TECHNOLOGY AND MANAGEMENT: A STUDY OF THE DIFFUSION OF NUMERICAL CONTROL MACHINERY IN CENTRAL CANADA

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Résumé/Abstract

Cette étude analyse la diffusion des machines-outils à commande numérique dans soixant firmes d'ingénierie et de métallurgie du Québec et de l'Ontario. Les données nécessaires à une évaluation critique de l'analyse du processus du travail et de la théorie de la diffusion économique ont été obtenues lors d'entrevues avec les directeurs de la production. La décision de l'administration en ce qui concerne l'adoption de la technologie à commande numérique est guidée par des critères techniques, ce qui n'est pas le cas de la théorie du processus du travail. Cependant, la théorie de la diffusion économique sous-estime l'ampleur du manque de connaissances de l'industrie en matiére de nouvelle technologie, les coûts et le temps requis pour faire l'apprentissage d'une technologie nouvelle, la complexité de l'évolution technologique, ainsi que la diversité des applications et des méthodes d'utilisation d'une technologie particulière.

This study analyses the diffusion of numerically controlled machine tools in sixty Quebec and Ontario engineering and metalworking firms. Interviews with production management

provide the data for a critical evaluation of labour process analysis and economic diffusion theory. Management decisions to adopt numerical control technology are found to be guided by technical criteria, contrary to labour process theory. However, economic diffusion theory is found to underestimate the extent of imperfections of knowledge of new technology in industry, the length and costs of learning to use new technology, the complexity of technological evolution, and the diversity of applications and methods of use of a particular technology.

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Chapter 1: Introduction

The technological developments associated with the emergence of the microprocessor have generated an extensive discussion about the consequences of computerised technology. Projections of catastrophic effects on employment levels (Jenkins and Sherman, 1979; Nora and Minc, 1980), of the rise of novel forms of social pathologies (Weizenbaum, 1976), and of authoritarian tendencies in political and economic organization (Bodington, 1973, Webster and Robins, 1981), of widespread job dissatisfaction and deskilling (Zureik 1983), have competed with utopian pictures of abundance and leisure (Bell, 1974; Gorz, 1982). While much of this literature often merely repeats the pessimistic speculations of the fifties' debate over automation, some empirical analysis is now beginning to accumulate (1). Two lines of research in particular have focused upon the development and application of computerised technology in manufacturing. The first line of research is the established tradition of economic research on innovation and diffusion largely originating with Schumpeter's ideas on business cycles and the role of the entrepreneur (Schumpeter, 1939). The second line of research is the

Marxist sociological focus on the industrial labour process inspired by the work of Braverman (1974). In this study I have attempted to evaluate the diffusion and the labour process theories of technical change by examining the spread of numerical control (NC) technology (2) in 60 engineering and metalworking firms located in Quebec and Ontario.

NC technology has attracted considerable attention from both orthodox economic analysts of diffusion and labour process writers. I shall first critically evaluate these two approaches to technological diffusion in industry in Chapter 2, and argue that neither has developed an adequate model of managerial orientations towards and decisions about contemporary computerized manufacturing technology. I shall argue that both the diffusion and the labour process conceptions of managerial decision making see technological decisions in too simple, too general and invariant terms; that they do not investigate in enough detail the specific technical advantages computer technology has for different forms of manufacturing (within engineering and metalworking); that these variations can account for much of the different levels and forms of use of the technology; that neither approach takes into account changes in technology as it diffuses, and the ways such changes affect the technology's applicability in different production areas.

In order to study the hypothesized variation in the specific technical advantages that computer technology has for different branches of engineering and metalworking, a large sample of 60 firms was selected from different fields of engineering and metalworking in Quebec and Ontario. These companies also differed in size, and in the extent of use and length of experience in working with numerical control machine tools.

To obtain information with enough detail about management's decisions concerning equipment investments I adopted an in-depth interview approach which allowed me to probe the reasons for the adoption of each NC tool and the experiences with NC technology. The results of these interviews are presented through extensive quotation of the informants in order to provide the detailed documentation of management perspectives and approaches to the adoption and use of new technology. Rich, in-depth detail was sought after in order to discover the complexities of technological decision making which I considered to be overlooked by both the diffusion and labour process writers. The interview technique and method of data presentation was designed to overcome the lack of such detail found in diffusion studies using telephone interviews and forced choice survey techniques, and labour process studies which used trade literature and fragmentary managerial statements. The interview data is also presented and analysed through the use of tables providing frequency distributions according to firm size, branch of engineering, and time of adoption of NC equipment. This simple mode of presentation is necessitated by the purposive nature of the sample and the qualitative data obtained from the interviews, but is useful in summarizing the findings so that general patterns can be documented and interpreted.

In addition to the analysis of field work data, historical evidence of technological diffusion and change is examined through an analysis of writers such as Landes (1969), Noble (1984), Rolt (1967) and Rosenberg (1982). In particular the historical analysis in Chapter 4 looks at the major changes in NC technology which have occurred since its pioneering development within the aircraft industry. This evolution is placed in the broader context of the pattern of technological change characterising machine tool design since the development of mass production metalworking in the early nineteenth century United States' firearms industry.

This historical account emphasizes the parallels between contemporary technological change associated with computerization and technical changes in nineteenth and earlier twentieth century manufacturing. This avoids the tendency to assume that dramatic changes in manufacturing technology are only associated with the most recent changes comprising the "microelectronics revolution." Moreover, the historical information provides additional weight to my argument that both diffusion and labour writers oversimplify the processes of technological diffusion.

The substantive chapters present the results of my investigation, proceeding from the processes of information gathering -- the first stage in diffusion -- to the impact of NC technology on labour relations. Thus Chapter 5 indicates that the cost of different information sources accounts for the variation in sources used by different sized firms in monitoring production technology and in obtaining detailed information in order to purchase machine tools. The evidence in this chapter suggests that smaller firms experience greater constraints in obtaining technological information and that, consequently their investment decisions are more likely to be affected by chance and short run considerations than is the case with larger firms whose acquisitions are more optimally planned. The evidence in this and the following chapter suggests that, in smaller firms, the greater constraints on information gathering, the smaller managerial and time resources available for long term planning, and isolation from other NC users, produces more incidents of less than optimal equipment purchase. However, larger firms have born the costs of experimenting with and developing the first generation of nc machinery. Further, over time, learning by using occurs resulting in both communication with machinery builders resulting in design improvements, and improvements in all firms' abilities to use the machinery with increasing efficiency. This information indicates that the adoption of new technology is, at least initially, characterised by high levels of uncertainty in which "satisficing" rather than optimizing decisions are made at best. While over the long run, gains in information and experience with using the machinery reduce much of the early uncertainty, changes in machine designs, programming, and controls occur at a rapid pace, introducing new problems such as the optimal timing of machine selection. The sources and extent of uncertainty in diffusion tend to be underemphasized by orthodox diffusion analysis which rests upon neo-classical optimizing assumptions or models of firm behaviour.

The core concern of the substantive chapters is to document the particular reasons offered for the adoption and use of NC machine tools in different engineering firms, and to explore changes in these reasons over time. While NC has spread from its original location in the aircraft industry, the reasons for its diffusion vary considerably across the different engineering subsectors. In my judgement the in-depth documentation of these reasons displays patterns of complexity not adequately accounted for by either labour process writers of by orthodox diffusion analysis. Much of the latter is flawed by the "black box" problem, i.e. of failing to analyse production technology in detail. Consequently, it is often unclear as to precisely why the adoption of particular equipment is viewed positively and how it is supposed to be profitable. The reasons for the profitability of NC use varies in different branches of engineering and metalworking, with different sized firms, and varies over time.

A second problem with diffusion analysis is its failure to develop "deviant case analysis," i.e. to analyse failures in technological adoption and use. I have attempted to pay detailed attention to instances of significant problems and cases of inability to utilize NC equipment well. Because of the cautious, conservative pattern of NC adoption which predominated in my sample, outstanding failures seemed to be infrequent. Where they did occur, they tended to be found in the earlier days of NC use, suggesting that a learning process occurred.

My informants discussed the reasons for NC adoption and use in overwhelmingly technical terms -- pertaining to such material conditions of production as precise tolerances, tough to machine materials, shape complexity, etc. Contrary to what one might expect from labour process theorizing, issues such as the costs or recalcitrance of skilled labour were hardly ever mentioned. In Chapters 7 and 8, then, I explore in some depth the connections between managerial perspectives on and use of NC technology and labour concerns. Labour is treated as a factor-cost issue in both the diffusion and labour process approaches but with considerable difference of emphasis. Diffusion analysis treats labour as one of several cost factors and not necessarily the most significant problem in many areas of production. Labour process analysts view labour as the primary focus of management concern. This is because labour is a uniquely "active" factor of production; potentially opposing all management attempts to rationalise, control and monitor work; and ultimately a potential class opponent to management in a broader social sense. However, the balance of evidence which emerges in this chapter is more supportive of the diffusion model than that of the labour process writers.

My data demonstrates, first, the persistence of a variety of manning patterns associated with NC use, without any evidence of a clear deskilling tendency occurring over time. Second, NC technology has not altered the traditional pattern of skill labour demands in engineering and metalworking. That is, the categories of labour most demanded and in short supply have remained the same over the past decade. Such labour skills as welding, machine maintenance, tool- making and skilled conventional machining remain the focus of recruiting concern in the industry. NC technology does not appear to be generating any skill demands specific to it. Third, incidents of trades union-management dispute in relation to nc installation and use are rare and, when they do occur, do not conform to labour process conceptions. That is, the disputes do not centre primarily around deskilling and job control. Most disputes centre on the rights of older workers to remain on conventional machinery, and most disputes have been limited and settled without any major disruptions in labour management relations.

Chapter 9 reviews the data in relation to the labour process and innovation-diffusion theories of technical change. First I will argue that managerial concern with controlling the labour process is rooted in the nature of markets for engineering products and in the technical characteristics of those products, and not in a concern to dominate labour or to weaken its bargaining power. The class interaction dynamics purported to exist in the United States by Noble and Shaiken, and in England by Wilkinson, appear to have no counterpart in the firms which I studied. Even with the adverse economic environment of the 1980s, when management concerns to cut costs have heightened, use of NC technology is not presented as a technique to be used specifically to reduce labour complements or cut down skill requirements in the majority of firms.

Secondly, I will argue that the optimizing model of diffusion is very problematic as a depiction of the diffusion process, at least in the short term. Early adoption of NC is constrained by lack of reliable performance information on which to base cost estimates for the utility of the new machinery; errors are made in the application of the machinery; machine tool builders' claims are often unrealistic; early machine designs have to go through a test period of production applications to eliminate design flaws. In addition, information gathering costs as well as ease of access to suppliers, programming supports, and maintenance sources constrain small firms' equipment selection for a longer period of time. Further, since NC technology has changed rapidly since the 1960s, some of the constraints on optimal selection persist over a long period of time. The persistence of these constraints explain the largely cautious and conservative approach to the adoption and use of NC technology which characterizes my sample of firms. Such constraints and the resulting conservativism in diffusion suggests that orthodox diffusion analysis, let alone the catastrophic predictions of the impact of computerization, overestimate the ease and rapidity with which new manufacturing technology spreads.

<u>Footnotes</u>

1. A useful summary of the earlier debates and research into the effects of automation is found in Sadler (1968). The same author has also compared the current controversies with the earlier automation debates in Sadler (1980).

2. Numerical control (NC) is a technique for automating machining processes by feeding a programme of instructions through a control device which activates the motor drive speeds, cutting tool feeds, etc. Punched paper tape was first used to feed instructions to the controls, later mylar and other more durable materials were substituted; later still magnetic tape and then computer disks or direct computer links by building microprocessors into the controls or connecting with a mainframe were used to programme the machine tools.

Chapter 2: Numerical Control Technology, Diffusion and the Labour Process

Introduction

NC technology has attracted the interest of two different sets of social scientists; economic analysts concerned with diffusion of industrial innovations, and neo-Marxist industrial sociologists interested in the role of technology in workplace relations between managers and shopfloor workers. In this chapter I shall survey and critically evaluate these writings in order to provide a theoretical context and focus for the research I report on in this thesis. I start out with the economic writings, looking at the general issues in economic analyses of industrial innovation and diffusion, and then discuss economic investigations of NC in particular. Following this I shall review some recent economic writers critical of the dominant traditions of economic analysis of innovation and diffusion. Finally, I shall look at Braverman and the works by industrial sociologists attempting to apply his theory to modern industrial automation and computerisation of manufacturing. In conclusion I shall indicate how my study attempts to address certain issues arising from these two avenues of research.

Economic Analyses of Innovation and Diffusion

Schumpeter's Approach

The causes and conditions of technological innovation and diffusion have been an important issue for economists and economic historians studying economic growth (Kennedy and Thirlwell, 1972). Analyses of these causes and conditions have been deeply influenced by Schumpeter (Kamien and Schwartz,1982; Kennedy and Thirlwell, 1972, p. 58; Rosenberg 1976 pp. 66-70, 75-78). Schumpeter defined three phases in the process of technological change: invention, innovation, and diffusion. Invention is an idea or model for a new improved device, product, process or system, which may often be patented but does not necessarily lead to technical innovation. The latter occurs with the initial commercial application of the invention. In principle, the process of innovation raises the level of technology to the standard of best practice techniques. Diffusion is the process by which the invention spreads within and across firms, sectors and entire economies.

Schumpeter saw innovations as the core of capitalist economic life, and business cycles as the recurrent fluctuations in the rate at which innovations are introduced into the economy. Innovation could involve the development of a new technique, new product, new forms of business organization, or the discovery of a new market. Generally, innovations were associated with new entrepreneurs and firms which break through the established patterns of economic activity and establish "an historic and irreversible change in the way of doing things" (1939, pp. 87-88). The success of the first innovator encourages imitation by many other entrepreneurs so that there is a wave of increasingly intense innovative activity until the innovation reaches some limit of diffusion. Thereafter the economy adjusts, often through recession, as the new production function (i.e. the maximum obtainable amount of product for any given amounts of factor inputs, under a given state of technological knowledge) becomes institutionalized and routinized (1).

Schumpeter's analysis was primarily focused upon major innovations generating new production functions and contributing to sharp cyclical movements in entire economies. This led to an overemphasis on the "gales of creative destruction" (1950, p. 85) where new technologies created entirely new industries and products, and radically changed economic organisation. As Rosenberg points out (1982, pp. 6-7), however, such events are only a small part of technical innovation and diffusion, and several historical studies have found long periods of coexistence of "old" and "new" generations of technology, as well as much evidence for the incremental nature of productivity-increasing technical change (2).

While interest in long term business cycles has revived, after a period of neglect (Blackburn, Coombs and Green, 1985; Freeman 1983), Schumpeter's depiction of the phases of innovation has been a continuing focus of investigation by economists interested in diffusion (Kingston 1977, pp. 68-74; Mansfield 1968; Metcalfe 1981). They argue that diffusion involves three distinct growth phases which can be graphically represented by a sigmoid curve (3). The first phase, the lower tail of the 'S', is one of slow growth when innovating firms try out a new technology. During this phase there is no established market and the industry supplying the new technology is characterised by a limited number of specialized, pioneering companies.

As the technology demonstrates its feasibility in its initial sphere of application and additional applications are found, confidence grows within the user group and so increases the number of potential users. This process is responsible for the upturn after the long tail of the 'S'. The market now grows to encompass "early users" as well as the original innovators. This is also a shake out period for suppliers as some are able to grow with the increased demands while others fail to make the transition from pioneer, small scale production operations.

Phase Two is a period of exponential growth accompanied by growing publicity about the new technology, whose suppliers now increasingly advertize their wares on a national and international scale. The new technology is increasingly adopted by established companies that have been able to survive by continuing to use an earlier generation technology because of their market dominance or sheer financial strength. Because of the latter, they are able to adopt the now proven new technology on a much vaster scale and reestablish their industrial dominance.

Finally, as the technology matures, it is now used by the majority of potential users and has become accepted as a conventional part of production. The rate of growth of new applications, new modifications of the technology for these new applications, and of new users, slows down. Much of the demand is now demand for replacement units rather than new units so that the supplying industry's rate of growth is now likely to be slower than it was in the first phase.

Innovation-Diffusion Analysis after Schumpeter

Economic analysis after Schumpeter has attempted to estimate technical progress as a separate item in the aggregate production function and to measure its contribution to economic growth (Schmookler 1952, Kendrick 1956). This concern resulted from the discovery that a large component of American economic growth could not be accounted for by increases in capital investment, labour force growth, or increases in raw material inputs, suggesting that technological progress must be responsible for the residual growth. Some of these studies suggested that as much as 80% to 90% of the growth of per capita output in the American economy during the twentieth century could not be accounted for by increases in capital per head but had to be due to some form of technical progress (Abramowitz 1956, Solow 1957). These findings and the associated attempts to precisely identify and measure technical progress encouraged the emergence of detailed studies of the conditions favouring commercial innovation and the spread of new technologies (4).

Analyses of these conditions have largely involved attempts to test the "Schumpeterian hypothesis" that size and monopoly power encourage technological advances. The results have been rather mixed. In reviews of the literature Scherer (1970) and Kamien and Schwartz (1975; 1976) have concluded that, in terms of the relationship between firm size and research and development expenditures or patent output, only the chemical industry conforms to Schumpeter's hypothesis. These writers also argue that the relationship between concentration or competitiveness , on the one hand, and research and development , on the other, is not linear. According to them, there appears to be an optimum research and development level associated with market concentrations intermediate between monopoly and perfect competition.

However, Soete (1979) has argued against these writers. Soete argues, they have no explanation for the finding that medium sized firms are more innovative and technically progressive. Methodologically much of the data is also limited to the 1950s or earlier, prior to a significant growth of industrial concentration during the 1960s. Further, innovation and research and development activity is measured in these studies in ways which underrepresent large firm activity. On the basis of later data and modified indicators, Soete finds that, despite some individual industry variations, there is positive support for the Schumpeter hypothesis. If his analysis is correct, as I believe it is, then one would would anticipate that in the field of engineering and metalworking, where small and medium firms predominate, technological innovation is not as salient as in industries characterised by large enterprise; and that larger firms in the industry should display a tendency towards greater innovation than smaller firms.

Economic analysts have defined the fundamental issue in diffusion as why, if a new technology is superior, it is not taken up immediately by all potential users. The pioneer in this field was Mansfield (1968) who considered information and uncertainty as keys to explaining why it is rational for firms to not immediately switch to new technology. Mansfield develops an "epidemic model" to apply to both intra- and inter-firm diffusion (i.e. the number of machines purchased by a single firm, and the number purchased by an industry or sector over time, respectively.) In this approach there is a fixed potential number of users, the proportion of which are actual users increases over time as an "epidemic" of learning reduces the uncertainty attached to the use of the new technology. The greater the extent of "infection" -- i.e. the greater the extent of the firm's or sector's production is generated by new technology -- the greater the rate of spread of that technology to hitherto "uninfected" regions. According to this model, intra- and inter-firm diffusion will follow a logistic curve. Technologies yielding higher expected profits with lower absolute capital requirements will diffuse fastest. Industries that gain most profit from an innovation will adopt it faster than others. The rate of innovation in a particular industry is affected by the durability of an industry's capital stock, its rate of growth of sales, and its stage in the business cycle. As a consequence of this set of factors diffusion rates will vary across industries and technologies.

Mansfield's work has been a pervasive influence on diffusion studies, but several criticisms have emerged. Rosegger (1977, 88-89) points out that Mansfield's model is structured so that "spread by contagion" occurs within some defined entity, the "population of potential adopters." But an industry is not a static or even a predictably changing population of firms. On the contrary, technological innovations are recognised (_pace_ Schumpeter) as one of the major means of entry for new firms; the failure to adopt an innovation may also lead to the forced exit of firms from the industry. In addition, not all firms in an industry make the same products or use identical processes, but they will consider shifts in either or both under certain conditions. Thus, who is a potential adopter of new technology is an empirical question and not a matter of prior assumption. Stoneman (1983, 74-77) argues that Mansfield is unclear on why and how the decision on use of technology depends on risk and profitability. Mansfield sees risk as related to uncertainty about the profitability of new technology and assumes that this risk diminishes with usage. But in Mansfield's model, while the uncertainty is reduced over time the firm's estimate of expected profitability does not alter over time. The firm merely learns that its initial estimate of profitability was the correct one. This assumption of entrepreneurial omniscience is never justified by Mansfield.

Gold (1981, 247-248) argues that Mansfield and most of the studies influenced by his work have a static conception of a given innovation which diffuses across a population according to changes in the receptiveness of the prospective adopters. The result of this weakness, firstly, is that he overlooks the probability of significant changes of the technology itself during the period of its diffusion and the way these changes continually modify receptiveness by affecting the costs and inputs associated with adoption. Secondly, neither Mansfield nor later diffusion studies have ever provided direct profitability evaluations by responding firms (Ibid., 257-258). Third, that the survey research techniques used in these studies usually involved counting the number of users of a technology without adequate supplementary indicators of the extent and nature of use and whether such use represents limited applications of the technology or pervasive commitment (Ibid., 249).

I shall return to Gold's critique of diffusion studies later in this chapter, but first I want to look at some studies of the diffusion of NC technology itself.

The Diffusion of NC Technology

The earliest study of NC technology was that of Little (1962) who looked at technical innovation in three mature industries - textiles, machine tools, and construction. All of these industries had had few innovations with any major economic impact in over three decades. Innovations which had occurred originated from independent inventions, from firms outside the industry, from foreign industrial units, or from new small firms.

Several other writers have documented the conservative nature of the machine tool industry with respect to technological change. The pressures to change machine tool designs and techniques have tended to come from its major client industries such as firearms in the nineteenth century (Rosenberg 1963), the automobile industry in the first half of the twentieth century (Wagonner 1966, ch. 2), and the aircraft industry after the Second World War (Noble 1984). Numerical control technology was a case in point. The development of the first technically feasible NC mill occurred as a result of the work of several M.I.T. mathematicians and engineers working under the sponsorship of the United States Air Force. The lag between the first demonstration of technical feasibility and the unveiling of the first commercially available nc mills at the Chicago Machine Show was only four years. This lag was relatively short for an industrial product but follows a pattern associated with government sponsored industrial innovation and diffusion (Mansfield 1968, 102).

However, NC machines developed as a technology devoted to machining aeronautical components. Items such as helicopter rotor blades, jet turbine blades and housings, and nose cones, were characterised by extreme complexity of shape and exacting tolerances and surface finishes. Until the 1970s, then, NC machine tools were largely used by engineering firms building airframes, jet engines, and their component subassemblies. As a result studies of NC diffusion were limited in number and focus.

Mansfield (1977, 126-43) looked at the factors affecting the diffusion of NC machine tools in 10 manufacturing industries, using a sample of 140 firms. He found that the diffusion of NC followed the characteristic logistic curve pattern initially predicted by Schumpeter for innovation patterns in general and found true of a variety of technical innovations in later studies (Metcalfe 1981). The key variables positively associated with the adoption of NC were the proportion of firms in the industry already using the innovation; the anticipated profitability of NC; and the size of the initial investment required. While the larger firms tended to be the faster adopters of NC and, within any one industry, the larger firms were preponderant among the users, it was in the less concentrated industries that diffusion of the new machining technology more rapidly occurred. Within firms, the higher the level of education of management, and the smaller the number of managers required to approve the purchase, the earlier the use and the greater the extent of NC use. Earlier users of NC heard about the innovation earlier than later users. In other words, the time lapse between knowing about NC and deciding to adopt did not necessarily differ between earlier and later users.

In relation to production characteristics, NC was regarded as unprofitable by management for very small batch production runs where conventional craft machining methods held their own. Yet NC was also inapplicable to very large batch and mass production runs where conventional automation was more profitable. Numerical control machining was perceived as most useful in medium batch production of items requiring high levels of precision.

A partial replication of Mansfield's studies was undertaken in Canada by Globerman (1974, pp.33-62,, 1975), who was primarily interested in the relative speed of diffusion of NC in comparison with the United States. Globerman found that Canada's rates of adoption of three new techniques in pulp and paper processing, textile manufacturing, and NC machining, were slower than in the

United States. However, within Canada a pattern of inter-firm differences in adoption similar to that found by Mansfield was discovered. That is, the larger firms with greater volumes of production and easier access to capital were the earliest adopters of new technology. The spread of NC use also followed this pattern.

Globerman argued that the slower overall rate of diffusion of NC in Canada reflected the smaller size of Canadian tool and die shops; the smaller production runs arising from the smaller scale of Canadian markets for engineering products; and the lower level of tool and die maker wages in Canada. In contrast to Mansfield, Globerman found no relationship between NC use and the level of managerial education. Analysing the information provided by a sample of non-NC using tool and die shops, Globerman found that this group cited three major reasons for non-use. The most important reason was the existence of inadequate demand in the form of too short production runs for profitable NC machining. Additional reasons for non-use were unfamiliarity with the technology and the inability to finance the higher outlay required for NC machinery and its programming adjuncts.

The final major study of NC diffusion using the traditional economic innovation-diffusion framework is that of Gebhardt and Hatzold (1974), who undertook a 140 firm, six country survey of the growth of NC use in the early seventies. They pointed to a critical difference between NC and many other manufacturing innovations; in contrast to NC most manufacturing techniques generate a precisely defined product or product range.

> "Machine tools, however, whether NC controlled or not, generally produce certain parts or components of extremely heterogeneous and often very complex final products, and operate over the entire field of metalworking. Accordingly the diffusion of NC is not restricted to specific branches of engineering. This makes the measurement of the level and the speed of diffusion difficult, and the difficulties become even greater when it comes to international comparisons, or to the factors influencing this diffusion. The wide range of application of machine tools, and the almost infinite number and heterogeneous character of their products, further multiply the possible situations and the number of factors to be taken into account" (1974, 21).

The number and variety of potential NC production applications may account for the difficulties Gebhardt and Hatzold have in coming up with findings about the causes and conditions of nc diffusion which could be accounted for by econometric models. It is just such diversity which led Gold and Rosegger to question the Mansfield model of diffusion, with its assumption of a clearly defined, stable user population. For these writers, a technology's range of applications is likely to shift significantly as early users experiment with it, modify the original design, etc., so that the population of potential users will also alter.

Gebhardt and Hatzold raised yet another problem for economic analysis; that is, how does one analyze a technology without a defined field of application. Such a situation could be simply defined as indicative of the technology being in the invention or very early innovation stage and so largely exogenous for economic analysis. However, Rosenberg (1982, pp. 120-124) argues that modern technical change in production incorporates continuous invention and innovation during commercial application so that these stages are not so clearly delineated in actual economic life as the Schumpeterian tradition of analysis has postulated.

Because NC machine tools had been promoted on the basis of their advantages in machining small and medium batches, specific sub-areas of engineering where this form of production predominated were sampled by Hatzold and Gebhardt. Thus the makers of pumps, impellers (rotating blades used in mixing large volumes of constituent substances in paints, chemicals, processed foods, etc.), turbines and printing machines were selected to reduce the heterogeneity of the metal working industries to a more uniform sector and to look at firms with comparable production conditions.

Several factors affecting the decision to adopt NC technology were discovered by Gebhardt and Hatzold, although the difficulties of measuring many of the significant ones prevented the development of an econometric model. Diffusion levels corresponded strongly with labour costs. In other words, the higher the wage levels the higher the proportion of NC machines to total machine tools in the sampled sector. However, other labour market conditions were not so clearly related to diffusion patterns. The authors argue that this is understandable since the

> "decision concerning changes in production techniques are very often influenced not by the shortage or abundance of labour in general, but by the local availability or lack of specific skilled labour....The situation is further complicated by the fact that the introduction of NC also required operatives specialised other than in metal working (for example, programmers) whose availability may be different from that of metalworkers even within the same region." (1974, 40-41).

Trade union resistance to NC automation was not significant, although isolated cases of opposition occurred in the United States and United Kingdom (the two countries with the highest levels of NC use at the time), and jurisdictional disputes between unions had occurred as a result of NC installation in some British firms.

General conditions for investment were also important determinants of the extent of diffusion. In countries with high rates of self-financing, or where there was easy access to outside financing, investment in NC machine tools had been more widespread. Again, though, this varied considerably from firm to firm and while it was a salient feature in the survey responses, the authors were unable to precisely estimate or formally model the effects. While government financial support to the initial development of NC technology in the United States and United Kingdom was extensive, diverse levels of government support for investment in NC technology did not correlate consistently with national differences in diffusion levels. Governmental promotion of a national aerospace industry, however, and the size of this industry in relation to engineering as a whole was positively related to the more rapid and widespread adoption of NC technology.

In terms of intra-firm conditions affecting NC use, the extent of cost reduction of machining by using NC machines was highly variable depending on the nature of the component (i.e. its contours, the tolerances required, and the materials used in its fabrication) and batch size. Because of the complexity and heterogeneity of manufacturing even within the sampled sub-sector of engineering, cost comparisons of NC versus conventional machining were difficult to make and many firms in apparently similar production and market situations had widely divergent patterns of NC adoption and use.

Consequently the authors argue that " ... it can be said with considerable certainty that the attitude of the management is one of the most important factors affecting the extent and the speed of the diffusion process." (1974, 51). However, their attempt to specify this variable was unsuccessful and they were unable to demonstrate any clear relationship between managerial attitudes to innovation and actual innovation policy. Thus despite the scope and sophistication of their study, Gebhardt and Hatzold are forced to conclude that " Because of the abundance of factors influencing the diffusion of numerically controlled machines, no list of these can claim to be complete. Their diversity is such that although we believe that our initial hypotheses, as well as our report, cover the most important factors, not even this can be guaranteed." (1974, 54).

New Directions in Innovation-Diffusion Analysis

Some of the possible reasons for this limited success of the traditional innovation - diffusion approach have been explored by Rosenberg (1976, 1982) and Gold (1977, ch. 7, 1981). Rosenberg has characterised economic research on innovation and diffusion as "a series of footnotes upon Schumpeter." (1976, 106). He has criticised the Schumpeterian approach for its narrow focus on major innovations; its disproportionate emphasis on discontinuities in the innovative process; the excessive emphasis on the role of pure science rather than on engineering; the biased model of entrepreneurship focussed on the early "heroic" stages of innovation to the neglect of analysing diffusion. (1981, ch. 5). Consequently, Rosenberg argues that many of the factors determining the nature, rate and direction of technological change in the economy are little understood. The nature and role of technology in economic growth remains an inadequately analysed "black box" in most economic analyses. In particular, the heroic vision of innovation obscured the processes of innovation such as "learning by doing", with the result that economic analyses tended to analyse the demand factors inducing technological change to the neglect of supply factors, such as the range of alternative production techniques available.

Rosenberg notes that technological change, when examined in detail by economic historians, displays much greater complexity than is accounted for by economic analyses. Where economists emphasize the development of new processes to reduce the costs of production of established products, the history of invention and innovation shows that technological change alters both processes and products (1982, pp. 4-5). Yet close examination of particular technological changes indicates, contrary to the Schumpeterian view, lengthy periods of coexistence between old and new techniques, indicating extensive conservativism and resistance against the spread of "best method" techniques (Ibid., pp. 6-8).

In opposition to the Schumpeterian emphasis on epochal shifts in technology, Rosenberg sees inventive activity as "a gradual process of accretion, a cumulation of events where, in general, continuities are much more important than discontinuities." (1976, p. 192). Closer attention to this cumulation of events at the technological level exposes the reasons for the overall slowness and wide variations in rates of acceptance in the diffusion of innovations. Where Schumpeter emphasized invention and innovation Rosenberg emphasizes the conditions surrounding diffusion as the key to significant shifts in production techniques. At the same time diffusion is usually characterised by acts of invention and gradual improvements in the technology so that what is diffused is a continually improved production technique (Ibid., pp. 195-197).

