15. CHOOSING WORK FOR N.C.

Please describe the criteria you use to choose work to be made by N.C. techniques.

(a) by geometric complexity of the workpieces? .... Yes No

(b) by the number of tools to be used? .... Yes No

(c) by the amount of metal to be removed? .... Yes No

(d) by the accuracy acquired? .... Yes No

(e) because of machinability problems? .... Yes No

16. IMPLICATIONS OF N.C. MACHINERY

(a) Who provides your operator training? .... Is it satisfactory? [Yes] [No]

(b) Who provides your programmer training? .... Is it satisfactory? [Yes] [No]

(c) Who provides your maintenance training? .... Is it satisfactory? [Yes] [No]

(d) Since N.C. machines produce parts three times faster than conventional machines the effects of a stoppage can be three times as bad. Have you experienced any problems due to this, and have taken any actions to reduce the consequences?

....

....

....

(e) Have you gained (or lost) work because of the introduction of N.C.? .... [Yes] [No]

(f) What (if any) organisational changes have you made because of the introduction of N.C.?

....

....

....

17. ORGANISATION FOR N.C.

Please sketch an organisation chart to show the responsibilities for N.C. operation.

i.e. who the operators are responsible to, and who the programmers are responsible to.

18. FUTURE PLANS

What changes would you like to make in your organisation to enhance its efficient use of N.C. techniques?

....

....

....

....

....

....

....

19. SIZE OF COMPANY

Please give the numbers of employees on this site as per the EITB annual returns and skill classification.

	WORKS EMPLOYEES	OFFICE EMPLOYEES	TOTAL
Jan 1985			
Jan 1984			
Jan 1980			

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