Accompanying the gradual modification and adaptation of new technology through the diffusion process are several other processes which affect the rate of diffusion. First, there is the development of technical skills among users. These may be slow in developing; they can only be learned on the job; and at the earlier stages of diffusion they are experimental, tentative and uncodified. Consequently, knowledge of the new technology in operation is not necessarily easily transmitted (Ibid., pp. 197-199). Second, new technologies may require new skills and techniques in manufacturing them. This requirement is itself subject to all the vagaries involved in the development of new technology. Third, there may be complementarities in diverse technologies which facilitate or retard the diffusion of new technologies. Rosenberg cites the work of Fishlow who discovered that an accumulation of small changes in the design of locomotives and freight cars between 1870 and 1900 tripled freight car capacity and doubled motive power. Yet greater loads and speeds would have been impossible without the telegraph, block signalling, steel rails, air brakes and automatic couplers -- instruments which were discovered independenly but were mutually necessary for railroad transport improvements (Ibid., p. 176, pp. 201-202). Thus, for Rosenberg technological change is the outcome of several processes which are often subject to delays, false starts and bottlenecks. Consequently much technological diffusion occurs only slowly and unevenly.

But applied science is now ubiquitous and the entire economy is subject to activities generated by scientific and technical change. In a science-based production system innovation is continuous and endemic. Production technology is generally complex and systemic so that learning by using is increasingly necessary to establish the reliability of new processes and/or products (1982, pp. 121-124, 135-140). The methods used by business organizations to institutionalize technical innovation, and to establish some control and stability over technological factors by funding R & D, establishing linkages to pure science research institutions, etc., merely multiply the sources of innovation and intensify the process of technological change. All these conditions force entrepreneurs and management to operate as brokers between what seems to be economically profitable and what is technologically possible despite the uncertainties involved. Rosenberg emphasizes the uncertainties associated with these conditions and downplays the dependability of rewards such as quasi-rents from patents and licences which can be earned from successful innovation.

Consequently Rosenberg is particularly critical of analyses which assume a simple relationship between the rate of technological change and the rates of innovation and diffusion. Yet exactly this assumption underlies much of the research into the phenomenon of technological lag. What such studies ignore in particular is the impact of expectations about the future course of technological innovation on entrepreneurial decisions about adopting new technology. By moving from the Schumpeterian approach which emphasizes discontinuities in innovation to an approach which emphasizes the ongoing nature of much technological change, Rosenberg argues, " the optimal timing of an innovation becomes heavily influenced by expectations concerning the timing and significance of <u>future</u>

improvements." (1982, pp. 107). Expectations of rapid continuous change in a technology can lead to a variety of responses on the part of potential adopters. They may opt to be "in on the ground floor" of the new technology and gamble that the early learning experiences in "debugging" and adapting it to their specific production needs will generate gains outweighing the costs of pioneering and experimentation. Other firms may adopt a conservative strategy, waiting for the pioneering experiments to pay off in the form of a second generation of designs more appropriate to their specific production conditions. Yet others may be able to operate with shorter amortisation cycles, building or using equipment which is cheaper or less longer lasting but does not survive into obsolescence. Thus the expectation of continuing technological change may be a condition in which technological lag represents the rational decision of a significant number of firms in a particular industry or sector.

Gold's critique of the innovation-diffusion literature converges with much of Rosenberg's commentary. He argues that much of the literature is dominated by a static conception of a given innovation and thus overlooks the processes of derived innovation through continuous modification and adaptation to different production circumstances which occur during diffusion. It is probable that this complex process of innovation-in-diffusion reflects in turn the complex, fluid and changing firm characteristics which intersect with technological adoption. Gold points out that field research demonstrates that in most countries plants differ in many respects affecting their relative competitive positions : product designs; product mix; the pattern of make or buy arrangements; equipment characteristics and modernity; quality standards; scale of production; locational factors in terms of access to inputs and markets; capacity utilisation; managerial objectives and financial resources. Since most technological innovations affect different sectors of operations and costs, and exert primary impacts on particular segments rather than on the entire array of production operations, the economic advantage of any particular innovation is likely to differ among plants within the sector using the technological innovation. It is scarcely surprising, Gold argues, that field research generates vastly different accounts of innovation and diffusion processes than are presented in aggregate models.

In particular, the common explanatory variables of profit seeking or profit expectations are problematic. Profit seeking is far too generalised as a causal variable. It is an orientation rather than a motive, and as such, is likely to be brought forward as a rationalisation for decisions made on less obvious grounds. Secondly, no diffusion studies have yet been able to provide direct profitability evaluations by responding firms. Consequently, there are major problems in getting firm information on profit expectations and estimates of prospective risks. In the conditions of real business decision-making Gold argues,

> "Because decisions involving commitments for future activities must almost always be made on the basis of serious informational inadequacies and consequent uncertainties, they tend to be based in large measure ... on the value orientations of influential management personnel, which are rooted in turn on their past training and experience ... Hence, managerial attitudes are not merely one of the actors to be included casually along with ostensibly more important quantitative determinants. On the contrary, such subject-judgements probably overshadow the latter in shaping most capital decisions." (1981, 259).

The implication of both Rosenberg's and Gold's criticisms of innovation-diffusion analysis is that technological change in industry is often of a gradual and piecemeal nature; originating in a diversity of intra-firm conditions ; and motivated by a variety of managerial perceptions, strategies, and impulses. Both writers appear to be arguing for much more disaggregated analysis, with greater attention to inter-firm variation, to continuous if slight technological modification; and they seem to be sceptical of management's own accounts of their decisions. It is to the issue of managerial motives and strategies in technical change that the Braverman-inspired labour process writers direct particular attention.

NC Technology and Labour Process Analysis

Braverman's Analysis

Braverman's theory (1974) is based on Marx's identification of the distinctive feature of the capitalist economy; that the direct producers sell neither themselves nor their labour services but their labour power - the capacity to labour - to the capitalist. The central problem in the capitalist labour process is, consequently, that management has to ensure that this capacity is transformed into work actually done and to maximise the work done in order to ensure profitability. The continuous search for profit necessarily leads to continuous refinement of the division of labour, as complex craft tasks are divided into simple, routinised steps and less skilled labour is hired to perform the resulting detail work at lower rates of pay. Or labour is reduced or eliminated entirely by the automation of the repetitive motions which comprise the simplified tasks. Further, in order to ensure that workers' labour power is turned into work actually done, management continuously tries to maximise its control over workers and to minimise its dependence on them. Management does this by enhancing its control of the labour process, by gaining knowledge of the production techniques and reducing workers to mere executors of management orders. This process reorganises work into low skill jobs without conceptual content, replacing craft work where conceptual and executive skills were integrated.

For Braverman, technical innovation is a key element in the drive for managerial control.

> "The capacity of humans to control the labour process through machinery is seized upon by management from the beginning of capitalism as the prime means whereby production may be controlled not by the direct producer but by the owners and representatives of capital."
> (1974, 193).

The problem of the automation of machine shop operations is explored as a significant case in point (1974, pp. 184-248). Traditionally machine tools have been used in unit or small batch production in which skilled machinists retain considerable control over production processes. Until the advent of NC the impact of the detailed division of labour had been limited; machinists specialised in one particular tool such as the mill or lathe; or skill divisions were introduced by making machine set-up a specialty. However, NC interposes an automatic control system -- in the form of punched or magnetic tape or direct computer communication -- between the machinist and the metal cutting operations.

Braverman argues that the machinist's technical knowledge of metal cutting could be advantageously used if machinists were to program or develop the control programs. But " this almost never happens ... due, of course, to the opportunities the process offers for the destruction of craft and the cheapening of the resulting pieces of labour into which it is broken." (1974, 199). As happens with the manufacturing process elsewhere, Braverman argues, " The process has become more complex, but this is lost to the workers, who do not rise with the process but sink beneath it. Each of these workers is required to know and understand not more than did the simple worker of before, but much less." (1974, 200). The skilled machinist is replaced by less skilled parts programmers, encoders, and machine operators. The entire production process involved combining cheapened, deskilled labour, with more versatile and powerful machinery.

Noble's Analysis

Two important studies of NC automation have adopted Braverman's approach, although not without adding significant nuances of their own. Noble's work (1984) is a detailed history of the development of NC technology and an interpretation of the forces affecting this development and its diffusion, primarily within the defence engineering sector in the United States. He characterises the engineering and metalworking industries of the United States in the 1940s as riddled with bitter industrial strife as management sought to curtail the advances in shopfloor power and in wages obtained under wartime production conditions. These general conditions impelled management to search for means to undercut their workers both in the area of control over the production process and in terms of the wage bill. Noble argues that the rise of vast postwar defence expenditures, particularly the rise of a large jet-powered airforce, created the possibility of a technological solution to labour-management problems in the engineering industry.

Military production involved complex parts made to high tolerances and often involved machining novel alloys, recalcitrant to traditional machining techniques. At the same time, defence grants subsidised the search for new manufacturing technologies and underwrote investment in new machinery. Prior to the development of NC technology, the fabrication of aircraft wings, rotor blades, and jet turbine blades through semi-automated techniques using templates and tracers, cams etc., had become increasingly costly. Particularly as the level of demand for jet aircraft increased, these techniques constituted a major bottleneck in production. They were dependent upon the manual skills, powers of concentration, and general stamina of machinists and consequently repeat batches often generated out-of-tolerance parts and scrapped output on an expensive scale.

By the late 1940s several explorations of new machining techniques were taking place. Noble documents in detail the innovations by Parsons Manufacturing, a small firm specialising in helicopter rotor blade production, to develop a precise digital tape method for rotor blade machining, and the subsequent adoption of this project by a research group at M.I.T. working on engineering applications of computer technology (1984, pp. 96-105). Impelled by the Korean War demand for large numbers of jet aircraft, a demand sustained by the arms race, a new technology of automatic machine tool control emerged in the aircraft industry and slowly spread through this industry during the 1950s.

The most convincing aspect of Noble's study is his demonstration that without extensive support from the Department of Defence, and the U.S.A.F., NC might not have enjoyed what limited success it obtained in the 1950s and 1960s even within the aircraft industry. Only with changes in computer technology in the 1970s has NC technology spread significantly beyond the original specialised aircraft component applications. But this early slow and limited growth of NC hardly fits Noble's conception of the technology as a solution to urgent labour problems arising from wartime and early postwar conditions. Had these problems been so pressing and the new technology so clearly advantageous for deskilling (and therefore cheapening) labour and controlling the labour process, one would have expected a much more rapid diffusion of NC technology.

Noble shares with Braverman a tendency to uncritically accept the claims of NC manufacturers about the potential benefits (to management) from NC installation. Braverman's principal authority for the job descriptions of parts programmers, encoders, and NC machine tool operators were machine tool advertisements and an introductory text on NC for management written by the chief executive of a major manufacturer of NC equipment (Leone 1967). Such sources might reasonably be expected to underestimate the demands NC makes for the maintenance of skilled labour inputs. Similarly, Noble's characterization of the labour process and skill requirements of NC technology are largely uncritically derived from machine tool manufacturer's advertisements and brochures, and the editorials and reportage of machine tool trade journals.

Unlike Braverman, Noble does undertake a study of firms operating NC equipment. However, his survey focuses upon the managerial motives for NC utilisation purely in terms of their concern to control the labour process and this is matched by surveys of workers' attempts to evade such controls. Since he does not provide the reader with his interview schedules it is hard to evaluate the validity of the responses he presents. Besides, that workers attempt to evade what controls exist does not mean that a technology was introduced to establish those controls (5).

Much of Noble's case that NC technology has developed as a result of managerial concerns to control and deskill labour rests upon his distinction between two types of NC controls which appeared in the pioneer days. The first -- record playback -- developed by General Electric, used a magnetic tape to record the motions of the machine tool as it was operated by the machinist in producing the prototype of a particular piece. The ~~tape~~ of these machine motions could then be used, fed through a suitable controlling device to reproduce identical machining motions without the machinist. Noble argues that this automation technique was easily installed, relatively cheap, required very little in the way of major capital investment, and had potentially widespread industrial applications. Yet it was not this system which was ultimately used in NC technology. Noble accounts for this by arguing that,

> " ...'the strength of the (record playback) approach, as a reproducer and thus a multi- plier of skill, proved to be its weakness, in the view of those with the power to determine its fate. For, although it constituted a major advance over conventional machining, it still relied too heavily upon the skills of machinists." (1982, 83).

Instead, another system developed, the system of numerical control whereby blueprint dimensions are transformed into Cartesian coordinates or some other mathematical-geometrical matrix and coded appropriately through the controlling device. It is hard to see why the record-playback system has less deskilling and labour process control potential than its rival NC system. Even in 1952 Kurt Vonnegut (who had worked in General Electric's publicity department in the late 1940s) was inspired by the record-playback experiments to write Player Piano , a major anti-utopian novel on the potentially catastrophic impact of this form of automation (Vonnegut 1952).

Furthermore, Noble's emphasis on the way in which the mathematical basis of NC fits with the engineering bias of industrial managers and with the control bias of engineers, leads him to seriously underestimate the technical advantages of such a machine control system. A record-playback system is dependent upon the existing stock of machinists' skills; a mathematical coordinate system has no such limitation. In other words, machine controls based upon mathematical codes rather than craft knowledge can, in principle, be used to produce anything designed by the engineer (within the limits of the physical and mechanical properties of the machines, tools and materials, of course). The record-playback system, however, only produces items which machinists are currently able to make. The major problem with the postwar generation of aircraft was that they contained components which were extremely difficult to make reliably by the best craftsmen. It is this <u>technical</u> difficulty which Noble underestimates in his interpretation of the choice of NC over record-playback.

Shaiken's Analysis

The appreciation of NC technology in detail permits Shaiken (1985) to present a far more nuanced analysis, although still within the Braverman tradition (6). This is in part due to the author's own training as a tool and die maker, and also due to the study design which recognises the heterogeneity of engineering and metal working industries in terms of products, firm sizes, markets, etc. Using a wide range of qualitative interviews with both workers and management in engineering Shaiken introduces a number of significant complexities into the Braverman-Noble picture.

First, any technological innovation in industry is used in such a way as to balance several different goals which are not easily simultaneously optimized. Thus quantitative output such as speed and volume may involve quality sacrifices or high wastage rates. Raw materials are often variable and machines and shopfloor conditions sufficiently idiosyncratic that managerial imposition of standardised procedures are less efficient than permitting considerable worker autonomy to take account of these conditions. Historically, there have always existed technical limitations to extensive or universal automation and also, because of the aforementioned conditions, enormous gaps between the level of automation which is possible in principle and what is actually applied. There are also social limitations on implementing "optimal" automation programmes; but these do not consist solely of worker resistance but are also the result of managerial conservativism, and a variety of economic pressures such as limited capital, market position, the need to amortise existing equipment,etc.

For Shaiken there is an interplay between all these factors as well as managerial desires to control the labour process. But it is the interplay of all these factors rather than a single, unilateral managerial strategy which determines the course of technological innovation. The very flexibility of NC production, its capacity to efficiently produce high quality, short runs of complex parts, has led to a shift in market expectations in engineering products for faster production, increasing complexity of parts, and greater customizing of products. NC technology reflects all of these complexities; there are considerable variations in the success with which various firms have adapted it to their own production needs; and there is great confusion among managers over precisely what benefits are to be obtained by its use. Included in this confusion is a lack of clarity on the part of management over the labour advantages of NC; the degree to which it reduces dependence upon skilled metalworkers; the degree to which cheaper, semi-skilled labour can be substituted for skilled machinists; or the degree to which new skills requirements are generated.

While retaining the Braverman-Noble framework Shaiken's evidence presents a picture of the diffusion of contemporary automation techniques as a complex, uneven process, marked as much by failures and sub-optimal applications as by solid successes. In short, his account of the latest round of work automation is somewhat closer to the innovation-diffusion school than are the writings of Braverman and Noble. In particular, his close attention to a very broad range of engineering and production management opinion prevents him from adopting the more simplistic Marxist approach of his predecessors. If there is a bias in the system, it takes the form of an " engineering ideology " best encapsulated by Shaiken's citation from Gideon Halevi as " an attempt to replace 'art' by 'science,' that is, to replace intuition by computation, while turning skill and experience into formulas." (1985, 60). This impulse is, of course, rooted in the expansion of science, and science-based technology in industry, and is not simply a fraudulent ideological cover-up disguising managerial attempts to control labour and to exclude workers from involvement in the labour process. Shaiken's documentation of this bias coexists uneasily with his class-control-of-the-labour-process approach, and is never satisfactorily resolved (7).

Modifications to Braverman's Analysis

Shaiken's work appears to be part of a "movement" among those sympathetic to the Braverman-Noble perspective towards a less rigid emphasis on a unilateral and universal managerial motivation for technological innovation. Two other works focusing explicitly upon NC have attempted to reconcile a class-control approach to industrial organization with a more nuanced sense of economic and technological complexities.

Wilkinson's study (1983) comprises four cases of NC automation in different engineering plants in the West Midlands (U.K.). He is critical of both Braverman and the innovation-diffusion analysts such as Freeman, Rosenberg, and Mansfield. He argues that the latter group depoliticises technical change; assumes that the physical characteristics of technology determine organisational requirements; analyses technology as a putative independent variable having "impacts" with little reference to how these impacts are at least modified by specific organisational actors. Technology itself is treated as a neutral input into production systems and the motivation behind its introduction or adoption is purely the product of market competitive pressures. The effects of technology, apart from the impact on the firm's economic position are viewed as largely incidental and go unexamined. Thus Wilkinson argues,

> "The context in which technological change occurs is treated as if of importance only to the extent that it constrains the changes, or is changed itself by the new technology. Thus instead of discussing, for instance, the nature and availability of skilled labour within a firm and the way this might affect the choice and use of technology, the skilled labour is treated simply as a possible constraint ... or as a phenomenon which is transformed by the technology (from craft worker to technical worker.) The fact that managers may introduce technology with the intention of transforming the nature of work simply will not fit the 'impacts of innovation framework." (1983, 11).

At the same time Wilkinson is also critical of the Braverman analysis of Taylorization of the work process which downplays the role of workers as active negotiators in the determination of work relations. In contradistinction to these two approaches, Wilkinson's aim is to "uncover the ways in which the values and interests of managers, engineers and workers profoundly influence the choice and use of technology, and thus the work organization which emerges." (1983, 12).

Wilkinson looks at four small-batch manufacturing plants -- two of these are small enterprises with about 50 employees, largely unskilled workers in a metal-plating plant, and skilled workers and technicians in an optical lens factory. The other two plants are medium-sized organisations, employing 350-450 people, one in rubber moulding and the other in machine tool manufacturing. These larger plants' labour forces comprise a mixture of skills, but both include cores of relatively skilled workers. All but the metal-plating company are subordinates of larger corporations.

These case studies are presented in support of Wilkinson's primary contention that neither the adoption of particular technologies nor the organisation of work based on them is objectively determined by the characteristics of the technology. Instead both are the result of informal political negotiations between management and workers. Contrary to the "impacts of innovation" approach, Wilkinson argues, management uses rather loose estimating methods in justifying capital expenditure on new technology and that even rougher measures were used in assessing the success of new technology once it was installed and in production. For Wilkinson, statements about efficiency or productivity, or about production quality, tend to be glosses or rationalizations for managerial action (1983, pp. 82-84, 86).

In these respects, of course, Wilkinson's findings are similar to those of Gold. However, while managers tend to feel most secure when their actions can be justified in terms of objective measures of improved performance, managerial intentions are more diverse than solely labour-directed desires to deskill or unilaterally control production. Thus, Wilkinson documents disputes between different levels of management; between management with financial as opposed to technical production concerns and orientations; between managers with shopfloor backgrounds versus those with university engineering degrees, and so on.

Moreover, just as the purely technical cost and productive efficiency pay-offs of technological innovation are difficult to estimate, the labour process control impact of technological change are also difficult to anticipate. Workers' efforts to control their work are often a function of unanticipated problems of technological changes , and shopfloor skills are often required to modify the planning engineer's designs for effective operation under real production conditions (1983, pp.91-92). The extent of shopfloor control is strongly affected by pre-existing work arrangements, which in turn, are the result of prior negotiations and shared understandings surrounding the operation of previous generations of technology and work organization (1983, pp. 86-92).

While Wilkinson's case material supports his main thesis that the adoption of a particular technology and the way it is used is not objectively determined but a matter of socio-political negotiation and definition, his study fails to satisfactorily interpret his findings. His approach is very much in the Braverman tradition, modified to allow for the active involvement of the work force in controlling work organisation as technology changes. The recourse to the term "politics" rather than the traditional "informal organization" is symptomatic of his reading class struggle meanings into rather more mundane industrial relations processes.

More substantially, however, Wilkinson fails to take advantage of his comparative case material and is unable to specify any of the patterns underlying the process of social definition in situations of technological change. For example, he does not develop any hypotheses about factors enabling workers to play a larger or smaller role in determining work procedures emerging with the new technology. His cases suggest some such factors including the extent to which the workers involved are skilled craftsmen or not, and the degree to which responsibility for implementation is assigned to middle or senior managers.

Similarly, the conditions determining variations in management attitudes and intentions are never systematically analysed. Wilkinson is too ready to dismiss competitive pressures, for example, but his cases appeared to be quite differently placed in relation to such pressures. His case material, in fact, seems to demonstrate that management concerns to control work procedures are quite directly linked to these pressures. Thus, while Wilkinson's analysis is useful in exposing the informal,organisational-political dimension as a conditioning factor in technical change, his analysis is entirely too inhibited by the labour process approach to advance our understanding of the precise ways this factor operates.

Finally, I should discuss Bryn Jones' analysis of NC use in British aerospace firms (1982). Jones is also a sympathetic critic of Braverman who, he argues, developed a theory of deskilling which was too "deterministic" and "universalistic." Jones wants to develop an explanation of the direction and nature of skill changes in contemporary capitalist industries which takes account of trades union strategy in relation to labour markets; the firm's product markets; the firm' product composition - i.e. whether standardized, batch size, steadiness or periodicity of demand, etc.; and the machine-management control systems which develop as technology changes. His case studies are not supportive of Braverman's vision of a single deskilling trend arising from the application of advanced technology.

More importantly from my perspective, Jones finds no single, coherent managerial strategy pertaining to the adoption of nc technology. Even though all the firms in the sample were involved in aerospace production and so might reasonably be assumed to be most familiar with, and under the most intense pressure to keep up with NC technology, none were organised uniquely around NC technology. Only one firm which was specifically established as an NC machining subcontractor, planned its investments solely in terms of its nc requirements. Even here, half of its machine tools were conventional ones used for finishing work, prototype and development items, etc. In the other firms sampled NC machines were scattered among conventional machine tools; they were acquired on an <u>ad hoc</u> basis as funds allowed, or as replacements were needed, and not as part of a separate conscious NC development strategy. In particular, there was no sign of wholesale reorganization along the lines suggested by NC technical literature, but a persistence of organizational patterns traditional to the engineering industry.

Furthermore, NC technology had not been adopted to save labour, although there was a widespread sense of its utility in the context of a scarcity of highly skilled labour. NC technology was seen almost entirely in technical-efficiency terms -- reduction of machining time, especially of the time in-between machining sequences; improving quality, finish and tolerances; and improving the capacity to repeat machine sequences without variability. At the same time there were divisions and disputes within management over precisely how useful NC technology was and how advantageous it could be in comparison with conventional machining techniques.

Conclusions

Noble, Shaiken and Wilkinson present their analyses either as simply confirming Braverman's theory, or as documenting a variety of intervening variables which qualify or modify the impact of management's striving for control over the labour process. The drive to control of the labour process is the logical equivalent for these writers to the profit motive in the profit maximizing theory of the firm which underlies most economic analyses of diffusion after Schumpeter. The intervening variables which account for the diversity of skills and methods of labour deployment associated with the introduction and use of NC and so obscure the "basic" tendency of deskilling are often similar to those adduced by economic analysts to explain the unevenness of diffusion.

Thus while remaining sympathetic to Braverman's emphasis on the labour process as the most significant area for understanding industrial relations, subsequent writers (apart from Noble) have moved closer to the innovation-diffusion perspectives on technological change. In the latter, as we have seen, there is an increased concern with "subjective" factors such as managerial attitudes, informal organizational dynamics, the complex interplay between market pull and technological push, the gap between formal accounting criteria and the "real" factors motivating decisions, etc. These factors deflect the diffusion process from the optimum path ensuing from profit maximizing firm behaviour. In both the labour process and the economic theory of the firm, the central assumption characterizing management decision making is problematic as a description of management behaviour. There remains a basic empirical question, then, of "How does management decide to adopt and use new technology?" This question is answered by assuming a single motivating strategy in both labour process and economic diffusion analyses.

Elster (1983, p. 111) has argued that technological change situations are too often characterised by too much uncertainty for rational choice to be well defined. Hence economic theories based on optimizing models have to be replaced by "postulating that firms search randomly and then decide on the basis of satisficing rather than optimizing" (Ibid.). Elster is concerned with the formal or logical issues associated with the development of a theory of technical change having satisficing rather than optimizing behaviour as its micro-foundations. However, there is a range of empirical issues requiring investigation involving the discovery of the constraints limiting optimization, the existence of multiple and conflicting goals, the existence of areas of uncertainty and limits to knowledge which make utility maximization a matter of luck rather than judgement.

New technologies bring with them a variety of uncertainties -- their performance characteristics are uknown, the products they turn out may affect demand and markets in novel ways, their operations may alter labour deployment, they may require new managerial inputs, etc. The diffusion of new technologies, because of these uncertainties, involve satisficing responses on the part of management. Are these responses consistent? What does management do to limit various uncertainties in the course of adopting and using new technology? How does management minimize the risks new technology brings to established patterns of work organization, market relationships, etc.?

Profit maximizing and labour process control models of managerial behaviour treat the processes and conditions of learning about new technology in a particular industry casually, as if knowledge and information are unproblematic or available easily and equally to all firms. How do managers get to know about changes in production technology in a situation of rapid and extensive technical change? How do they evaluate the information and sources of information they acquire? These are obvious questions and yet I find very little description and analysis of the way management keeps informed about production technology, despite the convergence of the literature on a "multilateral" vision of managerial decisions about technical change.

Further, there are two related problems about which we have little information : little attention is paid to changes in technology as it is diffusing and is adapted to a variety of operating conditions. As technology diffuses within and between firms, learning occurs and a range of successful adaptations, modifications and accumulated experience and knowledge develop. Much innovation-diffusion analysis treats technological items as static, unchanging entities which diffuse in their original form throughout some industrial sector. This underestimates the complexity of diffusion, and precludes looking at differences in firm experiences at different points in the time period of diffusion; at differences over time in the experiences with the (changing) technology within a single firm; and the interplay between these factors.

It is to redress some of these lacunae that my study was conceived. The central question framing my study is what perspective and strategies do management bring to the decision to adopt and use NC and CNC (8) technology in different branches of the engineering industry. How we have proceeded to develop this question as the basis of our investigation and the procedures used in it are the subject for our next chapter.

Footnotes

1. Schumpeter distinguished between Kitchin, Juglar and Kondratiev cycles, each of whose length depended on the type of disturbance producing it. Kondratiev cycles were of approximately 50 years' duration and triggered by major shifts in entire technologies and economic organization such as the rise of steam power or the birth of railway transportation. These shifts involved many interconnected innovations and, combined with exogenous events such as wars, gold discoveries and harvest failures, produced large scale economic changes over long periods of time. The shorter Kitchin (4 year) and Juglar (10 year) occur due to two other innovation related processes. The spread of technology and minor adaptations of established technologies constantly force firms to adapt to these changes by rationalizing their operations. This often takes the form of labour saving and capital saving reorganization which may have some recessionary effects on the economy. As well, some firms simply fail to adapt, go bankrupt and again cause declines in demand for various goods and services. A second process contributing to shorter term economic fluctuations arises from irrational entrepreneurial expectations. Over-optimistic estimates of profits to be obtained from innovation causes first a wave of overinvestment in a particular area of the economy and then an equally irrational reaction of withdrawal of investment.

2. See Enos (1962), Strassman (1959), (1959a), Usher (1954).

3. There is some dispute over the appropriateness of different sigmoid curves, whether there is any one type more appropriate than others, and what is the explanatory status of such graphica modelling. See Stoneman (1983), pp. 69-72.

4. See Kennedy and Thirlwell (1972, pp. 13-20) on the early development of the post-war American writings. Examples of later studies of technological change in detail include Griliches (1957), Hollander (1966) Mansfield (1968 and 1977), and Schmookler (1966).

5. Noble's main case for the manipulation of NC by management shows that plant management were under

severe pressure by central office management to rationalise and increase productivity. Local managers were in fact somewhat sympathetic to a project of job enrichment which was attempted with the introduction of NC to compensate for shifts in traditional methods of incentives calculation and job classification. In addition Noble's presentation of the costs of NC technology clearly demonstrates the purely economic justification for obtaining higher labour productivity levels. See Noble (1984), pp. 265-323, and especially pp. 266-269.

6. Shaiken's interpretations of NC automation in his 1985 work is less dogmatically Braverman-like than were his earlier essays (1971, 1981). However, his labour process approach appears to determine, to some extent, the selection and presentation of his case material. He gives prominence to the automotive industry's latest round of automation. Where other industries are discussed they are often small job shops apparently operating under extreme competitive pressures and directed by paternalistic, self-made entrepreneurs with markedly conservative business views. The fact that some of them probably come from the ranks of skilled metalworkers themselves is not explored by Shaiken.

7. If anything Shaiken tends to defer to Noble's analysis of the rise of the engineering profession in America (1977). Here Noble argues that engineers developed a professional identity as 'corporate reformers' who sought to design both technologies and production organizations according to rational precepts. Their efforts unwittingly supported the aims of a new generation of capitalist managers concerned with rationalizing and stabilising large corporate enterprises. An excellent review of the historical deficiencies in Noble's argument has been written by Merritt Roe Smith (1978).

8. CNC or computer numerical control technology is a system of machine tool control where the machining programme is fed directly to the controls either by a microcomputer built into the machine's controls or by direct input from mainframe. This method of control eliminates the process of preparing and transferring

a tape or disk from a programming centre to the machine tool. For descriptions of the development of this technology see Bylinski (1975), Gunn (1982), Marsh (1980 and 1982), Ruzic (1980).

Chapter 3: Study Design and Procedure

The two schools of thought examined in the preceding chapter have different conceptions of management strategies and decisions with respect to the adoption and use of new technologies. Of course, both approaches view profit maximisation as the fundamental, underlying management goal. Yet they diverge in their depiction of the means of achieving this goal. Diffusion writers stress the technical conditions favouring the profitable use of NC technology. For example, emphasis is placed upon the greater precision possible with NC machining; NC's reprogramming capacity as against the rigidities of fixed automation, etc. Labour process writers emphasize the social control aspects of nc machinery: the separation of planning and execution possible with preprogrammable machinery; the possibility of machine pacing workers' activities; the potential reduction of skilled machinists to tool loaders and monitors and so on. While there has been some dispute among diffusion analysts over the extent to which technological innovation has tended to be labour saving (Rosenberg 1982, pp. 14-16; Stoneman 1983, pp. 52-58), labour process writers assume labour saving consequences to be the primary objective in a conscious and coherent management strategy.

As is the case with organizational decision making in general (Perrow 1972, pp. 145-157, Simon 1979, pp.500-501), it is probable that management decisions about technology are too complex to be characterised by such monolithic, universal orientations as profit maximising or labour control. The in-depth case study method favoured by the labour process writers is, in my view, a better research approach to uncover the complexity of decision-making than is the method of large-scale, standardised questionnaire research favoured by the diffusion writers. However, the labour process writers such as Noble and Shaiken overgeneralise from industries such as aerospace and automobile manufacturing which have very specific characteristics. Wilkinson, in contrast, fails to make use of the variety of industrial characteristics present in his sample. Furthermore, the methods by which management and labour responses are elicited by these writers are never presented, so that it is extremely difficult to evaluate the strength of the evidence presented in support for the labour control hypothesis.

To avoid these problems I have developed a study design which satisfied three fundamental criteria: firstly, the sample should be large enough to reasonably represent the variability of production types and firm characteristics within the engineering and metalworking sector ; secondly, the method used should be adequate to allow probing potential complexities of managerial decision- making ; thirdly, the technique and sample should permit the investigation of the temporal dimension in order to take account of the rapid evolution of NC technology.

The size of the sample was determined partly by the range of firm variation I wanted to include and partly by the investigative technique used (an in-depth interview discussed below). Thus 60 firms provided me with multiple representation of all the major categories of metalworking plants (aerospace, tool and die shops, electrical equipment, transportation equipment, sheet metalworking, valves and pumps), as well as a broad range of other firms representing the diversity of this manufacturing sector. A smaller sample would have been less representative; a larger one would have taken the study beyond the capacity of a single researcher working with the resources available to me. In addition to being drawn from different branches within engineering and metalworking, the sample also included both recent and longer term users of nc machine tools. As well, the respondents were selected from a broad range of plants in terms of employment size. The latter was viewed as a proxy indicator for variation in a variety of firm characteristics such as level and mode of production, contracting relationships, market control, and so on, which might be significant factors impinging on management's considerations of nc technology.

The Sample

A sample frame was constructed using the NC user census carried out annually by the Canadian Machinery and Metalworking journal, and combining this with product line and employment size information from Scott's Industrial Directory. The Canadian Machinery and Metalworking journal sends out a mail questionnaire to its subscribers requesting information on the purchase of numerical machine tools. This survey was first undertaken in 1969, followed up in 1974 and 1977, and has taken place annually since 1980. In addition to the direct responses to the questionnaire, machine tool suppliers are surveyed on sales and this information is used to substantiate and expand the reader returns.

The other elements of my sample frame was provided by

Scott's Industrial Directory whose listings of manufacturing and other business establishments depends also upon voluntary registration. It is the most extensive listing of business units in Canada. It provides detailed information on products, ownership and employment for a large proportion of the firms which appear in the Canadian Machinery and Metalworking NC user census. Combining these two sources generated a list of NC users identified by type of industry, or product line, and size of employment. Wherever possible firms have been identified in terms of variation in two other aspects of nc technology. First, both long term users and more recent adopters within each industry branch have been identified. Second, variation in the extent of utilization of nc machine tools over time was identified. In other words, the sample frame included firms which seem to have expanded their NC investments, and firms which have held steady at a fixed number of machines over a long period of time.

Firms outside Quebec and Ontario were excluded from my sample frame. This was a pragmatic move designed to render the sample manageable in terms of a single-person study. However, these two provinces have an overwhelming dominance in the proportion of NC users, so that serious distortions in representativeness were not expected to arise from this decision (1).

Selection of the cases to be studied from the resulting list was not random. In some cases the number of firms of an industry subtype were just too few to sample. In other cases a firm was referred to as a significant example of NC use by many respondents, and as having an important influence on the diffusion of the technology in the local industry. The "overrepresentation" of aerospace firms among the Quebec group, reflects the prominence of this industry in the Montreal region. Thus many of my sample establishments which were listed as jobbing machine shops, or tool and die shops, turned out to be primarily aerospace subcontractors. This concentration was compensated for in the later sampling of Ontario firms by deliberately seeking out non-aerospace related NC users. The sample, then, is entirely a purposive one and not one developed through random selection. It was designed to obtain a diverse range of nc users (2).

The resulting sample comprises 28 Ontario firms and 32 Quebec firms belonging to the metalworking and engineering group of industries. Some basic characteristics of my sample are provided in Appendices A and B.

The Interview (1)

The two schools of thought referred to in Chapter One present decisions to adopt and use NC technology in quite different terms. Labour process writers argue that management operates with a relatively coherent strategy aiming at the reduction of labour costs and increasing managerial control over all phases of the production process. The diffusion analysts tend to present an optimising model of management strategy wherein a multiplicity of factors are weighed in adopting and using particular production techniques. In neither case is evidence of managerial assumptions and perspectives directly examined. It is to this gap that my study is addressed. The tool being used is an in-depth interview rather than a structured questionnaire. This tool was selected because I was interested in strategic assumptions and perspectives which might underly day-to-day managerial decisions in running production operations. I therefore needed the flexibility to probe and explore certain responses which may not immediately reflect the strategic orientation. Further, it was possible that, as Gold (1983, pp. 257-259) suggested, various post-hoc rationalisations may have existed and these have to be probed if they are discovered in the course of an interview. It was essential, then, to be able to assess responses in a face-to-face interview situation of some flexibility, rather than to adhere to a rigidly preset interview questionnaire.

As the field research progressed, a number of advantages of the interview method emerged, in addition to the anticipated capacity for probing. In many instances I was passed on to individuals more informed than the initial respondent -- those who had been with the firm longer, or who had been involved in specific decisions, for example. In the majority of cases, the personal interview culminated in an invitation to tour the plant. This provided me with opportunities for more detailed observations of manufacturing activities involving nc technology; for further probing as a result of these observations; and for contact and questioning of shopfloor personnel. In addition, the relative informality of the interview, as against committing oneself in written questionnaire responses, seemed to permit many respondents to freely discuss mistakes and failures in technological decisions, and to make a variety of critical observations about NC technology and their firm's utilisation of it.

It was intended that the subjects interviewed would be plant or production managers whenever possible. This category of management is responsible for directly overseeing the production process, and for translating overall price guidelines and product demands into actual production runs. These managers usually have engineering or technological training, are in close contact with production engineering, shopfloor supervisory and maintenance personnel, and are a key source of information guiding the adoption and use of technology in the plant.

In 50 of the cases I was able to interview this category of management, or a close counterpart who was directly involved in production engineering or process planning. In the case of one large aircraft company I was provided access only to the Director of Engineering Personnel. However, he was himself an engineer with a production background and appeared to be au courant with technological and production issues, and was certainly informative with respect to training, promotion, apprenticeship and other personnel matters.

In the remaining 9 cases (6 in Quebec, 3 in Ontario) my informants were junior management or technical personnel, primarily programmers for NC machinery. Although their perspectives on nc technology were virtually identical to that of plant and production managers, in 4 cases they were less informed about the history and background of their firms' adoption and use of nc than more senior personnel might have been. In particular they were ignorant of the organizational processes associated with machine tool selection -- which managers were responsible for developing capital investment plans and the exact sources of information used in the development of such plans. However, these informants were able to provide some useful information about the actual performance of the machines, especially with respect to their programming, and also provided detailed accounts of the way they worked with nc machinists and other shopfloor personnel.

Research Foci

My assessment of the current state of innovation-diffusion research (including the labour process analysts) did not suggest an adequate model of technological choice in relation to nc. Analysts such as Mansfield and Globerman point to profit expectations as crucial determinants of nc adoption. Yet, given the gap between the glowing descriptions of the potential profitability of NC in engineering trade journals and the actual level of diffusion (see chapter four), such expectations probably depend upon a number of other, underlying, conditions. Gebhardt and Hatzold's study begins to show some of the complexity of such conditions, and explore a variety of factors which facilitate or retard diffusion. Despite their success at identifying some of the determinants they note that the diffusion of nc is still highly uneven, even within a group of metalworking firms (valve and pump manufacturers) which should clearly benefit from NC. They suggest, but are unable to clearly prove, that managerial attitudes apart from profit expectations contribute to this pattern.

The labour process model is simpler - management's overriding strategy in the pursuit of profits is to reduce labour costs. This requires continuous expansion of management supervision and control of the labour process, and fragmentation and deskilling of labour. However, neither the evidence on managerial perspectives on labour (Gallie 1978), nor on deskilling (Jones 1982) support a strong version of this hypothesis. In other words, it is possible that there are instances where management do attempt to reduce the skill content of the labour process in search of cost reductions, or that this may sometimes be associated with conflicts with craft unions. So a more cautious labour process interpretation would lead one to expect that these instances are not as widespread, nor do they represent management's primary objective or tactic of first resort. Nonetheless, labour process theorists must claim that concerns with labour costs are in some quite frequent circumstances salient and central in decisions to purchase the technology.

In my judgement, then, the current literature provides us with a modified profit expectations model which still does not account for the variability of NC adoption and a labour process model which claims that labour costs are an important consideration for some unspecified proportion of decisions. The vagueness of these specifications of the theory does not allow rigorous tests of hypotheses. Consequently, I am attempting to discover what patterns exist in managerial perspectives and actions with respect to a number of aspects of the diffusion of nc technology, in a carefully selected number of firms.

i) The first aspect is management strategy. Gold (1984) and Freeman (1982) are among the most prominent diffusion writers who emphasize the significance of variation in management's strategic orientations for diffusion decisions. There are several possible strategic orientations (with some parallels to those which Freeman (

1982, ch. 8) suggests for innovation strategies): attempting to be among the leaders in testing new technologies by application in production situations; using new technology in carefully restricted applications and watching the results closely until the technology has proved itself *in situ* , waiting until the technology has been used successfully by others in the field. A fourth possibility is that there is no discernible overall strategy and that technological adoption decisions are made on an *ad hoc* basis, as and when circumstances require them. By this I mean that sometimes management waits for a technology to prove itself before adopting it; and at other times the same management will experiment and lead in the use of a new technology. The data discussed in Chapter 6 suggests that the bulk of the companies in my sample followed a conservative strategy, waiting until the technology had been proven and then adopting it for specific applications. Some companies did appear to operate on an *ad hoc* basis and a very few attempted to be technological leaders.

ii) The second aspect of concern, which is very closely connected with the first, is that of intelligence gathering and the learning processes associated with a technology which has tended to change increasingly rapidly since the arrival of the microprocessor. Before managers decide to purchase a piece of equipment they have to find out about its existence and its potential performance. The first issue here is how managers obtain information about production technologies and how they evaluate the sources and content of this information. What is the relative weight attached to trades journal reports, machine tool company representatives and salesmen, trade exhibitions, industry associations, etc.? How systematic is the search for a machine tool once the decision to invest specifically in nc technology is made.? To what extent is there systematic variation in access to information? These issues are explore in Chapter 5.

A related but distinct issue is that of the learning-by-using processes which may (or may not) occur, and the impact that these may have upon diffusion. It appears to be generally assumed that such processes facilitate diffusion either by leading the pioneer firms to become even more committed to the new technology, or by inducing the laggards to jump on the bandwagon before a large technological gap develops. However, pioneering could also involve declines in efficiency and resource diversion on a large enough scale to slow down or reduce the pioneer's commitment to new technology and to discourage emulation by others. Rosenberg (1982, p.107) suggests that the latter is particularly likely under conditions of very rapid technological change. The experiences associated with using NC technology are analysed in Chapter 6, pp. 211-227.

iii) The third area of investigation is that of the labour concerns management may have. When I started out this research it seemed to me that most of the labour process writings far too narrowly focuses on the issues of labour costs and control over the labour process. However, if these issues are indeed salient management concerns, then one would expect them to be doubly so in the engineering and metal working firms I planned to study, where much production is still dependent upon high wage, high skill labour inputs. In fact my evidence suggests that such concerns were major considerations for the majority of managers in my sample (see Chapter 7).

iv) However, wage costs do not exhaust the range of labour problems industrial management may confront. Skill shortages that were persistent (for example, tool and die makers) and short term (for example, maintenance workers with skills in both mechanical and electronic machine components analysis and repair) may exist or be intensified by the diffusion of new technology. Not all firms are able or willing to offer premium wages and different labour-technology combinations may emerge as managements develop different strategies to cope with skill shortages.

Under conditions of a rapid, broad-spectrum, shift in technology, as in the case of microprocessor technology, a skills generation gap may develop within the workforce. In this case younger workers, with less seniority may be more suited to promotion than more senior employees, and tensions might develop between traditional patterns of promotion and reward, and the demands of the new technology. The development of a skills generation gap may also disrupt the traditional arrangement of operating with a core group of established skilled workers employed, at least implicitly, on a last to be laid-off in bad times basis. Thus technical change and the diffusion of new technology may generate some very significant dilemmas for labour force management, dilemmas which have not been investigated or stressed in the class control approach of the labour process writers. Such issues of labour deployment, skill levels, labour training and labour shortages are explored in Chapter 7.

v) Finally, NC technology itself has changed over time. Prior to the development of the microprocessor, NC controls shared many of the limitations of the conventional computer -- particularly limitations concerning the slow speed, complexity, and error proneness of programming. Microprocessor controls are faster, easier to use, and have become diagnostically sophisticated so that errors are easier to discover before machining occurs. In addition, interactive programming and proofing has made the task of programming more "user friendly" and accessible to the machine operator. On the other hand, the rise of computer aided design and computer aided manufacturing (CAD and CAM respectively, on which topics see Chapter Four), which integrate engineering design, prototype development and testing through simulation in the course of producing the machining programmes, may have the potential to reduce shopfloor workers' role considerably. The history of NC technology is surveyed in Chapter 4, pp. 93-100.

The development of NC technology has had consequences for the machine tools themselves. NC automation involves more intensive and continuous use of machine tools which has led to changes in construction to improve durability and rigidity. Subsequently, the designs of NC machine tools themselves were altered. The "machining centre" has emerged which combines the functions of vertical and horizontal milling machines, with those of the lathe and the drill press. Novel attachments to machine tools such as automatic tool changers which automatically feed tools in preset sequences according to the machining operation required, have become standard attachments to NC mills, lathes and machining centres. Automatic multiple pallets for holding several pieces to be machined simultaneously or sequentially have also been developed for NC tools. Such changes are still in process and herald, according to some, a new age of flexible manufacturing systems or wholly integrated automatic factories where loading, unloading and all machining is entirely automated. As yet very few such operations exist with much approximation to this level of automation. However, these changes indicate that nc technology has itself altered very significantly since its emergence in the 1950s. I try to explore the impact such changes in NC technology has had on management's decisions to use it throughout the analysis in Chapter 6. As Gold (1982) again points out this aspect of the effect of technological changes on diffusion is not yet systematically incorporated into diffusion studies.

Conclusion

In summary, then, in order to uncover managerial assumptions, perspectives and strategies pertaining to NC technology, I have interviewed a sample of production and plant managers in engineering and metalworking firms currently using numerical control technology in Quebec and Ontario. The firms were drawn from different industrial groups within the engineering and metalworking sector: metal fabrication, machinery manufacturers, transportation equipment, and electrical and electronic goods. The sample also includes both recent and longer term users of NC machine tools. In addition the managers were selected from a broad range of plants in terms of employment size. Thus it is anticipated that the range of firms selected would provide a clearer picture of the variety of factors influencing the diffusion of nc technology than has emerged so far.

In my next chapter I shall survey the development of NC technology itself.

Footnotes

1. The one area of engineering which is excluded by the decision to research only those firms located in Quebec and Ontario is oil drilling and surveying equipment. Judging by the recent spread of nc using firms in oil drilling areas of Alberta and the Maritimes this is a significant new area of NC application. However, it is likely that such application is similar to heavy equipment manufacturing generally, and we do have several of these firms in our sample.

2. Unfortunately the bulk of the outright refusals (and what amounted, in practical terms, to the same thing, the months-long delays and evasions in becoming available for interviews) were from owner-operated small, precision machine shops which had adopted nc after 1981. In every case pressures of business were cited as obstacles to any interviews.

3. At the outset of my study I intended to tape all of the interviews. But first I found that this was impractical during factory tours where noise levels and mobility resulted in inaudible tapes. As well, my third informant refused to be taped, although he was willing to wait while I wrote down his responses. Consequently I developed the technique of writing out my interview notes in full in the company reception area (or in my car if there was no reception area) immediately after the interview from the "shorthand" versions I wrote during the interview itself. This permitted the recovery of the data "verbatim" without the use of tape recording.

Chapter 4: The Evolution of NC Technology

Introduction: Basic Types of NC

Numerical control is a technique for automatically controlling machine tools such as lathes, mills and punch presses. In NC, operating instructions are given to the machine as a prepared program of coded numbers indicating the feed, speed, depth and nature of cut, etc. This programme of instructions was at first prepared for storage on punched cards, but storage on punched paper tape or on magnetic tape quickly became standard in industry. With the development of mini- and microcomputors in the 1970s disk storage and then "direct numerical control" (DNC) emerged where the programme was directly routed to machine tool controls without the aid of a separate physical medium. Once the programme is provided to the machine controls, the instructions can be carried out automatically with a minimum of human intervention.

The idea of a flexible system for controlling the operation of production machinery originated in the eighteenth century. The first patent for such a mechanism was issued in France in 1725 for a knitting machine controlled by a perforated card. In 1804 another French inventor, Jacquard, patented a knitting and weaving machine controlled by punched cards. A gap of over a century occurred before another significant flexibly controlled machine was developed by an American inventor named Scheyer. He patented a continuous-path cloth cutting machine for the garment industry in 1916. This machine was controlled by perforations in a paper roll similar to the method used to operate the then popular player piano. In 1930 a patent was issued to another American for a method for controlling the operation of machine tools by punched cards. While all these examples incorporated the basic principles of numerical control, their control systems lacked versatility and reliability. The commercial development of contemporary numerically controlled machine tools is generally acknowledged to have originated with the post-Second World War experiments to improve the manufacture of helicoptor rotor blades by the Parsons Corporation in the United States (Howe, ed. 1969, chapter 1; Lynn, et al. 1966; Noble 1984, pp. 81-103).

There are basically four generic types of NC machine tools considered in terms of the degree and type of control system involved. The simplest type is <u>manual NC</u> which is the cheapest and least automatic. The numerical instruction selects or initiates a machining movement which, when completed, reaches a stop which has to be manually reset in order to repeat the movement again or to go on to the next movement in a sequence. Setting all the stops required for a particular job may take a lot of operator time if there is a large sequence, and even more time if particular inspection or gauging for tolerance and finish is required at the end of each movement. Because of the potentially large non-machining time and operator intervention, this type of NC is usually confined to simple work involving a small number of cutting movements and long production runs of large batches. This method was applied, for example, by one firm in my sample for a run of automotive engine block castings where high precision and fine surface finish were key requirements. In this instance the machining movement was a straight pass of the milling cutter over the two ends of the aluminium casting. At the end of each pass the machine would automatically stop while the operator unloaded the two finished castings and loaded the rough castings onto the machine.

The next simplest type of NC is positional control Here the machining and positioning of the cutting tool functions are controlled separately. The NC system controls the positioning of the tool by identifying the location of cuts in terms of a matrix via 'x' and 'y' coordinates. A simple timed machining cycle moves the tool to each coordinate location and then activates the cutting or machining process. The tool does not cut or machine as it is moved between each coordinate position. This was the first system of nc machining to spread significantly beyond ~~the~~ aircraft industry. It is the easiest to programme, requires relatively simple controls and is consequently, along with manual nc, the least expensive type. Yet it is eminently suitable for complicated drill work such as would be required for rivet locations on railroad freight cars and aircraft.

More complex is <u>paraxial control</u> which, in contrast to the previously mentioned types, includes the facility to perform machining operations while the cutter is moving between the 'x,' 'y' coordinate points. The most common form of this type of nc machining was straight line milling or NC controlled flame-cutting or welding. While it was at first applied independently to each axis or slide on the machine, later more sophisticated systems permitted the two axes to be moved at the same time and speed so that straight lines at angles to the major coordinate axes could be cut.

The most complex and costly form of NC is continuous path or contouring which developed early in the aircraft industry. Here numerical instructions can specify the required movements of several axes simultaneously. The simultaneous control of the cutter in several axes provides the machine tool with the capacity to produce the sculptored surfaces required for jet turbine blades, helicopter rotors and so on.

While early generations of NC machine tools tended to be specialised in one these four categories, later models have taken advantage of the greater flexibility and ease of programming and have combined elements of manual, positioning, paraxial, and contouring within a single machine.

Advantages of NC Machining

The proponents of NC have had a standard set of arguments with which to sustain their enthusiasm for this technique. This was clearly, if bombastically, expressed by the major North American metalworking trade journal soon after the 1960 Chicago Machine Tool Exhibition at which the first generally applicable nc tools were exhibited:

> "Numerical control is a giant step beyond conv-
> ional automatic control. Not just another

system, numerical control is a fundamental philosophy of communication. Heretofore, complete machining operations have been automatically executed under control of built-in devices such as cams, templets, masters, limit stops and metered hydraulic systems. However, the setup and tooling in using these controls are often elaborate, time consuming, and costly. These costs can be absorbed when large quantities of the same part are to be made, but cannot be justified in short-run production." (American Machinist, August 8, 1960, 100).

The common feature of the pre-NC mechanical automation methods is that before the first part can be made it is necessary to make a mechanical part ranging in complexity from a template (1) slightly simpler than the final part, through a model as complicated as the desired part, up to cams (2) very much more complicated than the part they produce on an automatic lathe. Mechanical methods of automation also present storage and maintenance problems since jigs (3), templates, models or cams have to be preserved in order for repeat batches to be made. Such items are often bulky and mechanically complex so that storage and maintenance costs can be significant. The more complicated, and therefore costly, the preliminary fabrication of pre-production mechanical devices, the larger the batches of parts which have to be produced before the process can be economical (Abegglen and Stalker, 1985, pp.

93-111). Herein lies the major difficulty for much of metalworking and engineering where the bulk of items are produced in runs of small and medium batch size. Consequently the industry literature on NC, whether user surveys or NC manufacturers' sales publicity, has consistently emphasized its advantages over preceding automatic machine tool systems primarily in terms of shorter lead times (i.e. less time spent setting up prior to actual production), the saving in jig and fixture (4) costs, and the flexibility and ability to economically produce small batches (Barron 1971; Howe 1972; Evans 1973; I.P.E. 1978). Other advantages are cited, most prominent of which are the ability to produce complex parts, or parts of consistent and high quality, and reduction of scrap. Direct labour savings and other labour related advantages, it should be emphasized, are far less prominently mentioned, usually at the end of lists of the "technical advantages" (5).

According to the labour process writers such as Shaiken, however, "in the design of new machines and manufacturing systems two pervasive managerial purposes stand out: reducing the amount of direct labour and increasing control over the manufacturing process" (1985, 45). These two design criteria reflect management's ulterior strategic orientation towards labour - deskilling, demobilization and social control at the workplace. In looking at the development of machine tools, culminating with NC machine tools in particular, an alternative interpretation of these design criteria can be suggested.

The History of Machine Tool Development

There is, however, an alternate model of the evolution of machine design available. In this model, designs evolve as a series of responses to demands for the mass production of new products and the consequent requirement for standardization (Landes, 1969, pp.306-317). As well, machine tool design develops through learning by using, as a process of responses to largely technical problems which are met, in the course of production with a given technology. Finally, processes of cross-fertilisation of techniques and instruments from one sector of manufacturing to another occur (Rosenberg, 1963, 1982). Mass production required durability and ease of maintenance of the manufacturing tools, and standardization and repeatability of output. These requirements intensified the search for mechanical solutions to the bottlenecks, poor quality and other problems that were typically encountered as the scale of operations increased. As more items became mechanized and mass produced, a greater variety of machine systems emerged which provided models, inspiration, and alternative solutions to a greater range of manufacturing problems (6).

The standard histories of machine tool development, culminating in the development of NC tend to present a picture more
consistent with the latter processes; they do not provide much evidence of a fixation on labour costs. The first generation of machine tools such as the lathe, the milling machine and the grinding machine was developed largely by British tool-makers or millwrights such as Maudsley, Nasmyth and Whitworth responding to the demands for improved performance of the Watt steam engine and the new water- or steam-powered textile machines (Rolt 1967, Steeds 1969). The rise of steam power and mass textile production demanded much greater precision in machine components than was required either by the earlier Newcomen steam engine used simply for pumping water out of flooded mines, or hand operated textile machinery.

In his detailed account of the development of this first generation of industrial tools and toolmakers Rolt argues,

> "It is an illusion to suppose that the machines evolved in Britain in the first half of the the

> nineteenth century by the first generation of tool-makers rapidly disposessed a nation of craftsmen. On the contrary, these tool-makers ... and their fellows were themselves high craftsmen who evolved their improved tools primarily to satisfy their own exacting standards of workmanship. They found that both existing tools and the existing level of human skill fell lamentably short of the standard they set, and the process of building the skill into the tool which they initiated was their answer to this dilemma...... Moreover, the first machine tools were not designed to replace traditional craft methods but to solve novel production problems which could not be surmounted in any other way." (Rolt 1967, 14).

In addition to the growing demand for efficient steam engines and durable textile machinery, there were several important consumer products developed during the nineteenth century which made similar demands upon industrial toolmaking for higher levels of precision ,standardization, and durability. In the United States, the mass demand for small arms generated major advances in precision machine tools many of whose designs originated in England but were rapidly transformed under New World manufacturing conditions (Rolt 1967, Rosenberg 1963). The American small arms industry pioneered tracer technology for making wooden gunstocks; elaborated the system of using jigs and fixtures - specialised holding devices enabling the precision machining of large numbers of complex parts; developed the toolmaker as a specialist craft, separate from that of the millwright who designed and maintained basic production machines; expanded enormously the range of application and the variety of special measuring devices (Saul, ed. 1970, Introduction; Smith 1976, pp.226-236). Subsequently, the mass demand for products like the bicycle, the sewing machine and the typewriter required new and improved machine tools able to mass produce complex parts or parts that would be combined in complex assemblies. In all these cases the parts had to be produced both in great numbers and with complete interchangeability and compatibility. While craft methods of production might have been able to produce parts precisely so that they were compatible and to standardised dimensions, such methods were completely incapable of fabricating these parts in the volumes that were demanded (Hounshell, 1984).

In the twentieth century the two most important sources of demand for machine tool design innovation have been the automobile and aircraft industries - the two largest customers for machine tools (Woodbury 1978). Both of these industries increased the demand for highly specialised machine tools of high speed, high precision, and capable of high volume production, for use in mass production characterised by the principle of interchangeability of parts. The automobile industry as shaped by Ford's mass production orientation led the way until the need for mass produced aircraft during and after the Second World War joined the automobile industry as the major source of innovative demands on the machine tool industry (Wagonner 1966).

In response to these demands the sources of machine tool improvement diversified so that a combination of advances in several fields have contributed to improvements in tool design and performance. Among the more significant developments have been the development of the science of metallurgy which made possible the reliable mass manufacture of high performance tool steel cutting tools, and later metallurgical chemistry which led to carbide tipped cutters; advances in industrial physics and chemistry produced synthetic abrasives and their tough bonding compounds for grinding machine wheels which have been crucial elements of automotive production. Basic research on the actual process of metal cutting pioneered by Frederick W. Taylor, among others, led to machine tool design changes producing heavier, more rugged machines, with greater rigidity of tool and part holders which permitted faster and heavier cuts with better surface finish and improved tolerances.

Electric power and hydraulic controls and transmissions improved smoothness of operations, permitted greater constancy and accuracy of cutting speeds (which also contributed to better surface finish), improved holding to specified tolerances, and consequently improved standardization and interchangeability of parts. The great range, precision and constancy of cutting speeds also permitted the easier machining of tough and recalcitrant metals and other materials used in twentieth century industry.

Another advance in machine design was the emergence of tracer technology which originated in nineteenth century manufacturing of rifle gunstocks (Noble 1984, 82). By the late nineteenth century cams, stops and trip dogs (7) were being incorporated into industrial lathes to automatically stop machining operations at a controlled point, to turn the workpiece for a new machine sequence, or to turn the tool holder to present a different cutting tool or change the tool angle in preparation for the next machining sequence. These mechanical automation devices continued to grow in application and to be standardised as adjuncts to most major machine tools during the early twentieth century. By the late 1930's very elaborate automated machining could be achieved using these devices. At this time also there emerged the "plugboard" technique of using electrical relays and switches instead of cams and dogs. By rearranging relays and switches on a plugboard a great variety of controlled machining sequences could be set up (Koenigsberger 1978). On the eve of the Second World War several techniques of machine tool automation had emerged and been demonstrated as technically feasible, although the inter-war depression had not generated high enough demand levels to generate commercial applications on any significant scale. Included in these pre-war automation systems were electro-mechanical devices, punch-card controls, and hydraulic controls. By the end of the war there had developed all-electric tracer controls, a digital computer-controlled lathe, photo-electric tracer controls, and a magnetic tape control system (Noble 1984, 82-88).

These diverse attempts to automate machining originated in the early 1920s boom in the demand for cars and other consumer durables, but were given even stronger impetus during the late 1930s by military concerns for high volume production of airplanes and weapons requiring new levels of design complexity and precision. Military production demanded rugged, durable products, easily replaced, whose assembled components were also easily maintained under adverse conditions. At the same time war manufacturing involved utilization of inexperienced, recently recruited and hurriedly trained manpower. These two conditions spurred industry to experiment with new forms of automation and manufacturing design. A third condition also imposed new constraints on industrial manufacturing: armaments designs changed through the war, as more sophisticated weapons were continuously developed. In industries serving the war effort, then, a new form of manufacturing that was both high volume and flexible was required. Such flexibility developed primarily in terms of traditional mechanization techniques, using automatic devices such as cams, tracers, etc. much more extensively; developing even more elaborate systems of jigs and fixtures; and developing more extensive specialisation of machine tool operators working with set-up men now limited to a single type of machine tool.

The Development of NC Technology

Modern NC control where machine tools receive instructions from a prepared punch paper or magnetic tape emerged after the Second World War as "...the brainchild of a defence subcontractor for Bell Aircraft, Jonathan Parsons, and engineers at M.I.T. subcontracted by Parsons" (Noble 1978, 326). Parsons had successfully built his company up to become the country's largest manufacturer of helicopter rotor blades. His success arose from his transformation of a custom and craft-based fabrication process into a mass production operation. This he developed by applying manufacturing methods he had learned working in the automobile industry, such as substituting a Chrysler metal-to-metal adhesive bonding for spot-welding (Noble 1984, 96-97).

The design of a helicopter rotor blade was very difficult because of the large numbers of complex calculations involved and typically took over one person year in production time. Parsons was one of the first to apply I.B.M. tabulating equipment to solve engineering problems. He also developed a punched-card record system for production control and inventory using this equipment. The complex contours of helicopter rotors meant that Parsons confronted not only design problems but considerable difficulties in manufacturing also. Especially difficult was the fabrication of accurate templates used in blade production to ensure that the contours would conform to specifications. The traditional ways of making the template was to calculate a set number of positions, use a French curve to manually connect the positions, then drill, saw, and manually file to finish. This process was tedious, time-consuming, and inaccurate. Attempts to develop other ways such as graphical techniques were equally time consuming and did not produce significant manufacturing gains. The ultimate solution was the use of the I.B.M. tabulating equipment at Parsons Corporation in calculating many more points along the curve, each with specific 'x' and 'y' coordinates. Then, using a technique of close drilling Parsons had seen in the automobile industry, the curve was cut leaving a light finish-filing only to produce the required contour. This process still involved tedious manual drilling of the Cartesian points. Consequently Parsons was impelled to explore the possibility of getting the tabulated coordinates to directly control the drilling process. This exploration coincided with the development of new United States' aircraft wing designs requiring integrally stiffened wing sections which posed novel problems for precision metal machining.

Both Parsons and the United States Airforce sought solutions to their problems from researchers at the Servo

Mechanisms Laboratory of M.I.T. These researchers were exploring practical applications for the emerging technology of computers. The basic problem which both Parsons and the U.S.A.F. faced was twofold: how to speed up and reduce error in the extensive mathematical calculations required for design engineering the latest generation of aircraft parts. Second, how to eliminate the tedious, time-consuming manual machining techniques required in producing the complex contours required. For both problems the M.I.T. research team's solution was to develop a computer tape actuated control system for the machine tools. The preparation of the computer tape contained the calculations required for design engineering. The work by the M.I.T. team resulted in a demonstration of the feasibility of continuous machining in March 1952 (Pease 1952). The subsequent developmental work was largely promoted by the U.S.A.F. in the pilot production of airframes for advanced military jets, the manufacturing of which required short cycle time between design and production of small lots of families of parts. During the 1950s the major users of NC equipment in the United States (and elsewhere, Gebhardt and Hatzold 1972) were the airframe manufacturers, aircraft instrumentation and electrical control companies, and some computer manufacturers. These user companies tended to build their own NC machine tools. Such machine tools were the most successful NC machines of the period, and were built before the established machine tool manufacturers began to offer NC tools on a commercial basis (Howe 1969, American Machinist 101, 102).

The close association between the development of NC and the primarily military requirements of the aircraft industry in the 1950s produced a peculiar pattern of evolution of NC machine tool design.

> "NC was developed backwards. The first M.I.T. control was a complicated, expensive monstrosity touted as the answer to mass production of complex machine parts for military aircraft. But due to NC's lack of infancy, ten years' of regressive development was required before NC (could make) its greatest contribution to industrial productivity. This contribution was a simple economical control easily adaptable to small machine tools. However, NC retained the complex programming of its birth. It has taken an additional ten years...... to develop the components and devices...... to limit size and programming complexities so that NC is now practical in the small job shop." (Bylinsky 1975).

Thus during the 1950s NC technology developed at the most complex level, as continuous path multi-axis machines capable of producing three-dimensional sculpted surfaces such as airplane and missile nose cones and jet turbine blades. Elsewhere in manufacturing, automated machine tools continued to develop largely on the basis of established tracer technology (N.C.S. Proceedings 1972). Continuous contouring machines were the most expensive to construct and the most complex to programme and had few applications outside the esoteric requirements of aircraft and military production. Noble's case that the development and diffusion of this NC technology would not have occurred without the U.S.A.F.'s support (Noble 1984, ch. 8), is echoed by the major American engineering trade journal which observed in 1957 that NC developed largely "as a result of the developments since the U.S.A.F. put its dollars on the NC barrelhead..." (American Machinist 101, 135). Gebhardt and Hatzold's study (1974) of NC diffusion also found a strong relationship between the diffusion of nc and the weight of military aircraft production in Western European economies even in the early 1970s (1974).

Thus while the more economical and the potentially more widely applicable developments of NC such as point-to-point positioning control and NC controlled tool changers were developed by 1956, and in November 1958 the first NC machining system developed for general as opposed to aircraft machining came on the market, the spread of the new technology was very slow. For instance, the Sixth Machine

Tool Exposition at Chicago in 1960 was touted as indicating a major breakthrough in the general availability of NC technology (Fortune November 1960, pp. 203-214, American Machinist July 1960). But the American Machinist review of the show indicated that more than 90% of the machine exhibits were not NC machines but were conventional ones (Ibid., pp.103-104). A review of a European machine tool exposition in the same issue also indicated that while various types of electically controlled machines were prominent, these were primarily tracer types, and NC machines were even less in evidence than at Chicago (Ibid., pp. 112-113). In 1960 an American Society of Tooling Engineers estimate put the proportion of NC machines as 7% (in dollar value) of the total machine tools produced (Howe 1969). However, the American Machinist did insist that NC was liable to expand considerably in point-to-point drilling applications -- the simplest and cheapest NC application. Indeed the first low-priced NC machine was Pratt and Whitney's 'Tape-O-Matic' drilling machine, introduced in October 1961.

The development of NC machines involved a variety of technical problems far beyond the coupling of computer technology with machine tool operations. Aircraft components are often very large, requiring large, specially configured cutting machines. The alloys which make up jet turbine blades and aircraft landing gear components are extremely tough, imposing new demands on power, rigidity and cutting tool characteristics. Manufacturing components to extremely close tolerances also imposes major demands on machine tool design and manufacture to eliminate backlash, looseness, etc., and to develop highly accurate instrumentation and guide beds to regulate feed rates, cutting angles, and to minimise cutting tool wear and breakdown. In all these requirements, however, the demands on machine tool design and performance can be said to be similar to previous cycles of machine tool development. That is, the machine tool industry, as providers of production equipment to others is periodically required to respond to the needs of a new rising industry. As we have mentioned, such cycles occurred in the mid-nineteenth century with the development of mass production of firearms, the later rise of the making of bicycles, sewing machines, and typewriters and, in the twentieth century, with the rise of the automotive industry.

The novelty of the development of NC lay not in the evolution of machine tools and cutting equipment as such but in the development of the controlling equipment. The latter evolved parallel with the development of the computer. Initially, as in the Parsons Corporation, mechanical tabulators were used to prepare more precise information on which to base conventional manual machining (Noble 1984, pp. 97-98). In the next stage these mechanical tabulating devices fed their calculations onto punched paper tape or magnetic tape which then directly actuated machine controls. Since NC was used originally by aircraft and related components manufacturers who tended to build their own nc equipment, a major problem of lack of standardization between the machine designs, programmes, input formats and control devices soon emerged (Noble 1984, p. 176). By 1958 the need for standards for nc equipment became critical. Electrical equipment manufacturers were trying to supply interchangeable controllers to all their customers while data processing companies tried to contain the growing diversity of programmes. The Electrical Industries Association sponsored and organised the efforts toward standardization and these gradually spread throughout the nc using industries (American Machinist, May 1958, p. 111).

In its early developmental stages, between 1953 and 1956, programming for NC required understanding machine tool operations and capabilities, tooling, machine practices, analytical geometry, advanced algebra and trigonometry, computer programming, coding techniques, and computer application and usage. It was difficult at that time for practical shop people with a tool analyst's background to write NC programmes. Subsequently this task was facilitated by the development of symbolic programming languages readily understood in the tool designer's trade. Such languages are based on contraction and/or truncation of the words used in the machining trades and on numerical parameters accepted in shop practice. Systematic development of NC programming began with continuous contouring programming at M.I.T. in June 1956, under contract to the U.S.A.F. as a corollary to a similar contract for the development of hardware. This work ultimately produced A.P.T. (Automatic Programmed Tools), and AUTOPROMPT, a more generalized machining programme subsequently marketed by I.B.M. from August 1961 on. Simpler point-to-point positioning programmes developed in 1962, and simplifications of AUTOPROMPT became available in 1964.

These programmes produced a generalized format, for example for a type of milling operation, or lathe operation. However, in most cases these programmes could not be used indiscriminately on all types of machine tools which differ according to make, size, tooling specifications, etc. Thus post-processor programmes were required to convert the generalized NC programme into one compatible with the qualities of a specific make of machine. The generalized programme provides arithmetic data relative to the pattern that the cutter centre must follow in order to produce a given part. The post-processor programme tabulates such data into a tape format tailored to the particular tool and its controller.

The advent of cheap and reliable computer power, first in the form of minicomputers and later in the form of microprocessors, made possible sophisticated, flexible, and easy-to-use programmable controls, with programme storage capacity in the machine tool control monitor itself. This meant that smaller engineering and metalworking firms could utilise NC without the need to build up expensive departments of specialised computer technicians and process engineers. Manual data input permitted programming, programme editing, and programme optimising by skilled machinists on the shop floor, marrying traditional shopfloor machining craft skills with the new, flexible computerised controlling techniques (Hatschek, 1978).

However, it was precisely the rise of cheap, flexible computer power which made possible the development of "computer aided design" (CAD), "computer aided manufacture" (CAM), computer integrated manufacturing, flexible manufacturing systems, group technology and other recently hailed forms of "high tech" production techniques (American Machinist, January }83, pp. 91-98; Bylinsky, 1981; Zeiderberg, 1984). Computer aided design is basically designing, drafting and analyzing using video display terminals and computer graphics. Computer aided design (CAD) both speeds up the traditionally slow and laborious work of drafting and integrates the design and analysis of products and components into the drafting operation. Current CAD technology often permits both design through assembly, disassembly, rotation through different elevations, and enlargement or shrinking of details, as well as analysis through simulated temperature changes, mechanical stresses and other conditions relevant to real world operation and use of the part. Such on-screen testing can save the enormous time and expense involved in fabricating prototypes and then testing, modifying and retesting.

Computer aided manufacture (CAM) is the latest phase of

NC, known as DNC, where machine tools are controlled by direct input from a computer rather than through the intermediary of paper or magnetic tape. When CAD and CAM are joined together the onscreen designing and testing of products generates a bank of computer instructions for manufacturing a component, or for making the required tools, dies and moulds necessary for making the component. This integration greatly reduces the time between design and production, making it cheaper to move to new models, to make mid-production design changes, to customize production, and to set up short production runs.

As was the case with the first decade of nc technology, the prime originators and users of CAD/CAM systems have been the aerospace industry whose production needs are the most complex and costly in engineering (Bylinsky 1981). But supporters of the technology have argued that CAD/CAM is part of an evolution toward 'computer integrated manufacturing' (CIM) which will make industrial metalworking and engineering into "a process as smooth and as easily supervised as the flow of liquids in computer-controlled oil and chemical refineries is today" (Bylinski 1981,108). C.E. Marchant, a director of scientific research at Cincinnati Milacron has hailed CIM as having "already demonstrated far greater potential to increase manufacturing productivity and quality and to reduce manufacturing costs than any other technology since the onset of the Industrial Revolution" (American Machinist January 1983,91). However, the fully automated factory envisioned by such people involves not just connecting CAD terminals to computer-controlled machine tools, but thoroughly computerizing a plant's manufacturing operations, including control of the flow of parts and materials and movement of products through the various stages of manufacture. In order to translate the entire manufacturing process into the precise, unambiguous steps of a programmed routine an enormous work study programme would have to be initiated, followed by much reorganization of traditional work patterns, followed by a long period of modification and testing as the new system was put into operation.

But manufacturing procedures are often irregular and idiosyncratic accretions of customs and personal quirks which vary from plant to plant, and even from one technician to another in a given plant. Even in engineering many activities are quite craft like in having no uniquely optimal solutions which can be adopted as standard procedure (Shaiken 1985, pp.190-216).). Moreover, the field of

CAD/CAM devices has developed so recently that there is a great diversity of incompatible computer software and hardware in use. Consequently, highly automated factory systems operate only in a few instances, generally with higher levels of labour input and conventional activities than their publicists initially forecast (Zygmont 1986). Firms which attempted ambitious computer integrated manufacturing programs have experienced problems ranging from extremely long periods of debugging, far less flexibility than initially anticipated, and a far more extensive array of expenses. Hence there appears to be some retreat from attempts to computer-automate entire plants and a move toward "group technology" where three or four machines are computer coordinated, often with automated transfer of parts from one machine to the next. These groups of computer coordinated machines operate as "islands of automation" in otherwise conventional plant production systems (Blackburn, Coombs and Green, 1985, pp.133-138). The overwhelming majority of engineering and metalworking plants still use a mixture of conventional and nc machinery.

Why and how such plants adopt nc machines is the subject of the following chapters. The method of data collection for these chapters allows one to appraise the extent to which gettting more detailed data than was available for writers of the standard histories of the technology reveals a more central role for labour costs than those histories would allow.

Footnotes

1. Templates are thin, hardened metal plates shaped to the contour required of the finished piece. These plates are clamped to the workpiece to force the cutting tool to follow their outline.

2. Cams are devices which convert circular motion into reciprocal or variable motion. They are used as levers to alter a tool's cutting path or as part of a mechanism to switch from one cutting tool to another.

3. A jig is a device for ensuring that holes to be drilled, tapped or reamed in a workpiece will be machined in their proper location. It consists of a clamping device to hold the workpiece under hardened steel bushings through which the drill and other tools can pass during each machining process.

4. Fixtures are devices for holding a workpiece during machining operations. It is fastened to a machine or bench in a fixed position. It does not contain special arrangements for guiding the cutting tool as jigs do.

5. What is a technical advantage and how it might be distinguished from a labour related advantage is not always clear. Thus the ability of NC machines to produce standardized precision parts etc. could be construed as an advantage over conventional machining dependent on craft skills and therefore a labour related advantage. I use the term labour related advantage to refer to such things as replacing skilled labour by less skilled labour, to organize production to impose machine pacing of jobs, and to significantly reduce labour input in the

production process.

6. Noble (1984, Chapter 4) provides an interesting example of this cross-fertilization in his discussion of the origins of the ideal of the "labourless" factory. He shows that the ideas of advanced automation of engineering in postwar United States were derived from the experience of the chemical and petroleum industries.

7. All of these devices are variations on the lever. As the cutting tool moved to the required finishing point, a cam or other device would be activated so that the next phase of machining could take place by changing the position of the cutting tool or, in the case of turrets or multiple tool holders, by rotating the turret so that a different tool would be in a position to machine the workpiece.

Chapter 5: Information and Machine Tool Selection.

Introduction

The diffusion of new technology is in part a process of gaining information about the performance capabilities of new machinery. It is possible that this obvious feature of diffusion accounts for diffusion writers taking it for granted. Where the costs of information, constraints on access to information, and other sources of imperfections in the distribution of information have been made explicit areas of analysis in a variety of economic concerns, this is not the case for diffusion analysis. For example, Mansfield's influential epidemic model assumes a population of potential new technology users operating with correct profit estimates (see above, p. 21); estimates which undergo no change as experience in using the new technology develops. The source of this surprisingly accurate knowledge is never explained. As a result it is not at all clear how management learns about new technology; whether managers keep abreast of technological change regardless of immediate capital investment needs and decisions; and whether sources of general information for such monitoring differ from those used when in the market for new equipment.

These issues are important because information about them could contribute to identifying more precisely the nature and limits to optimizing in the diffusion process, and to discovering whether these limits vary with different firm characteristics (such as size or market position), and change over time , i.e. as the technology becomes more widespread.

The analysis in this chapter focuses on responses to questions on the sources of information used in machine tool selection decisions, what company personnel were involved in machine acquisitions, and how the choice of a particular tooling package or machine was made. The responses to these questions were coded by identifying repeating response elements and weighting the order or sequence in which these elements occurred in statements (1). Each response's weighted score could then be used in calculating the salience of this element across the total sample response or within particular subgroups of firms in the sample (2). I shall analyse the responses by looking first at the most general patterns common to the bulk of the sample. Next we shall look for variations and differences between and within industry subgroups (aerospace, electronics, sheet metal, etc.), and for differences according to firm size. Since the questions asked about information in machine tool choice covered each company's entire period of NC usage, I shall look for changes over time as well as purely contemporaneous differences.

General Patterns

Clear differences emerged in the rank order of sources of information used generally, and in those used in the course of developing an actual machine tool acquisition request. The rank order of the weighted scores (see Footnote 1) summed across the whole sample are given in Tables 1 and 2.

Table 1

Information Sources for Monitoring Technology

Source	Score
Salesmen	75
Journals	59
Brochures	32
Shows	20
Other Users	19
Sub/Contractors	16
Trade Associations	5

Table 2

Information Sources for Machine Tool Acquisition

Source	Score
Brochures	81
Other Users	54
Price Quote Comparison	49
Shows	18

Table 1 indicates that machine tool salesemen and technical-trade journals are the prime sources of general information which plant and production management use in keeping up their stock of knowledge about current manufacturing technology. However, in developing requisitions statements outlining the plant or department's needs for new equipment neither of these information sources were relied upon. As indicated in Table 2, in the latter instance machine tool manufacturers' brochures were used as the major source of information concerning the technical specifications of the machine, its accessories, and its base price. Usually after some narrowing down of the field, the experiences of other users were sought in order to evaluate the performance of the equipment under actual production conditions.

The differences between the sources of information used in monitoring (Table 1) and those used in the search and selection process leading to acquisition (Table 2) suggests that industrial management use different sources of information in <u>monitoring</u> the progress of pertinent industrial technology, than in the capital <u>acquisition</u> process. Keeping informed about relevant technological developments involved using a quite diverse group of informational sources. Many of these sources involve very little cost to the firm. Indeed the prime source is costless, since it is the machine tool salesmen who routinely visit the plants in search of purchasers, bearing brochures and video cassettes containing detailed information about their machine tools. The bulk of our respondents indicated that once they had purchased their first NC tool they actually became part of the "circuit" in which NC salesmen routinely visited or mailed updated information. In this process the costs of information delivery fall on the machine tool manufacturers and suppliers. Several informants also mentioned that salesmen carried information of a more informal kind, i.e. concerning what other companies were doing, who was in the market for particular tooling packages, user experience of various machines, and so on. Salesmen, then, constituted a significant source of information about both the range of equipment available and forthcoming from the major machine tool manufacturers, and about the use of machinery in particular companies.

Technical or trade journals, the second most important source of information in technological monitoring,was also a relatively inexpensive mode of information gathering for many firms. Respondents from large firms tended to report that the firms they worked for had built up extensive technical libraries pertaining to manufacturing processes. The majority of respondents, however, indicated that they personally subscribed to trade or technical journals, or they received useful engineering journals as an accompaniment to their membership in trade or professional associations (3). Thus the costs of obtaining information from these sources was largely borne by the individuals in management positions and not the companies for whom they worked. (However, in the case of the four largest firms in my sample, such professional memberships were paid for by the employer.)

Several other sources of information mentioned such as contractors, subcontractors and Trade Associations are also low cost sources. Contacts and communications with contractors, subcontractors and Trade Associations are an essential part of most engineering and metalworking enterprises regardless of the possibility of technological information transfer. If such information can be disseminated during such contacts then it constitutes an added benefit. Much of the technological information obtained from other users seemed to arise either from casual contact or from contacts undertaken for other purposes so that transfer of knowledge about nc technology was again a low cost byproduct. Only the major machine tool exhibitions involved significant costs associated with absence from work, travel and accommodation expenses, diversion of managerial energies to prepare for optimum use of exhibitions,etc. However, such exhibitions bring together the world's leading machine tool manufacturers with a large array of demonstrations, the best informed technical personnel, together with seminars and conferences. In addition such events are occasional, so that the cost is episodic, and the amount and quality of information gathered is probably better than that provided by the regular "circuit."

While monitoring the state of manufacturing technology in their industry, production and plant managers used a broad range of diverse sources of information. In the search and evaluation process prior to capital investment, attention was focused much more narrowly. Information pertaining to the acquisitions process was limited primarily to machine tool builders' or distributor's brochures documenting the technical specifications of the machinery, and next to evaluating machine performance in production conditions by visiting other users. Brochures were used in most cases to develop a spread sheet which listed the equivalent machine models from several builders according to major technical characteristics, optional features, and base prices. In many instances this would be followed up by a request to the machine builder or distributor for a list of users of the particular machine, and a round of visits to other users would follow (4).

This process reflects two major aspects of capital investment - the sheer cost of the initial investment, and the longer term impact on costs and profits that the new capital equipment will have. Currently, NC machine tools such as mills, lathes and machining centres cost from $25,000 to $750,000, while their conventional counterparts cost from $15,000 to $60,000. The divergence in cost between the two types of machinery is often increased by the sometimes hidden expenses of the greater preparation and learning involved in using NC machines effectively (5). As the proprietor of a small general machine shop said, "Buying NC equipment is not like buying a car. Once you've got a new machine you have to learn how to make money with it fast. With a car you've got a fixed debt, with a machine you've got a debt which will grow unless you get rid of it through making enough money to payback its cost in the first two years. Then you have to make enough money before it wears out or gets obsolete to be able to finance a replacement."

While this sort of pressure is perhaps felt most acutely by small firms, it summarizes the conditions surrounding machine tool acquisition throughout industry. These conditions turn management's attention to close scrutiny of the machinery's technical characteristics and price. In the process the testimony of machine tool salesmen is discounted in the acquisition process. The reasons why this is so were suggested by informants in different branches of the aerospace industry. "Salesmen are the least reliable as sources of information about machine tools; you're much better off reading company brochures and comparing them carefully. In fact it's very difficult to be an effective machine tool salesman because you need practical shop experience on a whole range of machine tools in order to understand the requirements for nc. Most salesmen I've met have worked with a few of the machines and have really specialised knowledge of one or two types of machine at most. If you're interested in those machines specifically you might be lucky and hit on an expert salesman, but I'd still rather rely on my judgement since I don't really know what kind of machinists they were when they worked in a plant." A senior programmer at a jet aircraft parts plant who had been both a machinist and an NC machine tool salesman also pointed out that, "Even if you know a lot of machining techniques and you've used different types of machines, there are so many special applications in engineering that you can only give general advice to any company Each firm uses special materials, and the dimensions of parts can give rise to all sorts of problems of heat expansion and stress that you have to be careful with in setting up and process analysis. A salesman can't possibly know all these details of his customer's work, all he can know are the basic features of the machines he's selling."

Table 3 lists the weighted scores (see Footnote 1) for items found important in machine tool selection prior to purchase.

Table 3

Criteria Used in Selecting Machine Tools

Criteria	Score
Technical Specifications	110
Builder's Reputation	51
Price	34
Restricted Choice	17
Ease of Supply	7
User's Technical Leadership	6

By an overwhelming margin the technical specifications of machinery were the most important criterion used in evaluating models for potential purchase. The next most important criterion -- the machine tool builder's reputation -- is closely related to the primary choice criterion. It refers to the reputation the machines of particular builders have for reliability, longevity, and accuracy, and to the builder's record in providing advice, back-up in emergencies, routine maintenance and spare parts. For plant and production management, these two concerns - the right machine for the job, and a machine which will perform reliably with a minimum of down time or with swift servicing and backup - are obviously the essential critera for evaluating and selecting new machine tools.

Other criteria which were mentioned with some consistency included price, severe restrictions on choice of machinery, ease of supply and technical leadership. Price was mentioned as the first consideration in 10% (6 of 58 cases) of the responses. In general most respondents displayed a "you get what you pay for" approach to machine tool acquisition. Not surprisingly respondents from medium and large firms reported occasional arguments with financial management over the cost of recommended machine tool models, while the heads of small firms complained about the price of nc tools. In the former, instances were mentioned where financial managers failed to understand the need to pay for high quality production machinery.

In four cases, informants indicated that there was virtually no choice between machine tool builders or machinery models when they were in the market for NC equipment. For two of these cases, a custom sheet metal fabricator and a shoe mould manufacturer, this was due to their pioneering application of nc technology to their field of manufacturing. The other two cases were also early users of NC equipment, buying at a time when only one machine tool builder manufactured the appropriate machine tool. This situation was quite prominent in retrospective accounts of the initial choice experienced by early users of NC - those who had adopted this technology before 1970. Subsequently, the lack of a range of machine tool builders, suppliers, or models to choose from became an exceptional circumstance.

In terms of changes over time no respondents reported any significant change in the information sources they used to monitor NC technology. That is, the least cost sources such as salesmen, technical and trade journals, and brochures had been the major sources of information about production technology prior to computerisation of the field, and had not been displaced by alternative sources as a result of the rise of NC technology. The only change reported was an increase in the volume of information now available.

With respect to the machine tool selection and acquisition process there was a clear shift from situations of no choice between makes or models, or of extremely restricted choice, to a situation of abundant choice. Parallel with this change is the fact that fewer companies reported working with the machine tool builders to develop tooling packages geared specifically to their own special production needs. This reflects the development of off-the-shelf models which have been designed after years of such custom building to be flexible and adaptable to a broader range of applications (6). One example of this process was that of a large American auto firm which was negotiating with a Swiss manufacturer of NC lathes with a view to redesigning them for mass production applications (see below, pp. 148-150).

Two broad consequences of the growth of user experience as a result of the diffusion of NC technology were mentioned as significant by a number of respondents. First, the machine tool manufacturers themselves had become clearer about the requirements of NC users, so that both machine tool designs and the information contained in builders' brochures and cassettes were more realistic in the performance claims made and more adequate in terms of the technical information presented. The second consequence of growing experience is that the NC users themselves have developed a better sense of their own requirements, and their experiences have also provided a firmer foundation for evaluating manufacturers' claims and publicity material.

Before moving away from this discussion of general patterns in information gathering and use in relation to machine tool acquisition I should present the information gathered concerning the choosers of machinery in the firms investigated. The majority of the companies in the sample involved two or more individuals in the development of capital acquisition requests (36 of 57 companies, or 63%). In 11 cases the informant was not able to provide me with this information (see below, p. 136). Of the ten companies where it was reported that a single individual developed capital requisition statements, five of these were smaller machine shops in which the owner or senior partner made this decision. In the case of the largest of the tool and die companies, the toolroom supervisor-cum-NC programmer (an ex-tool and die maker) was responsible for acquisition requests. In the remaining four cases, production or manufacturing engineers who headed a particular manufacturing subdivision of a larger company were responsible. It is interesting to note that NC programming personnel were not prominent participants in the search and selection process. Primary or major involvement was the exception rather than the rule even though informants with this background argued that their exclusion had been associated with seriously flawed choices of equipment. This was reported in the case of a major aerospace manufacturer who has been a leader in the nc field, as well as occurring in the case of a major jet engine manufacturing plant.

Although the NC equipment investment justifications involved significant financial outlays financial management personnel were not often directly involved in the initial formulation of the requests. This was overwhelmingly the task of manufacturing, production and plant engineering management with a close relationship to the physical tasks of production. Financial management received these justifications and made the final investment decision. Even in times of rising demand the clear subordination of production management to strict financial justification was clearly expressed.

No doubt a labour process writer would make much of the fact that there were no references to shopfloor involvement in the selection and acquisition of machine tools. No one in my sample volunteered any information or case histories which suggested that workers are consulted about their experiences in any explicit or systematic way. Doubtless machinery and equipment which work well for workers are freer of maintenance problems and are more productive and so are likely to be seen as good selection choices by management. But this aspect of the labour process seems to be regarded as a technical feature of the machinery rather than as an element in labour relations which requires conscious attention. As we shall see in a later chapter, technological adoption is a management preserve which is rarely challenged by the workforce (at least in our sample).

The extent to which the selection of tooling packages is a management preserve is reflected in the difficulties I encountered in obtaining information in eleven cases. In nine cases I was unable to interview a management informant but was referred to a technician, usually an NC programmer. While these individuals were highly informed and informative about the utilisation of NC technology in their companies' manufacturing processes, they were very hazy about most aspects of information gathering and equipment acquisition. In particular they were uniformly unaware of who exactly was involved in machine tool selection, and the process of evaluation accompanying such selection. In one plant the technician, the chief NC programmer with a machinists background, guided me through his plant which specialised in repairing, rebuilding and making spare parts for jet aircraft engines. He pointed out four NC milling machines purchased in the early seventies (prior to his own employment at the plant) as examples of managerial blunders which were completely incomprehensible to him. Two of the mills were fitted with special tape controls to allow two separate machining programmes to be run in sequence. However, the machines with these controls lacked the automatic double pallets (7) which would permit switching over from one component to another as the tape controlled programme changed. He then pointed to another two mills which had the double pallets but whose controls lacked the double tape capacity which would render the dual pallet feature useable. The programmer's explanation for the installation of such mismatched equipment was that probably financial management had made the acquisitions decision and had found "someone else's mistakes going cheap on the used machine market."

Differences by Company Size

Thus far, I have looked at the central tendencies in the gathering and use of information for monitoring the state of production technology and for selecting new manufacturing equipment. Next I explore some of the variations in these patterns by looking at differences between firms of different sizes. In this section I shall interpret the data reorganised by plant size (small, less than 100 employees, medium, from 101 to 499, large, over 500). This information is presented in Table 4 (pp. 139-140).

All firms, whatever their size, display clearly the distinction between sources of monitoring information and information for selection and acquisition. Large firms appear to differ from medium and small firms in the relative importance of different sources of information used in monitoring manufacturing technology. Technical and trade journals are the prime source of such information for large companies, while salesmen are increasingly important as one moves down the organizational scale.

Large companies also referred to building technical libraries including technical and trade journals. No small company made any such references, while only two medium firms did so. However, technical and trade journals are a more important source of information, relative to all the sources used, for small companies than for medium ones. Brochures from machine tool builders and distributors were also of greater importance to small firms than to medium or large companies. All this confirms what might be expected, that while the cheapest sources of information are preferred by all firms, smaller companies are most dependent upon

Table 4

Information Sources and Selection Criteria by Firm Size
(Weighted mentions)[1]

	Large firms		Medium Firms		Small Firms	
Monitoring Information Sources[2]	Journals	32	Salesmen	19	Salesmen	30
	Salesmen	17	Journals	14	Journals	21
	Brochures	12	Brochures and shows	12	Brochures	19
	Other Users	11	Sub/Contractors	8	Shows	13
	Shows	10	Other Users	7	Sub/Contractors	8
	Sub/Contractors	8	Associations	6	Other Users	8
Acquisition Information Sources[3]	Brochure search	32	Brochure Search	28	Brochure search	35
	Price Quotation comparison	18	User Check	18	Price quote comparison	17
	Check other user experience/trade journals	13	Price quotation comparison	16	Shows	13
	Shows	8	Shows	7	Accidental contact	12
			Journals	3	Other Users	10
Selection Criteria[4]	Technical Specifications	36	Technical Specifications	32	Technical specif-actions	46
	Builder's reputation	24	Builder's reputation	11	Builder's reputation	13
	Price	5	Price	11	Price	12
	Limited choice	3	Limited choice	10	Ease of Supply	9
	Technical leadership considerations	2	Ease of Supply	2	Technical leadership considerations	2
Number of firms	21		23		16	

Table 4 continued:

Notes

1. The sequence in which the various sources or criteria were presented by the informants were scored in order to simplify comparisons across subgroups in the sample. First mention was scored 3, second mention 2, any other mention 1.

2. "Monitoring information" is information about the state of production technology gathered without any intent to purchase equipment.

3. "Acquisition information" refers to information sought out specifically to guide management in choosing new machine tools.

4. "Selection criteria" are the standards used in choosing among the various machine tools available.

these sources.

There were three types of inter-firm contacts referred to as sources of information by my informants -- other users, contractors and subcontractors, and trade or industry associations. In this respect, one aspect of monitoring information sources which stands out is the relative isolation of small firms. The large companies appeared to have greater contacts with other NC users, and to use these both for monitoring current manufacturing technology and for more focused acquisition information seeking.

While other users were less important than contractors and subcontractors as information sources for medium sized plants, they were still more significant than was the case for the small firms. Industry or trade associations were mentioned by informants from large and medium firms but not at all by those in small firms. Taking these three sources together, the medium firms use these diverse inter-firm contacts more than large firms. But both large and medium firms use these diverse inter-firm connections much more than small firms.

A parallel pattern of variation is found in information sources used in the course of search and selection of machine tools for capital investment. Medium sized companies make use of other users more often than either large or small firms, and both medium and large companies check other industrial users more than do small firms. A second tendency was that smaller companies relied upon machine tool exhibitions as sources of information when they were intending to purchase new equipment. However, the differences between different sized companies with respect to the importance of machine tool exhibitions as a source of information when planning machine tool acquisitions was not as marked as the other differences mentioned so far.

One category referring to acquisition information which appeared in responses from small company respondents only was that of "accidental" sources. In one instance the initial choice of NC equipment occurred on the basis of a close personal friendship between the company owner and a machine tool salesman. The salesman joined the company in a managerial capacity shortly after this transaction. Subsequent acquisitions by this firm, a small jobbing machine shop specialising primarily in small-sized aircraft components, were largely determined by the availability of machines from local suppliers in the face of upcoming contracts (8). The second firm whose initial acquisition of NC equipment was the result of happenstance was that of a shoe mould manufacturer which needed to replace a worn out copying machine. This need coincided with the visit of an NC salesman representing the distributor of one of the very few NC copying machines on the market. The subsequent acquisition of NC equipment proceeded on a systematic experimental basis, however, in marked contrast to the previously mentioned case.

Primary technical selection criteria were identical for all firms, with the technical specifications of the equipment being the dominant criterion. In other words the machining parameters of the work most likely to be handled by the machine -- size, shape, material, kind of machining to be done, level of tolerance required, surface finish, and so on -- were primary considerations. However, large companies emphasized "brand name" machine tool builders more than medium and small companies. This reflects the tendency of industrial equipment, farm machinery, lumber equipment, and the major aircraft makers to use large machine tools which are still the preserve of long-established U.S. machine tool builders. As well, informants from large companies often referred to "robustness," to "machines capable of running continuously without much downtime," to the need to "require minimum maintenance," as important technical criteria for tool selection. Further, fast dependable back up services by the machine tool builders in cases of major breakdown were indicated as very important to minimise the impact of downtime. The contexts in which these statements were made suggest that both the heavier machining of larger parts, longer production runs involving continuous running of machines, and very tightly organised production schedules were more characteristic of larger companies.

Price of equipment was a far less salient consideration for larger companies than for small and medium firms. The large companies' perspectives on machine tool price were aptly summed up by the manufacturing services manager of a large lumber equipment firm, "We go for quality machines which will perform the range of operations for the jobs we want, with minimum downtime. This usually involves going for top quality." He then gave as an example of this best-in-the-industry policy the U.S. lathes which the company had recently bought (all of this company's nc machines were of U.S. manufacture).

Differences by Industry Subgroup

Table 5 shows my data organised by industry subgroup.

Table 5

Information Sources and Selection Criteria Rank Ordered by Industry Subgroup

	Information Sources				Selection Criteria	
	Monitoring		Acquisition		Selection	
Aerospace	Salesmen	*22	Brochures	*17	Technical Specs	*40
	Journals	16	Other Users	15	Builder's rep	15
	Contractors	10	Shows	11	Price	6
	Other Users	9			Restricted choice/supply	3/3
Electronic Equipment	Salesmen	13	Other Users	12	Tech Specs	17
	Brochures	18	Brochures	9	Price	5
	Journals	4	Comp quotes	5	Builder's rep	3
	Shows	3	Shows		Tech leadership	1
Moulds, Tool and Die	Journals	10	Brochures	13	Tech specs	12
	Salesmen	8	Other users	5	Builder's rep	5
	Other users	8	Comp Quotes	3	Price/restr/choice	3
					Tech leadership/supply	2
Sheet Metal	Shows	8	Brochures	11	Restriced choice	11
	Salesmen	7	Other users	9	Tech specs	9
	Brochures/Assocs	5	Shows	3	Builder's rep	6
					Price	2
Valves and Pumps	Journals	10	Comp quotes	9	Tech specs	12
	Salesmen	8	Brochures	3	Price	5
	Brochures	7	Other users	3	Ease of supply	2
Trans-portation	Journals	12	Brochures	11	Tech specs	10
	Shows	8	Comp quotes	10	Builder's rep	11
	Sub/Contractor	6			Tech leadership	2
Industrial Equipment	Salesmen	6	Brochures	12	Tech specs	16
	Brochures	6	Comp quotes	6	Price	4
	Journals	4			Builder's rep	2
Lumber/ Agricul-tural Equipment	Salesmen	7	Comp quotes	18	Tech specs	11
	Brochures	5	Brochures	8	Builder's rep	9
	Journals	3			Price	1

* The numbers refer to weighted mentions. See footnote 1.

Sheet metal firms diverged from the rest of the sample in two respects. First, the sources of monitoring information cited were different from the other groups in that machine tool exhibitions and trade associations were more significant. Second, sheet metal company informants were more likely to report that the choice of machine tools was quite restricted. A combination of circumstances account for this subgroup pattern.

According to a Montreal NC consultant sheet metal machinery became computerised considerably later than chip cutting machinery (9). NC technology was applied to metal stamping from the mid-1970s onward because of the rise of computer technology which required printed circuitry to be protected from heat and dust by means of closely fitting cabinets and panels. Consequently, the metal housings which were stamped out by sheet metal firms for electronic equipment had to be fabricated to more precise dimensions than had been customary in this industry. Manufacturing sheet metal parts to more precise dimensions has been further reinforced by the development of laser technology in which lightproof containers are required. Such containers involve even more critical tolerances in their manufacture than merely dustproof containers. Four of the six sheet metal firms manufacturing electronic equipment cabinets and housings reported that this had been a major growth component in their business over the past decade.

A second factor contributing to the peculiarities of the sheet metal group with respect to monitoring and acquisition related information processes is that metal stamping presses tend to be large machine tools. It was pointed out to me by a Montreal area machine tool salesman (specialising in sheet metal presses) that the building of the larger ranges of machine tools has been dominated by U.S. machine tool builders. This tool sector has suffered less from overseas competition than the building of smaller industrial lathes and milling machines used in tool and die making and in jobbing machine shops (10). The same informant also said that this situation is changing rapidly as the Japanese machine tool manufacturers are now moving into the field with the vigour that had previously characterised their penetration of small and medium machine tool markets.

Another set of circumstances contributing to the sheet metal firms' specific characteristics was suggested by an informant working in a plant producing custom sheet metal grids and grills for heavy industrial users rather than electronic equipment. He pointed out that several technologies from outside the sheet metal industry are now affecting sheet metal work. The success of the automobile manufacturing industry with robotic welding has led to the displacement of rivetting by electric arc welding (11) as a major technique in joining together large metal sections. But electric arc welding requires close fitting components in order to produce strong and fault-free welds, consequently the fabrication of these components has to be to higher tolerances than was the case when they were rivetted. Similarly, the development of laser cutting and flame cutting large metal components, replacing bandsawing and filing, has produced increases in the dimensional accuracy of many large industrial subcomponents which, in turn, has led to demands on the sheet metal industry to match the tolerances of cast and forged components.

All of the above factors suggests that sheet metal fabrication is experiencing shifts in the demands for its product, accompanied by important changes in fabricating technology and in the supplies of equipment required for that fabrication. Despite the abundance of technological changes in all metalworking fields, this particular confluence of factors was found only in the sheet metal sector. It is reflected in the greater importance attached to machine tool shows as monitoring information sources, and in the references to the National Metal Stamping Association as a significant source of information. These circumstances might also explain why the only two companies who were concerned with the possibility that I might be working for another company and spying for my employer, were two sheet metal firms!

Despite these recent changes in sheet metal technology no informants from this group expressed a concern for technological innovation or leadership in the adoption of new technology. Technological change was mentioned as a process inititiated by competitors, especially those south of the border, and therefore as something which was forced on the firm in reaction to the pressures of competition.

Acquisition and Innovation

There were five cases where informants mentioned technological innovation as a factor in NC machine tool acquisition. In two cases reference to technological leadership were made in passing, and the informant's subsequent discussion of NC technology reverted back to an overwhelming concern with cost justification , technical and productivity criteria terms no different from the bulk of the sample. There were, however, three interesting cases where technological leadership as a criterion for machine tool acquisition was significant.

The most striking case was that of the small company making shoe moulds mentioned above, which had applied NC technology despite the advice of the NC tool manufacturer. The firm is currently the only computerised shoe mould maker in North America. The company needed to replace an aging copying machine (12) at a time when a visiting machine tool salesman happened to represent the distributors of the only nc copier on the market. The salesman warned the company president (also the owner of the firm which is small, having only 15 employees) that NC equipment was very expensive and advised the purchase of a conventional copier. However, the company president went to the NC copier maker's headquarters in Italy where he received the manufacturer's advice to stick with conventional machining because of the extremely small manufacturing runs involved. Despite the consistently negative advice the mould maker's president considered the NC copier as an advance over conventional models that brought with it the opportunity to experiment in computerised manufacturing methods.

The man who made this decision was an ex-ITT computer programme designer with wide experience and connections in the computer industry. Consequently he had a favourable bias towards the application of computer technology, and his own experience and contacts reduced the risks of such experiments (or at least made it possible to evaluate the risk with greater clarity.) He is currently working on the specifications for a more complex NC mould milling machine and exploring the possibilities of establishing a CAD/CAM system in the firm. As a result of his pioneering application of nc technology to the fabrication of shoe moulds he has collaborated with the Italian NC copier manufacturer in improving the design of their machines and in developing the software for mould making applications.

A second instance comes from the opposite end of industrial organization, the informant being a senior manufacturing project manager in one of the major U.S. automobile manufacturing plants in Ontario. He argued that any new technological applications undergo extremely rigorous cost justification but that the auto maker was consistently technologically innovative and "always looking for new applications for cutting edge manufacturing techniques." One "cutting edge technique" he was currently concerned with was the possibility of applying nc tooling to mass production. He argued that "We all know what NC can do in small and medium shops, or for tool and die work. That's been going on for fifteen or twenty years. But what can it do for mass production? That's what interests me." He had led a team of engineers for eighteen months who looked at the state-of-the-art NC machine tools with a view to placing them on the assembly line. The outcome was a proposal to use a Swiss NC lathe for the production of clutch components.

However, despite the fact that the NC lathe was the "cadillac of NC lathes" it had numerous design features which reflected its evolution as a small and medium batch production tool. All these design features resulted in a machine which moved too slowly for assembly line work. The project manager was to depart that evening for Switzerland to negotiate with the lathe manufacturer for redesigning the machine to "...shade off a tenth of a second here and there so that it won't be running slower than the rest of the plant and causing backups and bottlenecks." Since a successful redesign would result in the order of twenty three lathes at a price of almost a million dollars apiece, the financial inducement to the machine tool builder was considerable. This case is interesting not only as an indication of the probable next phase in the application of nc technology, but also as a clear example of the traditional process of design evolution of machine tools resulting from the demands on machine tool builders by their major customers as discussed in Chapter 3.

In the third case where technological leadership was referred to, the planning and development manager of a large railroad freight car construction company characterised his job as "to provide stimulus for change." He pointed out that only one of his firm's NC machine tools had not been acquired in connection with a specific large-scale contract impending. In this instance an NC lathe had been purchased. "This time the acquisition involved vaguer, non-specific management desires to introduce CNC machining into our operations, to see what it could do for us. But getting the machine this way meant that we didn't have any jobs lined up for it, so we had no real criteria in mind to test it against and we've been looking for things for it to do ever since. It is very much underutilized and we still haven't found an optimum way to use it. All the other machines were purchased in order to do a specific job, usually a very large one and one that was going to be repeated with fair regularity in the future." In contrast he cited the company's venture into the field of robotics, where the toolroom had constructed two robot welding arms to improve the quality of the increasing amount of welding being used in this manufacturing line (i.e. replacing rivetting as was mentioned above as a factor conducive to the spread of NC in sheet metal work). "Our firm was one of the first in Ontario outside the auto plants to install welding robots and as a result we're in a very good position to keep up with this technology. The robots have enabled us to keep to our contracts, to improve the product quality, and to solve a real bottleneck which everyone has had because of the shortage of qualified welders." The contrast between the CNC lathe and the robot welding arms highlights the way in which most machine tool acquisitions are considered. Cheaply and efficiently doing the manufacturing jobs which have to be done take clear priority over vague desires to be "first on the block" with the latest gadgetry.

At first sight it appears surprising that aerospace firms did not refer to innovation and technological leadership aspects of machine monitoring and acquisition. However, informants from these companies readily pointed out that Canadian firms installed NC equipment five to ten years after their U.S. counterparts by which time knowledge of NC technology was widely diffused in this branch of engineering. One of the pioneer subcontractors, a small jobbing machine shop in Montreal was introduced to NC by its then newly employed tool designer (now manufacturing manager), an English immigrant who had been trained on NC equipment in the British Rolls Royce jet engine plant. "We knew what we were getting into," was the common response to my questions about the problems of pioneering in NC technology, even though aerospace companies were the earliest users of NC in Canada, as in the U.S. Many informants throughout the entire sample but especially in aerospace also mentioned that U.S. head offices or contractors were a source of information about nc and other new manufacturing technologies.

The relationship between technical innovation considerations and market pressures was nicely expressed by the manager of CNC operations in a medium sized precision machining shop specialising heavily in defence and aerospace production. "We are faced with continually changing markets and technology, changes reinforced by the lack of a fixed product. Since we are a general job shop our company has to be willing to try anything our major contractors ask.

Investment in new technology is part of this situation. Contractors will impose tooling specifications so that some of our machines are obtained in order to get a specific contract. In other cases we invest in the new technology to ensure that we maintain our expertise and experience in developing areas and retain a leadership position in the industry necessary for later contracts." Thus pioneering in the application of new technology was a rather minor theme in the responses, very much subordinated to technical, and cost-efficiency imperatives.

Conclusion

The foregoing evidence suggests that diffusion theories cannot assume that information is perfectly distributed across a group of potential new technology adopters. Small firms stand out in following least cost but also least trustworthy information sources, using fewer inter-firm contacts both in monitoring and selection activities, and in having price, ease of supply, and accidental factors play a part in the acquisition process. Larger firms were able and more willing to "invest" in information. However, with the adoption of NC most firms reported their experience improved their capacity to evaluate information and to formulate acquisition criteria more precisely.

In addition, the machine tool builders and suppliers were reported to become increasingly attuned to a broad range of industrial applications and improve the technical presentation of brochures and other publicity material so that the quality of information improved over time. Informants reported also that, while the sheer volume of information has increased over time, there has been no significant shifts in the sources they used in either acquisition or monitoring activities. Thus over time both the range and the quality of information, as well as managerial experience in critically assessing information had increased, reducing some of the uncertainties in selecting NC equipment.

Sheet metal firms exhibited a somewhat different pattern with respect to information gathering than the rest of my sample. They tended to use machine tool exhibitions and trade association networks more than other firms. This pattern appears to be a result of the simultaneous development of different factors altering the markets for sheet metal products, the technology of sheet metal fabrication, and the range of machine tool suppliers in this industry. In this case, the resulting uncertainty has led to sheet metal management to pool information through the trade associations and to seek out information where comparison of equipment is possible at trade shows.

Finally, consideration of the advantages of technical leadership tended to be a minor theme in the responses. Technological monitoring, selection and acquisition seemed, for an overwhelming majority of my sample, to be part of a coping strategy, reacting to market demands rather than actively shaping markets. This response, of course, could be a reflection of the recent economic recession. However, to properly evaluate this requires the presentation of further data, commencing with the next chapter which looks at the patterns of diffusion of NC within our sample.

Footnotes

1. For example, when asked "What are your main sources of information about NC technology?" respondents would refer to two or three sources. The sequence in which the sources were presented was scored in order to compare responses by scoring 3 points for first place, 2 points for second, and 1 point for any other mention.

2. The analysis in this chapter refers to 57 of my 60 firms. The other three companies did not fit in terms of the issues dealt with here. One company was a case of "stalled" installation of NC equipment; a second a large steel plant where NC equipment was used in the maintenance toolroom; the third a firm specialising in computer manufacturing consultancy. In all these

cases, NC acquisitions and operations were so different from the rest of the sample that they will be analysed separately elsewhere.

3. Thus the American Institute of Plant Engineers, the Institute of Industrial Engineers, and the Society of Manufacturing Engineers all have monthly journals as well as a variety of newsheets, manuals, special reports and conference papers available to their members. These contain detailed technical information on the performance of industrial equipment in test situations, case studies of machine performance in actual production, and so on. In contrast, trade journals such as "American Machinist," "Production," or "Canadian Machinery or Metalworking," are surveys of what is commercially available and the bulk of the information comes from machine tool manufacturers themselves.

4. NC tool distributors would maintain a list of firms willing to host visits from potential users of similar equipment. There appeared to be a tacit agreement that potential users would not visit firms which were direct competitors in the same product markets.

5. In addition to obvious support expenses such as programming, additional tooling, labour retraining, etc., and the costs of learning to integrate the new equipment into shopfloor operations, NC equipment was widely perceived to require greater managerial input than conventional machinery, if they were to be used most effectively.

6. Thus the history of NC design evolution repeats the pattern of earlier machine tool development as documented in Rosenberg (1963, pp.414-43) and Wagonner (1968, pp. 20-30, 51-59).

7. Pallets are moveable beds to which the parts to be machined are clamped or bolted. A double pallet allows two identical parts to be mounted in such a way that either identical or sequential machining cuts may be made as the pallet is rotated.

8. Since machine tool acquisition was often associated with the bidding on a particularly lucrative contract, availability of suitable machines was of some concern. Larger firms in the past appear to have favoured the larger, established U. S. machine tool builders partly for this ease of supply reason. Smaller firms, however, took whatever tool was available at the time when they were in the market.

9. Metalworking machines are categorised as chip cutting or non-chip cutting. The former include the lathe, mill, drill and grinding machines. In each case metal is shaped by the action of a cutting tool which produces a chip of metal. In sheet metal stamping metal is shaped by the impact of a punch and die squeezing the metal to produce blanks of a a required shape, or produces a pattern such as grillwork in a sheet. Forging, swaging and extrusion are other methods used to shape or deform metal under intense pressure. In none of these cases is the waste or surplus metal chip shaped. Casting involves pouring the molten metal into moulds of the required form. Again the surplus metal is not produced in the form of chips.

10. This is reflected in the current estimates of the Japanese share of the U.S. machine tool markets in 1987 where machining centres are expected to constitute 52% of sales, lathes to be 57%, but punch and shearing machines only 19%. AMERICAN MACHINIST AND AUTOMATED MANUFACTURING, 131 (January, 1987), p. 35.

11. Welding generally is the process by two or more pieces of metal are united by the use of intense heat. Electric arc welding the work to be joined forms the negative pole of a circuit while the welding rod operates as the positive pole. When the rod is held a certain distance from the work and direct current fed through the circuit, an "arc" flame is formed which melts the end of the welding rod. The molten metal from the rod is deposited on to the heated part of the work to form the join. Chemical deposits on the welding rod evaporate as a result of the heat and operate as "fluxes" which prevent oxidisation during the weld. This ensures strong, uniform

and fault-free welds. In addition, by changing the chemical composition of these deposits it is possible to weld previously difficult to weld metals such as aluminium alloys.

12. Copying or duplicating machines are also known as die sinking machines because their primary application was in the manufacture of forging dies, steel moulds for glass, plastics and low temperature melting metals; for auto body dies; and for complex casting moulds such as those for ship propellers. These machines are fundamentally vertical milling machines with a tracer mechanism. The mill cutting tool or tools (they could have 1-4 tool spindles) was controlled by the path of a stylus or tracer which has the same diameter and shape as the cutter(s). The cutter(s) can move 360 degrees horizentally and up and down in the vertical plane (the amount of movement here depending on the size of the machine. The stylus or tracer mechanism was designed to work with a light pressure so that easily shaped materials such as wood, plaster, plastic and soft metals could be used in making the patterns.

Chapter 6: Adoption and Diffusion

Introduction

In Chapter 2 I argued that there were problems in both the innovation-diffusion and the labour process analyses of managerial decisions to adopt new technology. Both positions presented a single, all-enveloping determinant of technological adoption -- profit expections and class motivated control of labour respectively. Such unilateral theories overlook the specifically technical features of new technology and the variations in terms of firm size, sectoral location, and managerial perspectives which contribute to the determination of profit expectations and concerns over labour costs and labour processes. As well, changes in the technology itself over time further interact with these factors.

The survey research methods used by diffusion writers and the exclusive focus on labour skills, labour costs and labour bargaining power of the labour process writers produce overly narrow theories of managerial decision-making about new technology. In order to document the complexity of the diffusion process, I adopted the in-depth interview approach. This resulted in finding, first, that labour costs, skills and power concerns were of a far more secondary character than one would have anticipated from the labour process theory. Where NC adoption replaces conventional metalworking it did so because market demand for more complex, high precision engineering products, for reduced lead time and greater responsiveness to faster-changing customer requirements rendered traditional machining techniques inadequate. These market-induced moves away from conventional machining are very similar to Rolt's analysis of the changes in "millwrighting" produced by the spread of the Boulton and Watt steam engine (see above, p. 88), and to Landes' analysis of the changes in production systems in the second half of the nineteenth century (1969, pp. 309-317). The managers in my sample, then, referred to labour in very restricted, technical terms and not as a social factor of production necessitating some, special "class-political" strategy to undermine their bargaining power.

Further, the interviews provided much greater detail about technological adoption decisions than diffusion analysis surveys. This detail permits me to document the variety of reasons for NC adoption within engineering and metalworking. More importantly it shows that, in many cases, the decision to adopt was not undertaken with adequate knowledge and was accompanied by very unrealistic expectations; that it took a long period of learning by using to overcome these unrealistic expectations and develop a modicum of efficient utilization of the equipment; that some long term users are still not using NC equipment optimally. The overall thrust of these findings is to suggest that the diffusion process is characterized by considerable ignorance, error and uncertainty, and that while these diminish over time, they do not entirely disappear even with long term experience. Traditional economic diffusion analysis tends to overestimate the efficiency associated with the spread of new technology and to underestimate the problems and obstacles in the way of optimal use.

My analysis of adoption of, and experience with NC technology is based on the responses to questions asking why the firm originally installed nc equipment and what experiences (whether positive or negative) were associated with the use of this equipment. Similar questions were asked about each additional installation. As was the case with the questions analysed in the preceding chapter, the responses were examined to identify repeating themes and these themes were the basis of coding categories. However, since the responses usually involved much shorter sets of themes the tables present unweighted results (1). I shall look at three aspects of adoption and use of NC technology in turn -- the initial acquisition and the experience surrounding this, the subsequent acquisitions if any, and the more significant and enduring problems experienced with NC.

Initial Acquisition

Table 1 (pp. 166-167) shows the rank order of the reasons given by my respondents for the initial acquisition of NC machine tools in the different branches of engineering and metalworking. For the entire sample the most important reasons for adopting NC were: first, that it was the most appropriate technique for the manufacture of complex shapes and/or high tolerance components; second, that it enabled a higher volume of production to occur and allowed the company to cope with rising demand; third, that it was brought in to solve the problems associated with meeting a particularly lucrative contract.

The adoption of NC equipment in order to cope with increases in demand and/or to be able to manufacture

Codes for NC Acquisition Reasons

NC Acquired:

1. in connection with a specific contract.

2a. to cope with pressure of demand.

2b. to cope with specific bottlenecks.

3a. because of changes in materials or quality or design of product.

3b. to introduce flexibility in manufacturing to deal with shorter product cycles, shorter production runs, greater variability of demand and products.

3c. to reduce lead time and associated pre-production costs.

4. because it had become no more costly than conventional machinery.

5. in an attempt to overcome problems arising from unavailability of skilled labour, or because of rising labour costs.

6. to explore the potential of new technology.

Rank Order of Reasons for Initial NC Acquisitions

Table 1: By Engineering Group

Aerospace	Electrical	Sheet Metal	Transport Group	Pumps and Valves	Die and Mould	Industrial Equipment	Agriculture and Lumber	Total Sample
1, 6	3a	1	1 , 3a	2a, 3a, 5	2a	2a	3c	3a
2a, 3a, 5	2a, 3c, 5	3a	rest =	1 , 3c, 6	2b, 3a	3c	3a	2a
2b, 3b	2b, 3b, 4	rest=	mentions		6	5		1
		mentions				3a		3c
								5
								6
								2b
								3b
Number of Firms								
15	8	6	5*	5	6	10	4	59

* An automobile transmission plant was considering installation of NC equipment for the first time and is omitted here.

products of more sophisticated engineering design was a pattern common to small, medium and large firms as indicated in Table 2 (p. 169). Small and medium firms differed from large firms in adopting NC on the basis of obtaining a large, valuable contract. Large firms differed from others in their greater concern to use NC to reduce lead time -- the pre-production preparation of jigs and fixtures necessary to manufacturing with conventional machining techniques.

These differences in acquisition reasons for firms of differing size also probably contribute to the differences found in adoption patterns over time shown in Table 3 (p. 170). Coping with the requirements of changing product design, with rising demand, and reduced set up time, were the predominant reasons for adopting NC equipment before 1974. Eighteen of the thirty seven pre-1974 adopters were large firms. Those who adopted NC between 1975 and 1980 did so for similar reasons as the first generation of NC users, but contract related adoption is more significant in this group. This second generation user group comprises one large firm, six medium firms, and eight small firms. Post-1981 adopters number only five in my sample, and so generalization is extremely hazardous, but contract-related

Table 2: Initial Acquisition Reasons and Firm Size

	Small	Medium	Large
	1, 2a, 5	2a	3a
	3a	3a	2a
	4	1	3c
	2b	3c	2b
		6	1, 4, 5, 6,
		3b, 5	
Number of Firms	16	23	21 *

* An automobile transmission plant was considering installation of NC equipment for the first time and is omitted here.

Table 3: Initial Acquisition Reasons and Date of First NC Installation

	Pre-1974	1975-1980	1981
	3a	2a	1, 3a
	2a	3a	2a, 2b, 6
	3c	1	
	1	3c	
	5	4, 5, 6	
	6	3b	
	2b		
	3b		
	4		
Number of Firms	37	17	5 *

* An automobile transmission plant was considering installation of NC equipment for the first time and is omitted here.

adoptions is more prominent in this group than among previous users. Four of the five companies in this group are small ones, the lone exception being a medium sized aluminium foundry.

The aerospace industry in particular exemplified the pattern of the combined processes of demand and design change leading to the adoption of NC technology. Several respondents in jet plane airframe and engine component manufacturing firms explained why this should be so. "Jet aircraft speeds require wing and fuselage designs which are constrained by the dynamics of airflow, air resistance and friction. The airframe components have to be manufactured to these design specifications and the increased stress involved in high speed jet flight leaves no room for error or sloppiness. Small mistakes are big catastrophes in our business. So we need manufacturing technologies which give us one hundred percent repeatability -- we can't depend on the variation in performance which you'll find in even the best, most experienced machinist. NC programmes don't have hangovers, moods or quarrels with the wife. Once they've been proofed and the machine is set up you know what the results will be."

The decade of the 1960s was identified as one of spectacular growth for the aircraft industry by my informants, which in combination with other factors rendered nc technology increasingly attractive. Thus a programmer from a major jet engine manufacturer in Montreal pointed out, "During the early sixties it became necessary to develop large scale production of jet turbine blades, bearings and housings, etc. NC is ideal because it had been developed in the U.S. air industry to machine the complex contours found in jet engine components on a repeat basis. Also the sixties was a period of advances in metallurgy with the development of much tougher metals which required heavier cuts and more rigid machinery. NC was the only technology economically applicable at this time." The technical supervisor of an aircraft landing gear components firm pointed to another factor promoting the diffusion of NC in the aerospace industry during the 1960s. With "... the sixties surge in demand for aircraft, everyone' order books were full and you couldn't get enough conventional machinists to do the work. We got into NC to cope with the backlog and production bottlenecks. NC was developed in the U.S air industry and successfully proved itself so that by the sixties there were some good, proven machines on the market for us to use." Here nc was used, in part, to cope with rising demand in a tight labour market which made conventional techniques very difficult to apply on an expanded scale.

However, the increased precision, complex contours and new materials involved in jet aircraft manufacture also rendered conventional machining less appropriate to many areas of aircraft production. The engineering supervisor at a major jet engine fabrication and repair plant in Montreal highlighted this aspect of the interrelation between the development of large scale production of jet aircraft and the spread of NC technology. "NC gives you a control factor over the manufacturing process you didn't have before because the quality of the product depends so much on the quality of the part programme and not on the skills of an individual machinist. This gives you control over the repeatability of products in place of the individual variation of parts produced manually by conventional machining. Repeatability has become important because of the modularisation of aircraft engine components which began in the early sixties. Modularization occurred because larger numbers of engines were manufactured and in turn had to be maintained and spare parts provided for. This required a manufacturing system with extremely high levels of precision for certain assembly without extensive fitting processes which are subject to all the problems arising from the individual variation of skills." (2)

The depiction of the circumstances surrounding the adoption of NC in Canadian aircraft manufacturing, then, suggests that a combination of factors came together during the 1960s. The technology had been used successfully in the U.S. aircraft industry. There was an increase in the demand for jet aircraft, and metallurgical developments contributed to new manufacturing requirements involving greater complexity and precision. Finally, the period was characterised by tight labour markets in which certain categories of workers were particularly scarce and commanded high wages. The latter factor rendered conventional machining an unattractive alternative to the adoption of NC technology.

The design characteristics of jet aircraft, and the need for an expanded level of production of complex shapes, high tolerance parts, involving recalcitrant materials was also responsible for the spread of NC technology from the large aircraft manufacturers to their much smaller subcontractors. A consultant suggested that this took the form of very tight control by major aircraft companies over their subcontractors. "In Canada large aircraft firms like De Havilland, Douglas, Canadair, Pratt and Whitney forced their subcontractors to adopt NC. Subcontractors have to open their shops to inspection by contractors where even the steps in the machining sequences have to follow the contractor's instructions, let alone the tolerances, etc."

However, none of the respondents from aerospace subcontracting firms described their relationships with contractors in quite so restrictive terms, although all agreed that aerospace contracts were subject to the most rigorous quality control criteria in engineering. "As a subcontractor we're subject to very tight quality control audits. Last year we had some space components rejected because they had fingerprint marks on an anodyzed surface. But it's a good way to keep up with the latest manufacturing technologies and specifications......Pratt and Whitney is one of the toughest contractors. They really knocked us into shape in the early years and we hated them for it. But it was good for us in the long run since it enabled us to keep their contracts and compete in high price precision machining markets."

The emphasis on the advantages of close relations with the major contractors tended to be stressed by other subcontractors. "The particular machine we chose first, an NC profiler (3), was determined by what we saw as the weakest area of our production at the time; the area most vulnerable to competition in terms of product quality and lead time. As well, our major contractor at the time (McDonnel Douglas) advised us on the machine tool most generally useful for the sort of work they sent us." Another military and aerospace subcontractor informant also sums up this characteristic relationship, "We found NC to be essential for high tolerance machining of complex parts and difficult materials. Since its installation here it has done what we expected it to do with no great surprises or shocks. But we got a lot of guidance and information from our contractors on setting up NC and programming for these jobs. So we built on their experiences and avoided problems that way ... Our contractors were the most important source of technological information. They often made it quite clear to us that a contract depended on having a particular kind of nc tooling capacity."

A final observation pertaining to NC and aerospace firms is a very interesting case illustrating the diversity of diffusion processes even within a single branch of engineering. The case concerns the adoption of NC technology by a large firm manufacturing flight simulation equipment. In the words of the NC section supervisor, "We first got into NC around 1968 or 1969......We didn't go in because we are a production shop, far from it. We do largely one off jobs, with a rare exception of up to ten or twelve pieces per batch at the outside. But NC is great for us because it enables us to fabricate complex parts far more easily than with the knife and fork methods of conventional machining. The capacity to do complex parts easily is very important for us because we are making replicas of real aircraft cabins and we often found ourselves buying real aircraft components on a one off basis. This turned out to be enormously costly -- amounting to about forty percent of the purchasing price. Once we got started on NC we found that for example a throttle casing requiring four parts at $40,000 each could be manufactured using forty hours of programming time plus a two hour run on a machining centre to make all four at less than $50,000. This job saved the cost of the machine itself."

Respondents in other industries also identified the combination of increased demand and changing technical characteristics of their product as primary reasons for turning to NC technology. Thus in satellite transmissions components manufacturing the move to NC was "due to the growing geometrical complexity of the parts we make. This complexity made it difficult to machine in the conventional way because most of our work is one off so we can't afford to have any scrap since that's an entire unit of a very expensive kind. Geometric complexity has remained the basic and most important justification for all subsequent nc acquisition."

In land based telecommunications components, other technical factors were listed for the adoption of NC: first, the increased frequency of transmission ranges which require greater precision and better finish of microwave radio parts if they are to perform at all second, the development of metal alloys which adapt better to extremes of heat and cold than the originally used aluminium and brass alloys (and consequently retain the tolerances necessary for high frequency transmission) but are less easily machined, being susceptible to tearing and rough surface finish if machined by conventional methods. The greater rigidity and more control over cutting speeds and feeds associated with NC machining permits the use of these alloys (4).

I have described the recent changes contributing to the spread of NC technology in sheet metalworking firms in the preceding chapter and will merely point out here that it follows the pattern described so far of the rise of demand for higher quality, higher tolerance products, greater consistency of output, and greater volume demands.

In pumps and valves, die and mould, and industrial equipment, the pressure of increased demand volume was also an important cause of NC adoption. A characteristic response was, "We were falling deeper and deeper into a hole with our orders, we just couldn't keep up with demand. NC was seen as a major solution to sheer productivity in speed of production." For pump and valve manufacturers the primary production increase arose from the ease with which NC machines could be programmed and set up to machine families of parts (5), and the reduction of the amount of fixturing involved with its associated set-up and change times.

In the die and mould sector specific NC machines offered great advantages over conventional machining in very particular operations. Thus die makers found NC electro-discharge machining (edm) machines (6) are much faster in making certain die components than conventional methods of die making. Although edm machines are very expensive (currently around $300,000 including requisite hardware and software) they eliminate the use of high cost special form grinding tools (7), which also require a heavy investment in maintenance in order to ensure that their precision contours are maintained intact. In addition industrial dies, traditionally made of high-impact tool steel are increasingly now made of carbide (8), in order to get bigger production runs and reduce maintenance requirements arising from die wear. Carbide is an extremely tough mineral, so it takes a long time to machine by grinding and imposes heavy wear on the tools.

These changes were described by the toolroom supervisor at an automotive die subcontractor. "Conventional die making involved slow work on the jig borer (9) and the grinders using special purpose form tools. After boring holes the die would be heat treated and then the hole was tapped. For special contour cavities dies would have to be split up so that the special form grinders could get to that section of the die. This often involved making inserts of the required cavity form, and all the split sections required very accurate pinning and dowelling, requiring more jig boring and lapping (10). As a result our small dies would take at least two weeks in preparation before fitting, which could take another week. Now, using a combination of edm and conventional grinding we can produce a die in a week which requires a minimum of a few hours or no fitting at all. Overall, then, I'd say the Agie (edm machine) has cut down die preparation time to a third of what it used to be." Another informant working for a chain saw maker found that NC edm die making produced major cost savings. "In some cases die making operations which used to take eight hours has been reduced to thirty second which is an enormous saving in machining and man hour costs."

In the case of a manufacturer of moulds for soft drink bottles and other plastic containers which have replaced glass containers on an increasing scale, the first NC machine "...was obtained to reduce set up and machining time. Even with just four moulds taking them on and off machine fixtures or holders takes a long time. Especially since the molds are heavy solid blocks of aircraft aluminium and forged beryllium. NC saves time by combining operations in one set up, and doing several moulds at a time if they are small ones. Most of the moulds weigh around a hundred pounds or more when they begin so moving them around takes a lot of time and effort, even before you talk about precise placement on machine tables etc."

However, a tool and die company vice president argued that NC is probably used somewhat differently in this line of work than elsewhere in engineering and metalworking. "NC is not always the answer to die making work - it depends on the die's features, plus the number of cavities,etc. Deep pockets have to be dealt with by edm, certain kinds of contours are only possible with multi-axis CNC or are most cost efficient with cnc, others are best done by conventional tooling. Sometimes it is just as easy or even better to use tracer devices, but if the cuts are to be heavy then it is better to have the greater rigidity of the NC cutting tool mountings and combine this with NC programming."

Industrial equipment, agricultural and lumber machinery manufacturers all emphasized the contribution made by NC machining to reduction of lead times in machining by eliminating pre-production design and fabrication of special fixtures and holding devices. This concern with eliminating downtime emerges as one of the most important reasons for the later installation of NC, as I shall show in the next section.

Transportation equipment companies initially adopted NC in connection with the particular technical requirements of specific contracts. A nice example was cited by an informant with a railroad and transit equipment company. "We initially got into NC to cut down lead time in manufacturing diesel engine blocks which are very large components containing many holes at angles, with special contours, all requiring high precision for fuel efficiency. The North American railroads were trying to reduce maintenance costs, fuel costs, and so on, especially after the 1973 oil crisis, but they were always under the gun to cut costs so they always pressured us on our manufacturing specs. Also the 1970s was a period when an entire generation of railroad locos were worn out and needed to be replaced. This meant that we had to ensure the efficiency and reliability of engines, plus be able to deliver to tight schedules. These were the key to getting railroad loco contracts."

Apart from the foregoing sub-sectoral variations in NC adoption motives, there were some patterns which cut across the sectors. In six cases NC equipment had been installed in response to the demands of a specific upcoming contract. For example, two aerospace subcontractors purchased their first NC machines to cope with high precision, unusually high volume contracts for wing components with complex contours. In the case of the railroad freight car maker , discussed in the previous chapter, the original impulse to get NC machinery was due to a particular contract for a large number of box cars. The box car doors involved punching or drilling large numbers of small holes with accuracy, so an NC punch press was acquired.

An aluminium foundry installed NC mills to machine engine blocks to deal with a large order for a major auto maker. This was the simplest use of NC in our sample. In order to reduce costs the contractor required aluminium castings which no longer needed grinding at the auto plant before assembly. At the contractor's suggestion the foundry installed two NC mills which machined the two mating surfaces with a simply programmed single pass of the cutter. The two machines were manned by a single operator who merely loaded and unloaded the mills. Here NC machinery is used as a fully automatic operation. The contract was sufficiently lucrative for the foundry that it was content to absorb the cost of the new equipment and set up in order to retain it. However, there was some dispute within management over whether to continue using the NC mills as they were set up or to try to explore what other uses they might be put to. My informant felt that they were generating a sufficient revenue as set up and until that contract expired he saw no justification in experimenting with NC.

A sheet metal company installed an NC punch press to deal with a large order for ships' furniture and fittings for the Canadian navy. Another sheet metal firm won a contract for an unprecedentedly high volume of steel cabinets. In all these cases the informants said that the cost of the machine and its programming were absorbed by the first contract so that any subsequent use of the machine should be extremely profitable.

Several firms enjoyed the advantages of a specialised niche in the engineering market and the adoption of NC was often related to very specific technical problems of production associated with that product niche. Among these firms were the die making concerns already discussed in connection with their use of NC edm machines. A similar situation was found in a firm making gyroscopically stabilised camera platforms for surveillance aircraft and optical scanning devices for use by moving vehicles and the film industry. Gyroscopic devices alone require extremely high precision machining. This company's products involved combining gyroscopic devices, rigidly controlled turning platforms, and mountings for high quality long distance lenses requiring very sensitive focusing mechanisms. The milling machine selected for the production of these elements had the highest level of precision gauging, indexing and reading of the available mills.

Another specialised application was found in the case of the chain saw manufacturer where NC laser cutting was a major time saving advance over the traditional techniques of sawing, shearing, and grinding the extremely hard tool steels used to fabricate saw blades. In addition NC laser welding was introduced "as an important material saver because we weld stellite (11) to the ends of chain bars. Before laser welding we welded twenty percent of the stellite rod and lost eighty percent in the process. Since stellite costs sixty dollars a pound this was a very costly process. The laser welding process has virtually eliminated the stellite scrap."

Informants from five firms mentioned an exploratory or pioneering interest in NC as a factor in their initial adoption decision. According to the manufacturing engineering manager at a railroad braking equipment company, "Management in the mid-to-late sixties saw this new developing technology as having the versatility that fixed automation didn't have. They thought it was worth gaining experience by going in on the ground floor of new technical developments because the potential markets were likely to go with technological leaders." However, this company is now reorganising its plants and moving most of them toward more specialised production using conventional automation rather than nc. By reducing the range of products it manufactures, it is able to return to conventional mass production automation because it produces higher volumes.

Another case was that of an aircraft transmission components manufacturer. "We were one of the pioneers (of NC) in Canada ... We felt that NC was the natural trend of machinery in our field at the time, and that we should keep up with an emerging technology. We selected a simple machine - a point-to-point drill which fitted a slow spot in production. It was easy to use and programme, so it was a good machine to learn NC techniques by."

A variant of this pioneering interest was expressed by the owner-manager of a sheet metal company, identified by two competitors as one of the leaders in the field. "In the late 1960s U.S. sheet metal firms were moving towards NC manufacturing. It suggested to us that we needed to do this to stay ahead of the competition and cope with the rising production demands we were facing." Another sheet metal firm owner who claimed to export two thirds of his output to the United States, argued that from the late sixties, "U.S. contractors viewed shops without NC as mickey mouse operations. Putting in NC equipment lifted us up to a higher strata in the industry." (12).

In two cases an awareness of the spread of NC technology coincided with the need to replace worn out equipment. An aerospace firm making hydraulic and pump accessories had a longstanding informal policy of acquiring one new machine per year as long as market outlook was good. "We had heard quite a bit about NC and were attracted by the possibility of improving lead time through the reduction of jigs and fixtures made possible by NC. We were sceptical at first of claims made for NC but thought it worth trying one new machine which we bought to replace an ageing milling machine."

A more sweeping approach was taken by a major agricultural equipment firm. "By the early and mid-sixties a whole lot of our machinery was ready for replacement because it was very old. NC was the obvious way to go because you could get the production of three conventional machines out of one nc machine according to the consensus in engineering. Also it was a flexible technology appropriate to an up and down industry like agricultural equipment."

In eight cases labour advantages were mentioned as important reasons for getting nc equipment. Such reasons as increasing production volume without a proportionate increase in the labour force; improving product quality despite a shortage of skilled machinists; and substituting intelligent machines for hard to get skilled metalworkers were cited. I shall be dealing with these matters in the following chapter. Several firms also reported that the labour saving advantages they had anticipated from nc adoption did not materialise. I shall also report on these instances in the next section of this chapter. But now I want to explore the experiences of my sample of firms as they worked with NC technology; the reasons for expansion or non-expansion of NC machining; and the problems and advantages associated with nc utilization.

Later NC Installation and Experience

The reasons given for NC installations subsequent to the initial acquisition are given in Table 4 (pp. 190-191). Across the whole sample the most important reason was in order to reduce set up and non-machining or down time. The other most salient reasons were: to obtain quality improvements in terms of greater repeatability of output;

Code for Subsequent Installation

NC installated to:

1. cope with increasingly sophisticated designs of products.

1b. cope with recalcitrant materials such as "space age superalloys".

2. reduce set up and cross-machine transfer time.

3. improve quality in terms of finish, repeatability, tolerances.

4. increase machining time.

5. improve flexibility for small batch runs.

6. reduce waste and inspection time.

7. save labour costs.

8. open up new markets for firm.

9. gain experience with advanced new technology.

Rank Order of Reasons for Subsequent Acquisition Patterns

Table 4: By Engineering Group

Aerospace	Electrical	Sheet Metal	Transport Group	Pumps and Valves	Die and Mould	Industrial Equipment	Agriculture and Lumber	Total Sample
1	2	3, 4	2	2, 4	2	2	2	2
2, 3	1, 6	6, 8	3, 4	rest =	1	3	5	3
4	4, 5	1b	5, 7a	mentions	3	6	3, 6	4
1b, 8	7				6, 8	4, 7		1
5, 6						8		6
								5
								8
								7
								1b
Number of Firms								
15	8	5*	4*	5	6	10	4	57*

* Two firms had a single NC tool and consequently subsequent acquisition issues dit not arise. One firm was actively considering NC installation for the first time.

better surface finish and higher tolerances; to obtain faster machining of pieces by combining operations on a single set up; and to be able to undertake machining of more complex contours and facilitate the machining of difficult materials such as stainless steel alloys.

Throughout the engineering industry "downtime" when machine tools are not shaping metal is identified as the fundamental source of costs. Estimates of downtimes for particular pieces of work ranged from 40% to 95% of the time spent in the plant according to my informants. Even so, much of the machining that takes place is not the direct manufacture of parts to be sold but rather the fabrication of jigs and fixtures - devices to permit production to take place. In order for such production machining to take place the machine tools and their adjunct jigs and fixtures have to be carefully set up, yet another time-consuming process. Subsequently, inspection measurements have to be made at certain points during the machining process to ensure that it is working properly. Any parts that deviate from the required dimensions have to be considered for remachining which involves working out further, particular, specifications for the machining of those parts. Non-machining time, embodied in preparation for production and inspection during producion, contributes considerably to the costs of production in engineering and metalworking.

Another important aspect of downtime is the need to transfer pieces from one machine to another - from lathe to mill, to drill, to grinding machine, etc. - in order to effect the different machining processes required. Some of these machine processes can be slower than others, some require longer times to set up, etc., so that scheduling the route of the piece to minimise down time is an extremely complex process in large firms, the responsibility of entire departments of "process planning," and optimum scheduling extremely difficult to obtain (13). Consequently, components in the making spent much of their time waiting in between transfers from one type of machine to another. It is not surprising, then, that NC technology, which makes possible the combining of different machining processes using standard cutting tools and simplified holding arrangements also using standard clamps and bolts which largely eliminates the use of jigs and fixtures, is perceived to have reduced downtime costs significantly across all sections of metalworking and engineering (14).

It was in respect to these factors that the head of the NC machining section of a large airframe manufacturer told me, "Our reasons for going NC were its efficiency and time saving. You have fewer and simpler holding devices replacing many varieties of jigs and fixtures. Quality control processes are simplified: NC lowers the inspection required because you only have to inspect the first piece. More economies develop the more you use NC and all the bugs are eliminated from the programme and you learn the optimum patterns for scheduling work, feeds and speeds, tool monitoring and replacement and so on. Once this level is achieved you can run NC machines twenty four hours a day with minimum manpower, with most of the direct labour going into loading and unloading workpieces." This firm specialised in the manufacture of large airframe parts in relatively large batches. Its use of NC machinery was nearer to mass production operations than to the very small and variable runs found in subcontracting shops. Consequently, NC machinery was organized for production by semi-skilled operators who acted as machine loaders and watchers once the machines had been set up by skilled machinists who also loaded and proofed the NC programme (15) (these deployment patterns are discussed in the following chapter).

Another characteristic commentary illustrating the focus on downtime reduction was made by the programmer from a small general precision machining shop. "NC has altered the production sequence a lot. Very often before NC there were lots of problems with a piece waiting to be worked on because a particular machine was loaded with something else. With NC you can often completely machine a piece with only one or two set ups on the same machine. This increases productivity and avoids idle time for the process." Similarly, the manufacturing engineer of a large agricultural equipment firm said his company experienced three major advantages of NC over conventional machining. "The major gains were an increase in production rates through the reduction of set ups, messing around with fixtures and a combination of machining sequences with one set-up. This also lowered overall costs because you didn't have to stock additional materials for fixtures, store fixtures, make more than the required number of parts so as to reduce the possibility of setting up the production again in a few months' time. Then there were important labour savings since you didn't have people working up the tooling, setting up several times on the same piece, transferring the piece across machines and so on."

The results presented in Table 4 show marked uniformity of responses across my sample, with little inter-sectoral variation over the reasons for expanding NC utilisation. This is accounted for by the prominence of downtime and set up costs in all branches of engineering apart from areas of mass production which constitutes a quarter of engineering production volume at most (16). The importance of these technical advantages were underlined by the president of an advanced manufacturing systems research, development and consulting firm. "NC and CNC is a technology which is applicable with advantages virtually everywhere. Too many people see it as requiring high volume in order to pay back the higher cost as fast as possible. They don't understand that higher costs are not only found in high volume work but also in short runs which are extremely expensive in terms of set up, piece idle time, etc. It is the rather small runs and volumes which, by the way, characterise Canadian manufacturing very much, where the advantages are really felt to the full." He argued that the fundamental obstacle to the spread of NC and CNC was management conservativism, pointing out that North American management contains a significantly smaller proportion of engineers and scientists than is the case in Western Europe and Japan (17).

The sheet metal firms stood out as companies which did not emphasize these advantages of NC. This reflects the very different technology involved in metal stamping as opposed to metal cutting. Sheet metal firms obtain stamping dies from subcontracting tool and die workshops who absorb the costs of set ups, fixtures, etc. in making these parts. Setting up punch presses is a far simpler process than setting up fixtures on mills and lathes. It usually involves inserting the dies or other stamping pieces which fit over mating pins so that there is very little critical labour required to actually check this installation and then establish the correct feed rate and die pressure for the thickness and the composition of the metal sheet being worked on. In these circumstances the NC machines' most important advantage was the precision in setting feed rates. Pre-NC stamping presses had feeding mechanisms activated by rachets so that the feed rate which determined hole location was restricted by the ratchet gear ratios. Electronically activated feeding devices overcame this restriction and made feed rates far more flexible. NC also introduced design changes which made the installation of dies faster and increased the range of die patterns. In the words of one sheet metal firm owner, "NC machines give us repeatability of orders, computer storage of the patterns, faster programming, cheaper costs and faster productivity."

There were some variations in the reasons for subsequent NC acquisitions between firms of different size, as shown in Table 5 (p. 199). While the aim to reduce set up time was very prominent among all firms, the small firms were concerned with the need to cope with complex, very high precision manufacturing requirements. This reflects the weight of precision machine shops, aerospace subcontractors, and die and mould firms among the smaller plant size group. Medium sized firms were concerned to use NC equipment to upgrade the quality of their products which reflects the number of sheet metal and pump and valve companies in this group. Large firms viewed NC technology as a means to introduce greater flexibility into their production and so enable them to cope with the more variable and fluctuating markets which have emerged over the past decade.

The concerns of engineering management to reduce down time and to improve product quality are identical priorities for NC acquisition prior to 1974 and after 1981 (Table 6, p. 200). During the intervening years these concerns were displaced by the need to cope with increased complexity, design refinement, and precision of engineering products. The following section explores the reasons for these shifts.

Table 5: Subsequent Acquisitions and Firm Size

	Small	Medium	Large
	2	3	2
	1	2	3
	4	4	5
	3	5, 6, 7, 8	1, 4, 6
	6	1, 1b	7
	1b, 8		
	7		
Number of Firms	16	21*	20 *

* Two firms had a single NC tool and consequently subsequent acquisition issues dit not arise. One firm was actively considering NC installation for the first time.

Table 6: Subsequent Acquisition and Date of First NC Installation

	Pre-1974	1975-1980	1981
	2	1	2
	3	2, 4	3
	4	3	Rest =
	5	6	mentions
	1 , 6	8	
	7	1b, 7	
	1b, 8		
Number of Firms	36*	17	4 *

* Two firms had a single NC tool and consequently subsequent acquisition issues dit not arise. One firm was actively considering NC installation for the first time.

Temporal Shifts in NC Adoption

There were shifts in the reasons for adopting the technology as experience with it grew. An advantage of being a pioneer was pointed out in the case of a general precision machine shop. "We were persuaded to try NC because of the conventional arguments: engineering control of the operation because the operator was captive to the programme so you got reliable, repeatable parts of high quality, etc. We found though, the major initial advantage of being an innovator was that you could charge conventional machining rates for jobs done by NC tools in one tenth of the time. Also having NC capability carried you through the slumps when conventional machining jobs were scarce. As one of the few NC companies around you still got the complex jobs and the high precision machining contracts."

Two similar aerospace related precision machining job shops pointed out that they initially went into NC in an attempt to compensate for the shortage of skilled labour. "We got our first machine in 1971 hoping that we could use a skilled machine instead of skilled people......Later, parts have got so complex that NC machining is essential. You can't make them on a repeated basis by conventional machining even with skilled people."

In the second firm, which did a significant proportion of work making spars for U.S.A.F. fighter planes, "The company developed by building a skilled labour force of European immigrants with industrial apprenticeships and extensive qualifications and experience. For a long time highly skilled machinists were essential in the production of spars because the geometry was too complex for the programming capability of nc machines. Later it was difficult to maintain a full company of skilled machinists and our ever expanding work load led to the need for using smart machines and less skilled operaters. and the parts became more complicated and increasingly difficult to machine to the required tolerances. Over the past five to eight years there has been a shift in the airframe industry from aluminium to titanium alloys which are very tough to machine. Nc machines get the best results." (On tough materials and NC machining, see footnote 4).

Respondents in several branches of engineering and metalworking commented on the shift to ever closer tolerances and standards of precision. Some of the preceding statements have already alluded to this. In aerospace and military contracts NC machining has long been established as the norm and subcontractors are judged by extremely high quality standards with, for example, virtually no allowance for scrap producing errors. This is partly a reflection of the extremely expensive high stress alloys used, and partly a traditional emphasis on high technical precision.

The proprietor of a precision aluminium mould shop suggested that these standards are spreading from military and aerospace fields to engineering more generally. "In our line of work (making aluminium molds for precision castings) parts are now more complex than they used to be, they are larger than they used to be, and tighter tolerances are now imposed on manufacturing techniques because people are now designing through computer techniques. These changes are due to a combination of engineering changes. In metallurgy there has developed stronger but more castable and machinable alloys. This means investment casting (18) can be used for bigger sized parts which couldn't be made with earlier alloys which experienced all sorts of stress and weakness in large forms. Casting parts can cut down costs because a single cast part can eliminate the need to assemble several smaller parts which require careful design, manufacturing and fitting to end up together in the right way. And the more refined the casting technique possible the less waste of materials - you don't use a lot more metal than you really need because you have crude casting methods. The finer casting methods also minimizes machining and finishing of parts with all the potential bugger-ups that can involve. Now with cheap, powerful computer programmes, CNC machining centres and edm machines you can make the dies that make all this possible."[1]

Other areas of engineering which had experienced an increase in the complexity of machining in order to cope with increasingly rigorous design phenomena included pumps and valves where the refining of an ever growing array of toxic and corrosive chemicals required high pressure, corrosion resistent, leakproof and precisely adjustable valves and turncocks. Parallel developments have occurred in the use of pipelines to transport gas and oil over long distances, the use of special pressure devices for mixing compounds in the food and beverage, chemicals, and pharmaceuticals industries, rendering the design requirements of pumps and impellers similarly more rigorous.

In the printing industry, multicoloured, photographic reproduction requires very tightly controlled paper rolling feeds and precise coordination of multiple printing rollers. These requirements have led to the emergence of precision requirements "almost as tight as those in the aircraft industry," according to a printing machinery informant. In shoe moulding the use of different plastics and plasticised fibres in various combinations required very high accuracy in mould finishing because of the complexity of the allowances to be made for shrinkage as the plastics solidified and hardened. Similar trends to higher precision engineering in sheet metal and electrical products, as well as the move to carbide dies have, as I have already indicated, led to the consolidation of nc technology in these sectors of engineering and metalworking.

Apart from the various causes of the development of ever higher standards of precision in engineering manufacturing, the spread of NC technology was reinforced by another general tendency; an economic one affecting several industries. This was the increasing instability of markets arising from various causes during the seventies producing shorter product life cycles, reduced lead times to develop and manufacture a product, a greater tendency for customizing, all of which produced shorter and more varied product runs. Such tendencies have been most widely commented upon in the automotive industry but have spread to other industries during the 1970s (Blackburn et al.,1985, 115-145.)

For example, it was noted by a toolroom supervisor at a major automobile making plant. "NC was first installed here (in the plant's toolroom) because the firm wanted to cut down lead times for replacement parts and , later for prototype manufacture. We often get situations where the assembly line is potentially jeopardised if it can't get replacement parts in reasonable time. Also in this industry retooling times are very critical and we need to constantly cut the time needed to manufacture complex fixturing and components for manufacturing. But in the seventies response times have become increasingly critical as the North American auto industry is being required to become increasingly flexible in its range of models, its customising operations, expanding the range of models offered and changing models faster than before."

A variant of this situation was found in firms which suffered particularly marked ebbs and flows in the demand for their products. Thus the planning and development manager at a railroad freight car manufacturer pointed out, "Another important feature relates to the fact that this particular industry is subject to considerable fluctuation in demands so production levels move up and down quite extremely. In the past this has meant extensive layoffs during slack times and sometimes we have lost good people and couldn't get such high quality workers back. With NC and robotics we can produce at peak times with a lower labour force and retain them during slack times. In this way we have managed to develop and maintain a core labour force with higher education and qualifications which we hold onto during recessions. So there is an increase in employment stability and reliability in labour supply."

Similar emphases on the advantages of NC to industries with fluctuating markets were found in agricultural equipment. For example the manufacturing engineering supervisor in one such firm pointed to the shift in thinking as his company gained experience with NC. "We got into NC primarily to reduce costs and to increase output during the seventies when demand was increasing rapidly. NC promised more rapid production without skyrocketting costs of tooling, fixturing, and set up. It also promised to combine machining cycles and reduce piece transfers and non-machining time for any piece...... Later on the market started fluctuating, there was also a move to greater product variation. So NC technology's flexibility became more important when you needed to switch production from one product line to another and moved to smaller volume production of a greater variety of items."

Several informants in aerospace and precision machining shops pointed to the difficulties faced by their firms in a market subject to very high performance standards and violent cyclical shifts. "The work we've done for these contractors has enabled us to keep up with the best machining and metalworking technology so we do the highest quality work with the best precision machines and inspection procedures, and attract a quality labour force. But the technology in this area keeps changing so fast you have to keep the contracts coming in to be able to afford upgrading your equipment. And the standards are so high it takes years to build a reputation but only one bad order to ruin it." And another aerospace machining firm informant pointed out, "Job shops like us are under extreme pressure all the time. Our business is a very up and down one, it's either feast or famine. But even in the good times there's very fierce pressure to cut the costs on the jobs you do. It's a highly competitive business in certain areas; a good toolmaker can set up a one-man shop in his garage with negligible overhead and do a single operation job. All round machining shops are strapped because we have to maintain all round capacity with a range of machines and a core of skilled operatives, technicians and managers."

Patterns of NC Adoption and Use

While there was much convergence and overlap over the reasons given for the initial adoption and subsequent use of NC technology throughout my sample certain patterns of types of adoption and use occur. Several firms had adopted a careful one step at a time approach. This commenced with the identification of a particular bottleneck which might be opened up by using a relatively simple, easy to programme nc tool. The tool's simplicity made it an ideal learning instrument and did not require the infusion of major resources to support its operation. Four firms - a steel company which is to be outlined in detail below, an aircraft transmission and gearbox manufacturer, a pump, impeller and valve maker, and a manufacturer of swaging (19) and forming tools were examples of this approach.

A second pattern was the utilization of NC machinery to solve problems of a particularly difficult machining process. In this case there was no implication that NC's success would lead to the expansion of NC to other processes in the plant. This pattern was particularly marked in diemaking where edm machines worked side by side with conventional machinery for specific applications only. It was also found in several plants where the bulk of the product line was mass produced as castings, forgings, or welded parts, and NC was applied to a single line or family of parts.

Such was the case of the aluminium foundry finishing auto engine block parts on NC mills; a plant making heavy industrial rollers, bearings and bearing parts, which introduced NC in order to develop a line of aircraft engine bearing components; a firm making a large variety of steel pipes, pipe fittings and pressure vessels for the pulp and paper, petrochemical, food and beverage industries, which installed an NC press for a specific sheet metal stamping contract, and then spent many years using the machine rather episodically; an elevator and conveyor machinery manufacturer which used NC for the precision machining of guide bed components of these items. In all these cases NC existed as a tiny island of advanced manufacturing technology within a much larger sea of traditional mass production automation or high skill manual machining.

A third pattern was found in the case of several firms which adopted the policy of replacing conventional machine tools with NC tools as the former wore out. This policy was undertaken on the understanding that NC technology was the "wave of the future" in manufacturing technique and would become the mainstream mode of production in the near future. Such policies were undertaken by agricultural and forestry equipment firms, by a sheet metal firm identified by a competitor as one of the most technically advanced in the region, an aircraft fuel line component maker, two manufacturers of pumps and valves, two firms making heavy machinery for pulp and paper, mining and hydro electric utilities.

A fourth pattern was that of technological transfer from contractors to subcontractors, and the shift in demands on subcontractors from products requiring high conventional manual machining skills, to products characterised by ever greater complexity, greater precision and critical surface finish, and more difficult to machine materials. This was particularly marked in the aerospace industry, of course, but these pressures were found to exist in die casting, valves and pumps, and electrical transmission and communications equipment.

The Process of NC Adoption: Three Cases

While the foregoing analysis, I hope, sheds light on the reasons for NC adoption and utilisation, it does not provide perhaps, a very clear impression of the process a firm goes through in the course of installing and using new technology. In this section I want to present three cases which exemplify the extremes of the process of technological adoption. In two cases the firm just "muddled along," in the other case the process involved much more systematic and ongoing evaluation and planning at each phase of adoption and use.

Ironically a CNC research and consulting firm clearly displayed the muddling along approach and also exemplified some of the factors which contribute to this pattern. The company offered consulting advice to firms attempting to computerise their manufacturing operations, using its NC machines to experiment with different types of industrial production arrangements, to develop new programming software, and to make prototype NC and CNC machining parts and fixtures. The company developed out of the consulting activities of a number of university based mechanical, electrical, and computer engineers. However, in the process of setting it up "it did not follow our own principles of planning for machine tool selection. Our NC units were obtained on the basis of an opportunistic grabbing of what was available on the market, within a broad basic criterion of flexibility and ability to handle and explore a wide range of applications for our R&D work." My informant, the company president with an industrial engineering not a university background, went on to explain how this situation developed. "We had to get some equipment quickly because our first contracts were in hand and we felt we had to move fast to establish ourselves. After that our personnel tended to be so busy handling subsequent contracts that we didn't have the time or the resources to take stock systematically. As a result we fell into the same trap as a lot of our clients."

This statement clearly illustrates some of the constraints which deflect management away from optimum decisions and generate satisficing decisions. These constraints are the same as those which lead firms to the use of least cost sources of information in monitoring and selection of nc tools. Manufacturing firms are under continual demand pressure from their markets which diverts their attention and resources from anything beyond coping with such pressures. There is little scope for systematic planning and reorganisation for the optimum use of NC which is undertaken, if at all, only when serious and specific threats to market position develops.

While the advanced manufacturing consulting firm obtained NC equipment without the kind of systematic market survey it would advise its clients to undertake, it was still apparently using nc equipment in the intended fashion, i.e. as programmable machinery and not merely as highly accurate conventional tools with primarily manual operation, as was the case in the following example. In my second case there was considerable doubt that the NC equipment was really being used properly. The plant was a branch of a German engineering conglomerate manufacturing large, sophisticated, custom designed printing machinery. Each unit cost between half and two and a half million dollars, and less than ten such units were made in a year. It comprised many subcomponents, generally fabricated from very basic engineering materials with well known manufacturing properties but requiring very close tolerances, comparable to those of the aircraft industry.

In the course of expansion in the mid-seventies management had invested in an NC lathe and milling machine. On the basis of their understanding of the NC equipment's capabilities the company had committed itself to a larger number of contracts than it could effectively handle. Failure to live up to contractual commitments, prolonged difficulties in using the new equipment effectively and the increased debt load arising from capital and labour force expansion undermined the company's profit position by the end of the seventies. The recession of the early eighties produced a financial crisis and a new management team was brought in to restore profitability.

My informant, the current manager of operations, was one of the new managers, an engineer by training with managerial experience both in the United States and in Canada. His characterisation of the management's venture into NC production was wholly negative. He placed the experiment with NC in the context of "management's failure to make the necessary shift from entrepreneurial to corporate planning. The NC equipment was bought without planning because it happened to be on the market, and management thought they should be upgrading the plant. Both machines were second hand units with obsolete controls and should never have been bought. There was no preparation for NC either by the management or the workforce."

Among the management failures particularly common with the adoption of NC he saw several planning failures prior to nc installation, and some resulting problems for the pattern of NC utilization at the plant. "Management didn't see that people are the whole problem not hardware or dollars. You can only effectively use NC if you're organised to use it. We're not organised to use it even now, twelve years after we got it. There are certain preconditions for NC use we're just not meeting. First, we are not organised on the floor so that the NC equipment is fed jobs all the time. This is essential because NC machines are not just more expensive than conventional machine tools, but they carry a greater organization and technical burden. For NC the cost of operative labour is insignificant. But because they are more productive they require either higher inventory or an extremely well planned set of arrangements with suppliers and subcontractors for just-in-time delivery. They need different ancilliary equipment, more skilled maintenance personnel, and a very effective management and programming team to use effectively. . The cost of the NC tool itself is just the tip of a very large financial iceberg."

Because of the failure of prior evaluation and planning management had underestimated the costs of installing, maintaining and operating NC equipment, and they underestimated the degree to which all plant personnel required training and orientation in NC use. Both of these factors led to increases in production costs, and the latter undercut the gains which could be made in using NC. One significant potential gain is the reduction of set up and transfer time, but according to my informant this is only achieved by some reorganising in the physical layout of the shopfloor, and by grouping machines in such a way as to make automatic transfer of workpieces across machines possible, or by establishing work cells which permits an operator to work on one machining sequence as another is occurring at the same time. But work cell arrangements and shopfloor reorganisation "...requires new forms of organization with a lot closer communication between design manufacturing and shopfloor people. To prepare for this you have to get people to meet on a regular basis. You have to involve all relevant categories of personnel -- engineers, management, technicians, foremen and operatives. It is essential that operatives, and not just management, see the machines at the vendors do the sort of jobs they will be doing at the plant, and have several exposures as observers before having to try out their skills."

Not only were these preparatory organizational changes not undertaken, but the machine tool selection and application had been faulty. The machines acquired were old models and, it was discovered, had controls of a very short-lived design. Consequently the tape preparation machine was of a non-standard design and major problems soon emerged when spare parts and maintenance became necessary. Currently a local machine hobbyist has to be brought in to maintain it.

All programming is done on the shopfloor. This was a major error according to my informant, who was a vocal exponent of programming integrity. "The operators are unused to the fast movements and heavy cutting capacities of NC machines so they drastically reduce all feeds and speeds to the levels of conventional machine tools." The second problem was that with shopfloor progamming product inspection is still a necessity. "If you have programme integrity where the programme is the responsibility of the design group, the programming group, and the shopfloor foreman, there is absolutely no major alteration without all of these people's knowledge. This makes it possible to eliminate product inspection because the programme is ensured, the machine tool specifications are known and maintained, so that once the programme is proofed you know what the output will be." He further argued that because of the uninformed way in which NC was adopted no one got adequate training in parts programming. Consequently the operators' programmes consisted of "...far too many analogues of a conventional machinist's action and very little creative use of programming to compress machining sequences."

Despite all of these problems he admitted that many of his colleagues had felt that NC had been a worthwhile investment. They were able to think this because the NC machines had faster cutting action even when "turned down" by the operators, than conventional machines, and in the case of the NC mill, machining was significantly more accurate than its conventional counterpart. Consequently, when a Manufacturing Department audit recently showed that 53% of the plant's machinery was in very poor condition with over 10% maintenance down time, the report concluded that a programme of replacement with NC equipment be undertaken. According to my informant, however, no references were made to work rescheduling, shop layout, support structure, maintenance, training, etc. -- all the factors he maintained were required for effective utilisation of NC technology.

Very few of my cases in fact lived up to the criteria of efficient NC utilisation this informant put forward. It is probable that he presented a maximizing efficiency model of technological use, whereas most industrial managers have to operate in a satisficing fashion. In the latter instance it is probable that the visible gains of NC at this plant in terms of speed and accuracy of machining were sufficient for the technology to be judged useful. The particular confluence of factors in the company's recent past may have magnified some inefficiencies in the use of its NC equipment. Certainly the increases in overhead costs associated with NC use contributed to an already precarious financial position. However, this is not the same as holding that the <u>only</u> efficient use of NC in these circumstances would be a maximally efficient application involving wholesale reorganisation of the plant's operations.

In contrast to the constrained rationality of technological adoption characteristic of most of our sample I did find one case of exceptionally systematic planning operating in the course of adoption and utilisation of NC machine tools. The firm, a large steel manufacturer introduced NC into its machine shop at its largest mill and refining complex. The machine shop fabricates replacement parts for refinery and mill machines, repairs worn parts, and makes special equipment for the entire complex and its branches. In the words of its general foreman, "Our machine shop operates as a custom job shop with the rest of the plant being its captive market." The jobs involved are extremely diverse, ranging from single items to several hundreds of items such as bolts, sleeves, collars and other bearing parts for rollers and other rotating parts of mill machinery. These jobs also involve a wide variety of materials such as the various cast irons, steels, stainless steels and brass in diverse structural forms including plates and sheets, square, round and octagonal rods, girders of various sections, castings and forgings.

Numerical control technology was looked into in the late 1960s when steel production was soaring and the machine shop emerged as a bottleneck. The shop simply could not keep up with the maintenance and fabrication jobs arising from the very high levels of steel production. Consequently an increasing proportion of shop work was being subcontracted to outside shops. In addition, shop related labour costs were increasing more than anywhere else in the plant (according to the planning and development manager). The late 1960s was a period of generally high activity in the engineering and metalworking industries, consequently experienced shop workers were scarce and commanding premium wages. As a result it was both difficult and expensive to expand the productive capacity of the machine shop by expanding its labour force. The wage settlements following a strike in 1969 increased the wage bill even further.

In this context "we started with an NC drill. It was the least expensive in the NC line, and it was the drill which was the most used machine in the shop, where a lot of slowdowns occurred. The NC drill was a point-to-point machine so it was simple to programme. This simplicity meant that programming wasn't a large cost; it could be done manually and in-house, and it was easy to learn so we got the drill doing jobs fast."

Despite the fact that the drill was installed after a strike and that there was considerable uncertainty on the part of both union and management over job description and the appropriate skill level of the NC operator, the installation reportedly involved little labour-management friction. Probably this was largely due to the use of NC technology to bring more work into the machine and fabrication shops, so there was no sense that anyone would lose their job. Moreover, management was unsure whether NC would work, so they were not committed to any particular mode of application. Both management and the union agreed that manning NC tools should be the work of skilled machinists. However, programming was defined as a staff function, "since we felt it would control productivity of the drill, so we put a lot of effort into recruiting and training programmers from the best machinists we had and put them on staff."

On the basis of these arrangements the drill was installed in 1970 and operated on jobs requiring three or more holes per part. It was judged to be a clear success within three to four months of its installation. The experience with the drill led management to define other operations as areas where NC tools could prove productive. A turning centre (for drilling,tapping, boring,turning) was installed next. However, because of the flexibility of the machine and the diversity of operations which it could perform, its programming was far more complex than that of the drill. "To programme a simple bolt took a week to ten days to get a few hours of machining to turn out a year's supply. So while an NC machine had the productivity of four conventional machines in machining, their overall productivity adding in programming time wasn't enough to justify the greater expense of NC unless we could find a faster system of programming." The company then sought for an alternative to manual programming which could be learned relatively easily without a full programming background since its programmers were recruited from the shopfloor. The COMPAC II system, then a leader in the field of engineering programming languages which simplified the extremely complex aerospace NC languages, was adopted. Like many other companies using this system before the arrival of the microcomputer, it involved a time sharing arrangement with the programme manufacturer's mainframe in the United States. This solved the bottleneck in programming but after a year the costs of time sharing became apparent. These included "very heavy telephone costs, problems with line noise which increased programme errors and then required further telephone programming to straighten out." The discovery of these rising costs coincided with the decision to replace an aging lathe with an NC chucker (20). In fact three chuckers were installed - two for production and one spare - and their increased demands on programming "sent our programming costs through the roof." "In response to these problems with time sharing we acquired our own computer and brought the entire operation in house. We continued with the same software because we were satisfied with our experience with the original software choice and since we were familiar with it we did not lose time learning new software at the same time as learning the capabilities of our computer."

Two further NC acquisitions are illustrative of this firm's approach. "By 1974 we needed to increase our boring capacity parallel to our turning improvement because there was another increase in the machine shop's workload and boring jobs had to be subcontracted. As before we wanted to bring these jobs back in house, so we bought a four and a half axis Giddings and Lewis boring mill. Around about the same time we found that the machine shop couldn't feed material fast enough to the NC machines and that certain operations in particular were slowing things down. We found that conventional boring of large holes (more than five inches in diameter) was slow on a boring machine and took up a lot of machine time which is expensive enough on conventional machinery and about 50% more so on NC machines. Our fabricating shop suggested burning large holes, but when we tried this we found it still too slow because of the conventional machinery used by the fabricating people at the time. So we bought in an NC flame cutter and, using NC programming techniques, its six torches increased the accuracy and productivity more than eightfold."

The adoption and utilisation of NC in this company, then, was marked by systematic focus upon bottlenecks and areas of high cost problems within its plant. Increasing demands for the company's products had disclosed bottlenecks which were not easily overcome by traditional methods of combining an increased labour force with conventional machinery. It was felt that increased subcontracting involved lack of control over costs and production schedules, so alternative solutions were sought (21). After a cautious trial involving the simplest possible equipment to solve a specific bottleneck problem, NC tools were introduced in very specific locations where similar problems emerged. The introduction of NC machines produced consequences which led management to expand their use. In some cases the experience with NC tools such as the drill suggested other ways in which the technology could be applied. In other cases the use of NC tools produced imbalances in scheduling or unexpected bottlenecks and costs which require further tooling innovations or, as in the case of manual and then time-sharing programming, changes in the tooling support system (Landes 1969, pp.301-317, documents this as an important part of the impetus to the development of nineteenth century manufacturing organization and technologies.) Programming support was also developed systematically to maximise the use of the company's own shopfloor skills, and in house computer programming was developed once the NC operations render time sharing costs significant.

A similarly systematic approach towards maintenance was also indicated. "Maintenance problems are significant Numerical control machines are expensive to maintain and they add electronics vulnerability to the normal mechanical problems. Our solution was to develop a complete in house maintenance group to minimise downtime. We did this because we thought our maintenance problems might be greater because we are not a production shop but a repair and adjunct shop for our own plant. In a production shop machines tend to be cycled out and replaced on a regular basis, ours are not."

The status of the machine and fabrication shops as support units to the steel plant and the possibly longer time NC machines would be used before being scrapped, led the shop foreman and the senior planner to speculate that their utilisation of nc was obsolete in comparison with other branches of engineering and particularly with respect to current computer technology and programming. However, they argued that in its strictly machining aspects their use of NC technology was current and is continually monitored. For example, ceramic cutting tools are being tried on particularly tough and recalcitrant materials to reduce the expensive repair and maintenance required for traditional high speed steel tools. Experiments are also being made with the latest European cutting tool designs. The latter are of different design from North American tools and appear to require less horsepower per machining cycle, suffer from less wear of cutting edges, and produce smoother surface finishes than cutting tools traditionally used in North American metalworking. The interest in European cutting tool technology has been impelled by the rising costs of power supplies, and a general move to search for cost reductions in possible areas of the manufacturing process.

The final aspect of the firm's systematic approach to incorporating NC technology in its operations is a recently introduced programme of continuous evaluation of NC machining productivity through regular evaluations of machining programmes. "We have found that NC requires new tooling forms to really take advantage of its production capabilities, its precision and surface finish potential.

So we are now moving to a three yearly process of evaluation of all NC programmes. Any programme over three years old is automatically evaluated to see if it should be upgraded to current NC machining capabilities. In future all programmes reaching three years of age will be evaluated this way."

Problems with NC Technology

Thus far our analysis has tended to present a relatively problem-free picture of NC adoption and diffusion. Observors such as Shaiken (1984) and Wilkinson (1983), however, suggest that the very complexity of computerised manufacturing systems generate problems of their own, observations which are now being echoed in industry publications. My final section, then, looks at the difficulties experienced with NC technology in my sample of companies.

The general patterns of problems associated with NC use are presented in Tables 7 through 11. Respondents for 25 of the 60 firms said that they had not experienced any significant problems from the outset (Table 7, p. 230). In this group, which included companies in all sectors of engineering and metalworking, there were 12 large companies (five of these were international firms and mentioned help

Problem Free NC Experience

Table 7: Problem Free Firms by Industry Subgroup

Aerospace	Electrical	Sheet Metal	Transport Group	Pumps and Valves	Die and Mould	Industrial Equipment	Agriculture and Lumber	Total Sample
Firms Free of Problems								
7	6	1	3	2	2	3	1	25
Number of Firms in Group								
15	8	6	5*	5	6	10	4	59*

* Excludes automotive plant considering NC equipment but not using any at the time of interview.

from other branches or head offices in setting up NC operations). Two smaller companies were also branch plants and built on the experiences of their overseas headquarters. Three other small companies claimed to have received much advice from contractors. Overall, problem-free experience was positively associated with firm size (Table 8, p. 232). As well, proportionally more firms experienced problem free NC operation in the post-1981 group (Table 9, p.233).

Even though 25 firms were reported to have experienced problems with NC installations, it is possible that this is an underestimate. As was pointed out above, even the aerospace firms in Canada were installing NC after it had become established in the United States. Further, the radical changes in computer technology in the seventies, along with the rapid development of better designed nc machines, produced major improvements in reliability and ease of use, so that firms adopting NC tools after 1974 had a much easier period of initial learning.

There are also some other factors which might bias my sample of informants toward presenting a more positive view of NC than was actually experienced. First, 9 of my informants were not with the firm at the time of the initial installation of NC, or were not closely involved with this

Table 8: Firms Size and Problem Free Experience

	Small	Medium	Large
Problem Free Firms	5 (24%)	8 (35%)	12 (75%)
Number of Firms in Group	21	23	16

Table 9: Date of First NC Installation and Problem Free Experience

	Pre-1974	1975-1980	1980-
Problem Free Firms	17 (46%)	6 (35%)	3 (60%)
Number of Firms in Group	37	17	5

installation. Second, initial difficulties with NC were often dismissed as something which characterised all users of this technology, or as normal setting up and debugging problems. Probes of such responses would produce accounts of specific difficulties which, in other firms, were labelled as major problems. This pattern of "labelling" differences was found across the sample. In other words I found both problem free and problem full firms in each subsector of engineering and metalworking, with the exception of tool and die firms where the adoption of NC was both late (in terms of the evolution of nc tools) and highly restricted in application. Willingness to identify problems with NC, then, seems to be quite variable and questions about problems with technology seems to have touched a far more sensitive area than questions about labour matters (as shall be shown in the following chapter).

In terms of problem free experience in different branches of engineering (Table 7), electrical products firms experienced the least problems in my sample. Most of these companies had electrical and electronic expertise which other branches of engineering often lacked. Consequently they reported having installed in-house maintenance and programming from the outset, in contrast to other subsectors. The sheet metal firms in my sample seemed to have more problems than other kinds of firm. However, most of the reported difficulties referred to the initial breaking in of the machine. Proportionally more respondents in sheet-metal mentioned that each new machine they bought had sufficiently dissimilar features from its predecessors to require three to six months' familiarisation work. It is possible that this reflects the recency of the application of nc technology to this branch of metalworking and the consequent lack of standardization of machine tool design.

Freedom from problems is directly associated with size of firm (Table 8). This is scarcely surprising. As was shown in Chapter 5, larger firms have greater resources to use in careful preparatory work, information gathering and selections of smaller companies are more dependent on machine tool vendors and do not have the depth of technical and production resources to use in the preparation and setting up of complex technology. These differences were summarized by the Canadian Machinery and Metalworking journal in its "First NC Report" in 1970, "The spread of numerical control in Canadian industry has been primarily through the actions of larger engineering firms. The large companies are largely self-taught and have hired or trained competent management and supervisory staff to handle NC. The selection and purchase of NC equipment has been a top management decision made after intensive economic and technological studies. Small companies are influenced by contractors, but have problems with NC because they lack the personnel able to examine the economic and technical conditions for adoption. Consequently during the 1969-70 lull in aerospace business, small subcontractors were often in difficulty in finding other uses for their expensive nc equipment." (Canadian Machinery and Metalworking March 1970, 73.)

As might be expected, problem-free experience increased after 1981 (Table 9), but did not grow consistently prior to this period. This probably reflects two diffusion processes. The first is the spread of NC technology to all branches of engineering and metalworking, and the continuous development of new NC tools, equipment and software. Such diffusion is likely to have been marked by trial and error processes which are reflected in the problems which different plants experience in adopting NC for the first time. In addition, after 1978 the spread of NC equipment is particularly marked among smaller companies which, as was shown in Chapter 5, often lacked the resources for in house maintenance, the use of skilled operators, and developing optimum programming for the equipment.

The single largest category of problems was related to lack of knowledge and consequent unrealistic expectations about NC technology (Table 10, p. 238-239). Many informants remembered the initial installation as one which required considerable experimentation and debugging before becoming productive. As might be expected by far the greatest problems were experienced in the earliest stages of NC use -- earliest, that is, both in terms of the general diffusion of NC and of the individual company's adoption of it. This was expressed by an NC department manager from a major aircraft maker who pointed out that even though his company had adopted NC 15 years after the major United States aircraft manufacturers and 5 years after Canadair, "These early years, into the early seventies, were difficult ones though. Because there was little sharing of knowledge with the other aircraft companies back up was minimum and limited. It took a long time to build up a 'black book' of friendly and reliable contacts. It wasn't until I joined the Numerical Control Society in 1974 that we really changed from floundering experimentation."

Another informant, from a precision machining shop

Codes for Type of Problem in NC Use

1. Unrealistic expectations accompanying general inexperience with NC technology.
2. Maintenance related difficulties.
3. Technical problems related to machine tool design, problems of lack of fit with adjunct equipment.
4. Problems with parts programming.
5. Imbalances in production sequence resulting from the high productivity of NC equipment.
6. Difficulties in "retrofitting" conventional machine tools with NC controls.

NB: The tables present responses in rank order according to unweighted number of mentions.

Types of Problems Associated with NC Use

Table 10: Rank Order of Problems by Engineering Group

Aerospace	Electrical	Sheet Metal	Transport Group	Pumps and Valves	Die and Mould	Industrial Equipment	Agriculture and Lumber	Total Sample
1	1	1	1	1	3	1	1, 2	1
3	3	4, 6	2	2	2	2, 4, 5		2
2					6			3
								4, 6
								1
Number of Firms with problems								
8	2	5	2	3	4	7	3	34
Total Firms in Group								
15	8	6	6*	5	6	10	4	60

* One automotive plant was not yet using NC equipment.

Table 11: Problems and Firm Size

	Small	Medium	Large
	1	1	1
	2, 3	2, 3, 4, 6	2
	6		3
			5
Number of Firms with Problems	15 (%)	10 (%)	10 (%)
Total Number of Firms in Group	16	23	21 *

* Excludes nonuser firm.

Table 12: Problems and Date First NC Acquisition

	Pre-1974	1975-1980	1981-
	1	1	1, 3
	2, 3	2	
	4, 5, 7	3, 4, 7	
Number of Firms with Problems	20 (54%)	11 (64%)	3 (60%)
Total Number in Group	37	17	5

specialising mainly in aircraft components described the initial contact with NC tools in graphic terms. "When we plugged it in it lit up like a Christmas tree. I think we blew every one of those lights before we got it to mill an inch. Somehow we got it working but I reckon none of us could honestly say we understood how we got it to do the things we did. It probably took two years before we got some honest-to-God production out of it. But those two years were very good for us all and set us up to use the improved NC machines that were coming out by the end of the sixties." Similarly a pump, valve and piston component firm informant said, "We initially underestimated the skill level required for operating NC machines. We really had very little understanding of the technology and we often had problems understanding what was happening. We imagined things were going on which were impossible, and didn't think things were happening when they did."

This sense of floundering around without guidance was quite prominent among smaller aerospace machine shops who took up NC machining in the 1960s. For these and other companies there was also an additional learning process -- that of discovering the actual capabilities of NC machines were rather more restricted than NC makers and sales agents had presented them to be. Several respondents found that NC machining did not significantly reduce the manufacturing processes' need for skilled operatives. "We got our first machine in 1971 hoping that we could use a skilled machine instead of skilled people. Even though it was a point to point machine we found that we could not use it with an unskilled operator - it just produced large amounts of scrap because tool settings and inspections were critical, and you had to understand machining in order to see when things were likely to go wrong, or were wrong. Also the advantage of these machines is in making very sophisticated parts combining many machining operations in doing what cutting had to be done in what order and so on."

A respondent from an elevator and conveying machinery firm also said," We got into NC in 1970 during a period of extreme labour shortage when we found it very hard to get skilled machinists to manufacture components. At that time NC was being sold as a technology allowing industry to use less skilled labour. It turned out that it wasn't the case at all, NC just wasn't a push-button production tool allowing you to use people without real machining experience."

Most informants saw NC as sufficiently different from conventional machining technology to require some period of learning to use it in an optimal fashion. While the preceding examples are those of earlier users, the more routine process of "learning by using" (explored by Rosenberg, 1982 Chapter 6) is nicely summarized by the manufacturing manager of a small aerial surveillance equipment firm. "It took a while to find the best way to use the machine. At first we used it for everything we could, but we soon found out that this tied up the machine needlessly for simple jobs while others which really needed NC work were backlogged. Now we identify carefully areas such as compound tolerances (22) where nc machining is necessary to lay the foundations for accurate assembly. For example, we found skilled machinists making differential gear frames conventionally were unable to hold tolerances and this required a lot of backing and filing to get straight. So now we do this on the Moog (an NC milling machine) and we don't have these problems."

In other cases more realistic expectations had to be learned about the technical capabilities of NC. The technical director of a medium-sized precision aerospace machining shop said, "Although there were no major surprises in NC for us we did find that the manufacturers and sales people made some false claims about the speed and other advantages of NC. But after the first couple of experiences with those you soon learn to adjust your expectations." A British-trained production engineer argued that most of the NC manufacturers' claims about the speed of NC machining were illusory and irrelevent. "Certain conventional tools are easily as fast as NC machines but they require special form tools as opposed to standard tooling used on NC. Most of the extraordinary production increase claims made by NC companies were usually based on mating NC machines with special form tools which really undercuts their real advantage of flexibility and elimination of form tools. I see NC advantages as its ability to do complex shapes and using standard tooling which is far cheaper, along with an associated reduction in costs of maintenance and worker skills required when special form tools are used."

The 1960s was a period of diffusion of NC technology from aerospace to other engineering sectors, often involving the development of the first generation of particular types of NC machines. Consequently, it is not surprising that Canadian users in the sixties and often through the early seventies experienced a variety of technical problems with the equipment, independent of the learning processes involved. An aircraft fuel components maker remembered the unreliability of nc even in the aircraft field. "NC productivity gains did not materialise in the early years - the early to mid-sixties. There was too much downtime; there were malfunctions and inaccuracies. There were also problems with the accessories and controls. It took two to three years of problem solving before all the bugs were out and we were happy with NC machine performance."

Another informant who was a programmer when the first NC equipment was installed in his firm making railway braking equipment remembered,"There was very little choice and we chose the first generation NC machines by U.S. builders. But it quickly emerged that the first generation models were not the best designed and improvements occurred every six months for the next five to ten years. So we held off any further NC purchases for eight years when we switched to Japanese builders who were proving themselves superior in terms of deliveries, quality, and back up servicing."

Many informants pointed out that the worst features of first generation NC technology were the pre-solid state control systems (i.e. predating the transistor, microchip, or microprocessor). These were combinations of "hard wired" electrical circuits, electromechanical relays and magnetic switches, and pneumatic devices. They were vulnerable to atmospheric oxidisation and corrosion, dust, vibrations and temperature fluctuations. All these are conditions endemic to factory conditions and consequently NC machines required very high levels of maintenance to keep them going.

Other salient problems were particularly marked in the programming of NC machine tools. The first generation of NC tools were programmed by hand computation and the results punched onto paper tape, both particularly error prone processes. The next development was the use of computer time sharing which permitted more complex functions and elaborate machining processes to be programmed relatively swiftly and with less error. As was seen in the case of the steel company, however, time sharing had its own problems and the process became obsolete with the development of microchip circuitry and microcomputer technology. It was universally agreed that the greatest advances in NC technology eliminating these problems occurred with the microchip revolution in the seventies which had improved both controls and programming.

Despite these advances no generation of NC machine tools has been found to be fault free and some complaints of design inadequacies were found referring to all periods of

NC tooling. Moreover, NC technology appears to have some inherent problems which were reflected in the largest category of problems after those referring to the initial adjustment phase. These problems relate primarily to issues of maintenance. While a few respondents argued that NC and CNC machines required no more, or even less maintenance, than conventional machine tools, more argued that maintenance problems were significant. An informant with a large agricultural equipment firm argued, "NC is a more complex manufacturing system combining electrical and electronic controls, and computer programming systems all linked to more precise machinery. These more sophisticated systems require more maintenance. Diagnoses are much more difficult so that downtimes are significantly longer than in the case of conventional machine tools. The aerial surveillance company informant said, "Overall there are far more breakdowns than the NC makers claim. I've found this true in other companies using top of the line Cincinnati machines... It takes very expensive people to put NC machines back to work after they break down. Our own NC mill is the only kind we could use but it has some very bad design features in terms of checking systems so you get into very complicated high calibre engineering diagnoses just to find actually simple things."

Several respondents made similar points about the combination of electrical and mechanical systems in NC technology as a significant source of maintenance problems. Even though there was some consensus that CNC machines were now better equipped with diagnostic features, smaller firms lacked the funds to replace their NC machines with CNC ones, and even the latter had maintenance problems. As one NC programmer with a machinist's background pointed out, "When a post processor goes down you're faced with a black box with no moving parts. There isn't enough electronics knowledge either on the shop floor or in management in most engineering firms. Even maintenance people are mechanical people first, with some electrician skills, but rarely any electronic expertise. So all you can do is to wait for some time for servicing or replacement." Such outside maintenance dependence was more remarked upon by smaller companies who complained about the cost of such services. Large firms identified maintenance as a major element in developing a set of in-house support services for their NC operations.

Certain applications involving only episodic, irregular use of NC equipment rendered regular maintenance appropriate to amounts of machine usage difficult to schedule. This was experienced by two companies at extremes of the organisational scale - the steel plant and the gyro-optical tracking apparatus company. Some large companies who had installed NC early, and maintained it well were now running into the problem of obsolescence , resulting in increasing difficulty in obtaining replacement parts to maintain the tools in running order.

Finally, two observations on problems were made which point to the fact that complex technologies generate their own inherent, systemic problems (an issue explored at length in Perrow (1984) and to which NC and CNC technology is no exception. A programmer for a pulp and paper equipment maker pointed out the persistent problems in his experience, "When a job returns that you did a year or two ago it should be easy because you have the tape already. But the same machine may not be available and you have to reprogramme for a different machine which may be very similar but actually has a whole bunch of little, subtle differences. Or the old tooling is no longer available and you have to reprogramme to deal with the differences in the dimensions of the new toolings. Or the first machine may have been reconfigured to cope with a new job, or rebuilt in the course of servicing or upgrading so you've got basically a completely new machine. Unless you have a very good system of information and records, you can waste a lot of time on old jobs which turn out to be worse than new jobs."

Another programmer working for a company making hydro turbines and generators observed, "Although NC has worked well for us in both manufacturing and in relation to labour overall, we have had problems in using it optimally. For example, I will spend three or four days writing up a programme for a piece and then when it gets to the shop floor the machine involved is loaded with another job so the foreman shuffles my piece to another machine and my programme will have to be rewritten. If I have other work then and I can't rewrite immediately the Programming Department gets the blame for the delay. This sort of problem has been significant and we're trying to get greater control over shop schedules to overcome it. Another sort of problem I think is there's not enough careful evaluation of costs in business, or policing shop floor productivity. As a result people only have a vague idea where their costs are too high and nc isn't necessarily an answer to all costs or problems. Operators tend to slow NC machines down too much. I don't know why -- whether they're scared of the speed of the machines or fear being put out of work -- I just don't know. There's also a tendency I've seen where the first shift guys slow things down so they don't have to deal with taking a piece down and making a new set up; the second shift comes in and goes even slower to avoid the same thing."

Both of these programmers worked for companies who had been using NC since the early sixties. Their observations suggest that a manufacturing technology's optimum utilisation is an ideal toward which management may strive without reaching because of the many sources of suboptimality built into the technique itself and into the broader sociotechnical system.

Conclusion

The first aspect of my investigation of diffusion I should like to underline is the very limited way in which labour is a source of concern influencing adoption decisions. On the basis of labour process analysis one would have anticipated more cases of attempts to use NC machinery as part of a strategy to reduce reliance upon the amount of skilled labour required in machining and metalworking, and least some explicit references to the need to curtail the costs and power of skilled craftsmen. What emerged, however, was a concern for labour in a very restricted, technical manner. Thus, some firms turned to NC to solve problems arising from labour shortages in a period of rising demand for engineering products. Meeting the demand was just impossible using conventional machinery because there was no pool of labour available to be recruited. Other companies found that conventional manual machining was just inadequate for the consistent manufacture of repeated batches of very precise, complex parts. The complexity and precision involved required far too long to be crafted on conventional machinery. In addition, engineering products increasingly use expensive materials so that scrap rates associated with manual machining became unacceptable. In other cases, the slow pace of conventional machining, and particularly the lengthy preparation of jigs and fixtures, setting up, and cross machine transfer of workpieces reduced the firm's ability to respond to rapidly changing markets and increased demands for shorter lead times. Contrary to the theories of Braverman, Noble, Shaiken and Wilkinson, then, I found that in all these instances conventional machining emerged as <u>technically</u> inferior to NC machining and this factor, not considerations of labour's bargaining position or control over the work process is the paramount consideration of management.

The second aspect of my investigation which I should like to emphasize is that the adoption process is a considerably more complex one than is depicted by Mansfield and other economic writers on diffusion. Overall, the spread of NC technology in my sample was a "demand pull" phenomenon. That is, firms adopted NC in response to increases in the volume demanded, or as a means of responding to shifts in demand toward more sophisticated engineering products (i.e. involving higher levels of precision, complexity and new materials), or as a means of obtaining particularly lucrative contracts. Of course, the precise nature of the factors associated with demand shifts, leading to production problems requiring new technological solutions in the form of NC equipment, varied in each branch of engineering and metalworking. However, major problems were experienced in using the technology by a majority of companies (of different sizes and different branches of engineering production) and the problems associated with NC technology did not substantially diminish until the 1980s. Several informants pointed to the less-than-optimal utilization of NC equipment even though their firms had been using it for a decade or more. Adoption patterns of different firms also ranged from a virtual blind "leap of faith" to carefully planned one-step-at-a-time adoption. All of this suggests that diffusion is accompanied by less than perfect information, less than best-practice application, and long term, persisting inefficiencies and sub-optimal use. In particular, orthodox diffusion analysis seems to me to underestimate the widespread existence of unrealistic expectations associated with the initial adoption of new technology, and the consequently long period of adjustment as "learning by using" (in both its embodied and disembodied forms) occurs. And even then, what is learnt is not always swiftly applied or necessarily results in optimizing practice, as the last informant cited indicated.

Footnotes

1. Unweighted scores, or mere counts of the number of times an item was mentioned, were used since the responses usually involved a single item. Weighting items for first or second mention did not alter the rank for the first four items but did produce slight variations in the tail end ranks.

2. Landes' analysis of the new mass production industries emerging in the latter half of the nineteenth century suggested that repeatability has been an enduring in manufacturing precision components for large batches of assembled products (1969, pp. 309-317). Rolt's discussion of the history of machine tools also

emphasizes the inadequacies of traditional handicrafts techniques as an impetus to the development of industrial mechanization.

3. A profiler is a kind of milling machine used in the manufacture of airframe parts involving complex curves.

4. Because of the original application of nc machining to aircraft components made of very tough high stress alloys, NC machine tools were designed to operate with much lower speeds and feed ranges than conventional machines built for less recalcitrant metals. The difficulties of machining aircraft industry metals are presented in American Society of Tool and Manufacturing Engineers (1965), pp. 67-97.

5. Families of parts are parts of similar geometric outline but different dimensions. Thus valves of identical shape often come in a range of sizes to accommodate different diameter pipes. In conventional machining each part size required setting up machines to each set of dimensions. In nc machining a programme establishing the basic geometry permits the input of a few key dimensions to rapidly change the machining to produce different sizes of valve.

6. Electro-discharge machining is a process whereby an electric spark is used to erode or cut metal. The cutting tool is usually carbon and is made to the shape of the cavity required in the workpiece. Both tool and work piece are immersed in a light lubricating oil which is a semiconductor of electricity. A direct current of low voltage and high amperage is fed to the carbon tool in high frequency pulses. The electrical energy pulses become sparks which jump the gap between the electrode and the workpiece. Intense heat is created in the area of the spark impact, the metal melts and a small particle of molten metal falls away from the workpiece. The lubricating oil is continuously circulated to dissipate the heat caused by the sparks and to carry away the eroded metal particles.

7. Form grinding tools are grinding wheels made with special angles, radii, ridges, tapered and other contours. Since grinding is a process involving heavy wear on the grinding wheel, such tools require constant checking with gauges and "dressing" or trueing the surfaces with diamond tools, again with the aid of special gauging devices requiring accurate setting up, etc. These special grinding wheels, then, are themselves expensive and involve heavy maintenance costs. In addition because they are special tools they may spend long periods not being used.

8. Carbide, more properly silicon carbide, is a synthetic abrasive originally developed as a substitute for industrial diamonds. It is used to make dies and cutting tools by mixing carbide powder with fine particles of tough metals such as tungsten. The mixture is then compressed under high heat to form extremely hard blocks.

9. A jig borer is a machine designed to bore holes with exceedingly high degrees of concentricity, roundness, and parallelism. These holes are also bored with very high locational accuracy. This was originally developed for the manufacture of jigs and fixtures where accuracy of holes guiding drills and other tools, or the location and straightness of locating pins and matching holes were essential.

10. Lapping is a technique for removing very small amounts of material from a surface in order to obtain the most accuracy, flatness, and smoothest surface finish. Traditionally it was a manual process - a long, tedius but highly skilled operation. However, lapping machines have been developed, and these along with the evolution of more refined surface grinding techniques have considerably reduced the amount of lapping done.

11. Stellite is an alloy of tungsten, cobalt, carbon and chromium. It combines the qualities of remaining very hard at high temperatures, and of corrosion and oxydisation resistence, also at high temperatures. Because of these qualities it is

used to coat ferrous metal items used in hot and corrosive environments.

12. This observation suggests that the "image" of up-to-date technological practices may be at least as important for sales as the purported gains in quality and efficiency. See Harrison White (1961) for an interesting case study of the way in which and R & D department appeared to contribute more to the image than to the production of a small abrasives plant. There has been some questioning of the spread of precision engineering standards to sheet metal products. See PRODUCTION MANAGEMENT (1985), pp. 54-57.

13. A beautiful example of the complexity of engineering materials handling is presented in Abegglen and Stalker (1984), Figure 5-2, p. 98. A useful discussion of the problems of rationalizing small batch engineering production is found in Blackburn, et. al. (1985), pp. 116-22.

14. According to Abegglen and Stalker (1985), Japanese plants following Toyota's "kanban" (just-in-time) parts delivery system are more concerned with high worker utilization rather than with high machine utilization. It is possible that machine downtime is simply the easiest or most accessible indicator of production inefficiencies. Other methods such as precise time-budgets of worker activities, or tracing the route of the various workpieces may be too difficult, costly, or disruptive to be of use.

15. Because of the reduction in downtime and the longer periods of machining time of NC equipment, tool wear does emerge as significant problem in NC machining. Consequently, my informants emphasized the importance of "inspection skills" as a key quality for NC machinists and operators who were responsible for monitoring the wear of cutting tools. On the issue of NC machining skills see below, Chapter 7.

16. At least this was the consensus of two NC consultants, the President of the computer manufacturing research company, and of engineering managers in the steel and automotive plants I spoke to.

17. Two or three managers did observe that Japanese and European solutions appeared to be rather different from the North American method of "throwing technology at every problem." Two who had visited Japan noted more extensive use of simple machines (explained by Abegglen and Stalker as a means of maximising worker utilization by reducing nonproductive materials handling activities), while those who had visited Europe observed the use of tools considered as obsolete in North America to produce sophisticated engineering products but involving a much more highly skilled labour force.

18. Investment casting is a method of precision casting where a wax or plastic model of the article to be cast is electroplated or covered with a heat hardening clay. When the outer shell is in place it is heated so that the model melts away. The shell is carefully cut open to provide the exact dimensions for a working casting die which will be fabricated from tough aluminium alloy or tool steel.

19. Swaging is a process of shaping metal bar or rod by feeding it under pressure into a series of dies which successively compress the metal into the required contours.

20. A chucker is a type of lathe designed for machining large parts such as castings, forgings, or blocks of bar or rod. These parts have to be hoisted onto the lathe and mounted into the chuck manually. This distinguishes the chucker from the bar machine which is a lathe designed for machining small parts. The material to be machined can be automatically fed through the lathe's machine spindle which replaces the chuck.

21. Subcontracting tended to be viewed with distaste by the majority of managers in my sample (except by those from large firms), as a practice to be avoided if possible. Perhaps Lloyd-Jones (1986) observations on the way North American managers have reacted to the Japanese just-in-time parts delivery system applies to subcontracting. "North Americans are used to thinking that spreading

responsibility means losing responsibility. Managers are horrified by the thought of Japanese factories where each one of several hundred workers can shut down the line to correct something. But this spreading of responsibility seems to promote a spread of responsible people."

22. Compound tolerances refer to allowances of variation in dimensions in assemblies involving rotating components with axes in different planes. Gyroscopic camera mounts require gear trains to provide accurate 360 degree movements in both horizental and vertical planes.

Chapter 7: NC Technology and Labour Skills

In Chapter Two I discussed the labour process writers such as Braverman and his successors who use NC technology as a prime example of the deskilling dynamic alleged to be inherent in industrial capitalism. Several problems were identified in these writings both in respect to the logic of their argument and with the evidence used to support the deskilling theory. The preceding chapter found that the evidence for deskilling and labour process control as motives in the adoption of NC technology was slight. Only a very small number of informants mentioned that their primary interest in first adopting NC machinery was to replace skilled machinists with less skilled machine operators. In most cases where NC machinery was used as a labour saving technology it was done in a context of severe labour shortage and not in response to problems in controlling the work activities of shopfloor craftsmen.

NC machining was viewed favourably as a replacement for conventional machining because of the technical limits of the latter in relation to contemporary engineering product requirements and markets. Changes such as the increased complexity of shapes, refinement of tolerances, the use of difficult to machine materials, and the shift in market demands towards shorter lead times, were placing demands on engineering firms which were difficult to meet using conventional machining techniques (see Chapter 6.) It is ironic that these economic and technical factors should be ignored by a neo-Marxist theory that claims to be "economic" and "materialist".

It is possible, perhaps, that these findings merely reflect merely managerial illusions or ideology. That is, my informants were diplomatic or disingenuous and that their class strategies were disguised by presenting their actions in a purely technological manner which translates all labour-management issues into technical problems pertaining to machinery and equipment. With this possibility partly in mind, the second part of my interview schedule was designed to probe labour aspects of the adoption and use of NC equipment. Questions were asked about each plant's labour force, its turnover or stability; the effect of the recent recession upon company employment; the skill level of NC workers and their recruitment and training; whether the adoption of NC machine tools had caused labour reductions or redeployment to occur; and in the case of unionised plants, whether there had been disputes with the union which focused specifically on the application and use of computerised technology in manufacturing. In this chapter I shall look at the skill level of nc workers (1), their training and deployment, and compare NC machining skills with those involved in conventional machining. Secondly, the problem of labour shortages in engineering and metalworking will be examined. As well, I looked at managerial perspectives on labour skills, labour shortages and labour training. The evidence on these matters suggest that the labour process theory that technological innovation is associated with labour deskilling and the increase in the industrial reserve army, is false. The actions of the unions in relation to NC technology will be dealt with in the next chapter.

Skills and Training of NC Workers

Table 1 (p. 263), presents information about the skill level of NC operators in relation to branch of engineering and metalworking.

In terms of the proportion of companies using skilled workers - i.e. toolmakers, all-round machinists, European-trained tradesmen - mould and die shops, industrial equipment and agriculture and lumber firms stand out. As might be expected in mould and die shops, NC machines are

Table 1: Skills of Workers Assigned to NC by Sector

Sector	No. of Firms in Sector	Number of Firms Assigning Unskilled/ Semi-Skilled Workers to NC Machinery	No. of Firms Assigning Skilled Workers to NC Machinery	% of Firms Assigning Skilled Workers to NC Machinery
Aerospace	15	10	5	33%
Electrical	8	4	4	50%
Sheet Metal	6	4	2	33%
Mould and Die	6	0	6	100%
Industrial Equipment	10	1	9	90%
Pumps and Valves	5	3	2	40%
Agriculture and Lumber	4	1	3	75%
Transport Equipment	5*	2	3	60%
Total	59	25	34	

* Excludes automotive plant considering but not yet using NC.

merely one type of machine tool among the full range used by highly skilled all-round machinists and toolmakers. This distinctive tool and die shop pattern was described well by an informant quoted in the preceding chapter. In these shops workers would use NC machines among others as the job demanded. Further, while specific personnel were designated programmers in these shops, programming skills were common on the shop floor and were routinely used by the machinists and toolmakers. The same informant noted of his shop, "As a job shop with small runs we can't divide people into skilled, set up, operator classes of workers. We try to get people exposed to all the machines and aspects of diemaking. Everyone involved in NC and other skilled operations has to know both cutting technology and programming. We have no NC operators as such...Consequently our NC work is done by NC toolmakers not NC operators."

In all the cases where edm machines were used to make dies, the diemakers running the machines were also responsible for their programming. Such cases were found in agriculture and lumber firms, aerospace, transportation and industrial equipment plants as well as in the die and mould shops. In the largest die and mould shop, one specialising in the manufacture of aluminium blow moulds for plastic containers, programming was centralised as the responsibility of the shop foreman -- an ex-toolmaker with NC operating experience in a major electrical goods producer. However, he pointed out that "The NC machinists (all experienced general machinists) have to check the programmes and know exactly what is going to go on. I work closely with them in developing programmes and I want feedback so that I can do better programming next time."

The pattern of "polyvalent" machinists, able to use NC as well as conventional machines was found in agricultural and lumber equipment firms, industrial equipment manufacturing plants, certain electrical goods companies, and some aerospace firms. The element common to these firms responsible for the nc manning pattern, is that their products are small batches of complex units consisting of many subcomponents which have to be carefully machined and fitted for problem-free assembly and functioning. In these cases skilled workers would use NC machines, among others, as the job required. In several instances it was reported that, even though the men were skilled machinists, a further six months' to a year's experience was necessary before they were considered qualified NC operators. This training period was necessary in order to work with the diversity of parts and parts programmes involved in nc product lines. For these companies, batch sizes were very small, and each unit expensive, so that the machining jobs varied continually and little leeway was possible for learning errors.

In contrast, the die makers who were moved from conventional diemaking to NC edm operations routinely took charge of all programming for the edm machines and were uniformly described as having very short basic training periods - usually less than a month before production was satisfactorily under way. The ease of transition was explained by one edm diemaker, "In die making, NC is like conventional machining in the sense that it is based on doing things in logical sequence. Programming involves breaking down the process into a large number of small, simple steps. You do that in conventional die making anyway - and the more complicated the die the smaller the steps and the more of them. In programming for edm and in process planning for an ordinary die you take the blueprint apart and put it back together step by step." This was echoed by the plant manager of another die shop. "The evolution to NC from tracer technology and then to Cnc has been a natural progression and a smooth development. Because of the technology of diemaking - you break down the die complex and build it up layer by layer - this process lends itself to digitizing and programming."

Where the polyvalent manning of NC machine tools occurred outside mould and die shops, parts programming was usually an "office" function and only minor editing was allowed on the shopfloor. This was generally justified as an efficient way to ensure that the part's engineering specifications would be strictly adhered to, and any variability of product arising from variations in manual skills avoided. In several instances this concern conflicted with the obvious potential inefficiencies of the additional communications and breaks in machining occurring when programmes had to be returned to the programmer for alterations. Such problems were outlined at the end of the last chapter. Consequently various compromises developed to permit shopfloor editing on a routine basis. Thus at a factory producing elevators and industrial conveyor machinery, "Quite a few of our machines, being early models had just tape readers without memory. We have added memory capacity to all of them so that tape editing could be done at the machine. To facilitate this I very reluctantly put a tape punching machine on the floor - and it floats to whatever work station needing it (i.e. NC machine where tape editing was required). There was some dispute over this practice with the Manufacturing Engineering Department, but we've developed a set of rules to ensure that there's only one tape on the floor and all changes are clearly registered so that it's clear which is the latest version."

In other cases where skilled NC operators worked, a shift system operated to control parts programme editing. "First shift " machinists were the more experienced and proofed and edited programmes or conferred with the programmer to effect programme changes. These machinists also set up NC machines to ensure that they could be worked on the succeeding shift without tape editing, complex part inspection or major tooling changes so that the "second shift" machinists worked largely as loaders and unloaders who merely monitored the NC equipment. Elsewhere this system often operated in a more informal way, where trusted experienced workers were permitted to perform shopfloor programming, to act as lead hands and set up men for the less skilled workers on a "buddy system." In companies as diverse as a large custom perforated sheet metal fabricator, a small precision machining shop, and a medium sized aircraft jet engine repair shop, NC programming was described as a grey area in terms of managerial control over it. Where parts programming was simple it often occurred on the shop floor; where it was complex, or involved expensive materials, or related to contracts with restricted scrap allowances, it was undertaken by company programmers away from the shop floor.

Finally, in some larger companies using skilled machinists to operate their NC tools, illicit shop floor programming occurred. These companies included the steel company, two electrical products firms, and a major jet aircraft engine manufacturer, all using ex-machinists and toolmakers as programmers. In all these cases management expressed the firm belief in the need to control parts programming. As the steel company's planner put it, "We see programming as a way of controlling productivity or intended output, and we've always insisted that programming be a staff function. So our programmers are recruited from our machinists and toolmakers, but their position is defined as supervisory- track." Similarly the programming department head at an electrical products firm said, "Because of the complex engineering and critical tolerances involved in our products we have always separated programming from manufacturing. A few senior machinists are allowed to do a limited amount of editing, but most don't - things are too critical and we could lose control of the operation. There are feed and speed overrides and these can be used to change these variables by any machinist to cope with uneven castings or problem material."

I was fortunate in being able to speak to the programmers in these four firms. According to them the best shopfloor machinists find ways of "getting into" the NC programmes precisely to alter parameters and sequences and not just feeds and speeds. No problems had arisen with this practice, to the programmers' knowledge. The programmers were in constant communication with these machinists every day so that much mutual exchange of knowledge occurred which probably reduced the risk of major "crashes." In all these cases the programmers argued that shopfloor feedback was very important in their preparation of parts programmes. Although none of them admitted to showing NC machinists how to get into the machine controls' memory, they did point out that the more the machinist understood programming the easier it was for the programmers to work with him. Consequently they often did explain aspects of the programming in order to discuss particular problems in each parts programme at hand. It seems likely that, under these circumstances, managerial visions of "programme integrity" are rather illusory.

It is interesting to note that aerospace firms had the smallest proportion of companies in its sector operating nc machine tools with skilled personnel. This in a sector where refined tolerances, complex contours and recalcitrant materials as well as a lot of small and medium batch productions runs, customizing and prototype work are significant features of production. (Only two firms mentioned having single production runs of over ten thousand pieces. Both were small contractors. Most firms reported that standardized items were produced in small batches, as contractors needed them, often years apart in execution). Production runs are the basic features of production. Because these conditions contributed greatly to the early use of NC in this sector it is possible that the low skill of nc machine operators reflects the process of deskilling stemming from the widespread diffusion of this technology since the mid-sixties. A closer look at this sector, then is necessary.

Tables 2, 3 and 4 (pp. 272-273) present my information on size of firm and NC operator skill, firm size and length of nc operator training, and the relationship

Table 2: Skill Level and Firm Size in Aerospace

Firm Size	Number of Firms Assigning Unskilled/Semi-Skilled Workers to NC Machinery	Number of Firms Assigning Skilled Workers to NC Machines
Small	3	4
Medium	3	1
Large	3	1

Table 3: Firm Size and Length of NC Operator Training in Aerospace Companies

Firm Size		Training Period	
	N	Up to 3 Months	More Than 3 Months
*Small	7	2	3
Medium	4	1	3
Large	4	3	1

* No information on this from 2 small companies.

Table 4: Skill Level and Length of Training for NC Operation in Aerospace Firms

NC Operator Skill Level	Training Period: Up to 3 Months	Training Period: More Than 3 Months
Unskilled	2	2
Semi-Skilled	3	3
Skilled *	3	-

* No information on training period from 2 companies.

between skill level and length of training in aerospace firms. As can be seen, there is considerable diversity across aerospace firms in terms of these associations. But small firms try to get skilled machinists to run NC equipment and none of these firms provide long periods of supervised on the job training for novice NC operators whatever their skill level and experience. Even so, only one small subcontractor, specialising mainly in the fabrication of wing components, expressed satisfaction with its use of vocational high school and CEGEP graduates on NC machine tools. However, it was stressed that the recruitment process was rigorous, including tests for mathematical abilities, and that the firm's core of 30%-40% skilled, European-trained tradesmen included some very good instructors in on the job training.

Two other small subcontractor precision machining shops expressed dissatisfaction with their use of semi-skilled and unskilled workers for NC operations. The informants from these firms claimed that the shortage of skilled machinists and experienced NC operators made it very difficult for small companies who could not compete with the wage levels which attracted skilled and experienced workers to larger firms. A programmer-supervisor from one of these smaller shops described his companies NC workers as "...semi-skilled workers who don't know how the machine works. They just press the button and get the part." He maintained that these operators are trained by "...introducing them to the basic ideas and to specific jobs on the machine for a period of two or three days by one of the experienced operators. We have to get unskilled people and give them enough training to work on nc...We don't have time to train properly. People are given two or three days with someone working with them and then they are on their own. But this can be very dangerous. With the speeds and power of NC machines crashes can be very serious, not just breaking cutters and workpieces but whole machines can come flying apart."[8] While no other small shop's situation seemed quite so desparate, this sense of improvising by using NC operators with less than desirable skill levels was stronger in this group than among larger firms.

The latter more often operated with semi-skilled and unskilled NC operators, using skilled workers as lead hands responsible for proofing and editing parts programmes, setting up the machines, and inspecting the first part produced with a new programme. Only one of the four large firms in this sector used skilled nc operators. This was a manufacturer of aircraft transmission and gear train assemblies. These products involve the manufacture of many subcomponents which are assembled into larger, very complex units. Hence the range of items manufactured is very great and the tolerance requirements very precise (2). It was on these grounds that the manufacturing manager argued that skilled workers were necessary for NC operations. The training time for these NC workers was "three to four weeks." In four smaller aerospace shops where the diversity and precision of NC manufactured parts was also great, but semi-skilled operators - people who had some specialised machining skills on one type of conventional machine tool only - were used. Their training period was estimated to be six to twelve months.

The other three larger aerospace companies appeared to operate by manufacturing a restricted range of products and in making final assemblies of airframes and jet engines. As well, these companies also engaged in prototype production and testing. Apart from the latter, however, the NC product range was restricted so that a higher volume of continuous production predominated. Very small batch runs, and items requiring innumerable subcomponents were sub-contracted to precision machining shops. This contracting arrangement made it possible for the larger companies to operate NC as a medium batch production, customizing, and occasional prototype development manufacturing process, while sub-contractors used their NC equipment on smaller batch runs. For the former, it was easier to use semi-skilled or unskilled workers under the direction of lead hands. For the latter, either skilled workers or semi-skilled or unskilled workers, usually with longer training periods than their large firm counterparts, were used on NC equipment.

These patterns of aerospace NC operator deployment neither strongly support nor clearly disconfirm the deskilling hypothesis. The latter requires time sequence data of a far more extensive kind than the retrospective information my informants were able to provide. However, in terms of that retrospective information, my informants in this sector indicated that where labour cost or labour skill factors were involved in the course of NC adoption decisions, the predominant problem was one of the shortage of skilled labour in the context of rising demand for aircraft and aircraft parts production, where a capital good substitute for labour was available. Further, what emerges from my data is evidence that NC is not necessarily a technology with deskilling consequences, and that it is rarely applied in conjunction with a deskilling deployment strategy. Rather, the deployment patterns associated with NC equipment in aerospace depends largely on batch size and uniformity of production runs; production characteristics which are, in turn, associated with firm size and contractual status in the aerospace market.

Two other engineering and metalworking subgroups - pumps and valves, and sheet metal - are characterised by a small proportion of firms within each sector using skilled workers to operate NC equipment. One owner-manager of a Montreal sheet metal firm described shop floor work in his industry as mainly "grunt work," involving very little skill development and avenues of mobility. Certain types of machines -- particularly press brakes for bending sheet metal -- were defined as requiring higher skill levels than ordinary punch presses. One steel products company had only one such NC machine. Its operator had been with the machine since its installation twelve years' ago, and was responsible for parts programming and tape preparation. Much of his skill was required in obtaining quality production with an aging machine. Interestingly, the machine was to be replaced by a CNC model and the same operator would continue working on this one. However, the new machine was to be programmed directly from a microcomputer in the Engineering Office and the operator would be editing the parts programmes and not generating them. This was the only sheet metal operation with shopfloor programming. But where sheet metal firms employed press brakes as well as punch presses - skilled operators were allocated to the former, while operators of the latter were designated as semi-skilled or unskilled. All but one of the sheet metal firms used the lead hand system whereby unskilled operators operated machines after they had been set up and the parts programme proofed by the lead hands.

The exception to the lead hand-operator system was a custom perforating shop which employed only experienced punch press operators who were, in the words of the shop supervisor "The best calibre people who can understand why the machine is doing the things it's doing, why the sequence is set up the way it is, etc." The shop produced customized perforated sheets in a variety of metals, fibres, and plastics, some of which were quite expensive materials in contrast to the common grades of machine steel ("mild steel") used by most sheet metal firms. This firm had worked with the Whitney tool company in the early seventies to design an NC punch press for its specific requirements; a design which Whitney subsequently put on the machine tool market. In this instance production occurred in very small batches, and included work with expensive materials such as stainless steel, brass, and aluminium alloys. Here scrap and error was much more expensive than for other sheet metal firms producing larger runs in much cheaper machine steel sheet. My informant pointed out that the pressures on the company to reduce scrap and improve quality had increased as a result of "...customer demands; for example, equipment manufacturers like Caterpiller are facing increased Japanese competition which they are trying to respond to by quality control improvements. So our products have to be of higher quality and our clients are less generous than they used to be in paying for waste in materials as part of their order."

The manufacture of pumps and valves primarily involves machining castings to produce regular, tight fitting, well sealed mating surfaces, accurately rotating threaded faucet or valve components, or tightly nesting pump pistons and cylinders. The work includes most of the standard machining operations - surface grinding, boring and threading, drilling and tapping. However, for most industrial applications machining tolerances are not nearly so restricted and precise as those found in die making or aerospace precision machining. Batch sizes are also often quite large, and there is relatively little customizing work. The dimensions and contours of most pumps and valves are determined by the dimensions of standard industrial products such as pipes and cylinders produced in very large quantities by steel firms.

Three of the five informants from pump and valve firms characterised their NC workers as unskilled or semi-skilled, all of them trained for a single machine doing a single operation such as grinding or boring. Training time was characterised as variable, depending upon the machine and whether or not the trainee had any shop background. All pump and valve firms used NC operators both with and without shop backgrounds. As in sheet metal firms, the lead hand/operator division was strongly in evidence; in fact used in all pump and valve companies. But in only one firm were the senior operators permitted to modify or edit part programmes. While modifications to the speed and feed of cutting, grinding, etc. is essential to deal with the variable qualities of castings (thickness, density, hardness), in two firms even these modifications did not occur without the supervision of the lead hand in one case, and the NC programmer in the other case.

Two pump and valve firms characterised their NC labour force as primarily skilled workers. One was a medium-sized branch plant of a European maker of an enormous variety of industrial valves, including specialty items for aerospace, medical and pharmaceutical, and the nuclear industries. The other plant made smaller, precision valves also for aerospace and medical applications. In both cases expensive and difficult to machine substances were worked on with higher than normal precision requirements, which in turn required more experienced machinists. In the case of the larger company, the sheer variety of valves as well as a large range of specialty items rarely allowed an nc operator to settle down to routine production of medium or large batches. Apart from these two cases, NC operators in this sector tended to be the least skilled in the entire sample, in terms of length of training and amount of involvement in programming.

Variations in NC operator skill level, in relation to firm size and date of first NC acquisition, are summarized in Tables 5 and 6 (pp. 283-284). The patterns displayed there reflect the weight of the different branches of engineering and metalworking in affecting skill deployment patterns. Thus sheet metal and pump and valve firms are

Table 5: Firm Size and NC Operator Skill Level for Whole Sample *

Firm Size	Unskilled/Semi-Skilled	Skilled
Large	4	12
Medium	7 *	13
Small	5	11

* The vagueness of 11 responses on NC operators' skills did not permit categorization of the entire sample. One other plant was exploring NC technology and was not yet decided about manning arrangements.

Table 6: Skill Level and Date of First Installation

First Installation Date	N	NC Operator Skill Level: Unskilled/Semi-Skilled	Skilled
Pre-1974	37	13	21 (56%)
1975-1980	17	4	8 (49%)
1981 onward	*5	1	4 (80%)

* One firm has not yet installed NC but is considering it.

mostly medium sized and so contribute to the small proportion of medium-sized firms using skilled operators on NC equipment in comparison with large and small firms. Die and mould firms contribute to both the relatively high proportion of smaller firms using skilled workers on NC tools, and to the four out of five post-1981 NC adopters doing so. Similarly, most agricultural equipment, lumber equipment, and electric products firms are large and use skilled operators for nc work and so contribute to the greater proportion of large firms operating with this deployment. The high proportion of aerospace firms in the pre-1974 NC adopter group contributes to the lower proportion of these firms using skilled NC operators as compared with post -1974 users.

NC Operator Skills

Conventional machining skills involve the ability to set up, operate and perform basic maintenance on a standard machine tool such as a lathe or mill; to perform manual or "bench operations" such as file finishing, laying out with scribes and punches the lines and points indicating where the metal is to be machined, etc. Setting up a machine to operate on a workpiece requires the analysis of blueprints and the ability to translate their two dimensional presentation into a sequence of machining operations using the appropriate cutting tools set to the correct angle; a knowledge of the machining qualities of various metals in order to establish the appropriate speeds and feeds and tool cutter contours to produce the appropriate surface finish; an ability to use accurate measuring gauges such as verniers and micrometers and the ability to perform arithmetical and geometrical calculations in the course of setting up and machining; and finally an understanding of tolerances - the margins of variations permissible given the dimensions and shape of a given part.

The more skilled the machinist the greater the number of machine tools, metals and diverse machining operations (in terms of shape, complexity, level of tolerances, etc.) he is capable of working with. Toolmakers, the highest skill level in the machinist trade, are general machinists, able to work with all major types of machine tools, capable of designing and making cutting tools, and jigs and fixtures for special types of machining jobs, and capable of setting up and machining to higher levels of precision and complexity. The consensus among my respondents was that four to five years' general experience on a diversity of tools and machining jobs could make a good machinist from a high school or CEGEP/CAT graduate with two years' education in metal working and shop mathematics. The best of these good machinists would need at least another ten years experience of precision machining of great variety, along with close contact with manufacturing engineers, in order to become a toolmaker.

There was considerable equivocation and uncertainty among my informants when asked to specify the differences in skill required for NC as opposed to conventional machining. Table 7 (p. 288) presents the skills most often identified as necessary for NC operators. Most informants argued that the combination of mental and manual skills characteristic of conventional machining were no longer required in NC to the degree that they were in conventional machining. "NC doesn't require good machinists so much as people with good inspection skills; people who are involved and attentive, who'll be with the machine the whole time and not wander off or day dream. NC operators have to size up situations very quickly and they often have to make very fast inspections and measurements between machining sequences to ensure the programme is working," according to a programmer in an aerospace precision machine shop.

Table 7: Skills Required of NC Operators *

	Skills	Number of Mentions
1.	Understand machining sounds and sequences in order to anticipate or to identify problems swiftly.	17
2.	To be responsible, conscientious, attentive, alert.	9
	Able to use inspection equipment and gauges.	9
3.	Have an eye for surface finishes.	8
4.	To be able to judge cutting tool wear.	5
	To have mathematical ability.	5
5.	To know enough machining to be able to adjust cutting tools to compensate for wear.	4
6.	To know feeds and speeds, set-up, and how to change tools.	3
7.	To understand programming.	2
8.	To understand principles involved in tolerances.	1

* Respondents from 32 plants provided clear enough responses to be categorized as in Table 7.

In the course of these descriptions of NC skills, conventional machining skills were mentioned as a kind of monitoring or backup facility. That is, NC operators' manual machining skills were important in knowing when the programming sequence was not going correctly, at which point the operator uses the manual override to stop the machining sequence. This was nicely put by the manufacturing manager of a railroad braking equipment manufacturer. "It's hard to pinpoint any special characteristics (of NC operators). They have to show an interest in new technology, have certain intelligence, and basic shop abilities. But they're not necessarily good machinists because you have to unlearn some machinist ways of doing and thinking to become a good NC operator. But machining experience is usually an asset because you have to know what is happening in the machining sequence and spot where things are likely to go wrong or may be slightly off before they actually go badly astray. It's a matter of machinist's knowledge being a plus in preventing crashes rather than positively helping when things are going normally."

While many firms used the most skilled machinists they could obtain to operate their NC machine tools, others were doubtful that it was really necessary even as a crash prevention measure. In one precision machine shop, "We can take people off the street. Often they work out better than experienced machinists at nc. But they have to have a certain sensitivity. They have to get to know the right sound and appearance of machining going right, and they have to have an eye for surface finish." Thus firms reported that while they used people with conventional machining experience on NC equipment, these were not the "most skilled," or the "very best," or not "all round" machinists.

The clearest characterization of NC machining in contrast to conventional machining came from the engineering supervisor at a major jet engine plant in Montreal. "The major problem with NC is that it takes the art away from metal cutting. Metal cutting is both science and art. It's an art because no two pieces of metal are identical - they may have been made of the same alloy and poured from the same ladle into "identical" moulds or forged into stock of identical nominal dimensions. But there are always microscopic molecular differences which can show up in machining. That's where the master machinist can show his stuff by compensating for slight differences to produce the same piece over and over again, with the same sizes and surface finish. In NC machining an identical programme runs the machine through the same set of cutting operations for every piece. This can mean that you can get inexplicable events - failures to meet tolerances, sub-standard finishes, distortions, etc. that just shouldn't be there. The programme is right, the machine is fine, the operator has done his job, but the result are still substandard, and no one can figure out why."

While this informant, along with many others, was able to describe clearly the skills involved in conventional machining, the skill content of NC machine operating remained unclear. The operations manager of a printing machinery plant (brought in to return the branch to higher profit levels and scathingly critical of the recent managerial decisions, including the way NC equipment had been adopted and deployed) expressed some very firm ideas about what characteristics an NC operator should have. "You have to have someone with the full deck of smarts, preferably an experienced machinist or set up man. But you can train workers from Macdonalds, at least for three axis or less machining. In any case you can't nickel and dime the training of NC operators...There is no way to save money on this point. Also you can't use foremen as trainers because this takes them from their other responsibilities...

There is no middle ground...NC machine tool operators have to have the right attitude because with NC machining higher quality and higher volumes of production are at stake, which means breakdowns cost more. So you need people who are alert and know what they are doing, who have a sense of responsibility. They need basic mathematical aptitudes to understand cutting geometry, understand feeds and speeds, and tolerance and finish relationships. They should have some inspection measuring skills as part of this knowledge but this is minor if you have programme integrity and adequate machine maintenance. They don't need to know anything about programming."

In this description the knowledge of machining - cutting geometry, feeds, etc. - is not required in order to undertake any machining itself, but in order to be alert for signs of trouble in the machining parts programme. In this way NC technology introduces into machine operating the stochastic qualities of work characteristic of oil and chemical and nuclear power plants. That is, there are long periods of routine activity and occasional, though unpredictable and usually brief, periods of very intense activity when something goes wrong (Blauner, 1964, pp. 132-136). This aspect was clearly expressed by the production manager at a large valve and pump firm. "The person on an NC machine is not just a puppet. nc increases the number of tools operated in a single machining sequence so tool quality detection is extremely important. It needs a highly conscientious, attentive worker with open eyes, sharp ears, a quick mind and reaction and sure movements. nc tools are machines without mercy - if anything's slightly off it will produce a mountain of scrap."

Where reference was made to the deployment of skilled machinists to man NC machines, it was often qualified by suggesting that such machinists were a second echelon group, rather than at the very top skill level. This was brought out when one informant described the learning experience his company went through in matching skill levels and NC operations. "Our major problem with NC was in believing the vendor's claims that is was a push button technology. This created false expectations that we could use unskilled workers but this just didn't work out. Then we went the other way and put on expert machinists. But they didn't feel involved enough in the actual machining processes. Ultimately we found that NC often does best with people who have some machining skills but not the best. People who have a large sense of responsibility towards the controls."

Another company also went through a variant of this process. "At first we picked the best all round machinists because the equipment was being used for the most complicated jobs and it was expensive so we wanted it maintained properly. But we found general machinists found the work too easy once they picked it up and they didn't want to be stuck with just one machine. Over the years we've moved over to using these men as set up, tape proofing, and maintenance people, and kept them happy by moving them around to different machines for variety. The NC machines, once they're set up and running satisfactorily are operated by machinist operators with less experience. Usually they've just been trained for one type of machining only."

I have quoted a couple of informants who referred to the "unlearning" which was required of conventional machinists when they became NC operators. Part of this unlearning consisted of adapting to the higher speeds and heavier cuts NC machinery makes. A programmer at a pump and valve plant commented, "I find that people used to conventional machining with manual controls can get scared by the speed and heavy cuts the larger nc equipment operates with. Some of the best people, in terms of making the switch from conventional to NC equipment are ones who've worked with automatic machinery, unloading and loading it. Automatic machinery is usually fast and heavy in its action just like nc, so people who've worked with it aren't so scared of nc's action." Another informant suggested that this probably affected all levels of shopfloor personnel. "With the introduction of NC for the first time, it's very hard to get management, unless they're engineers, foremen and operators to break with conventional machining habits and ways of thinking. Management doesn't understand NC's impact on capital accounting...Foremen and operatives are used to cuts and chip qualities of conventional machine tools, and find the heavy cutting producing red hot giant chips terrifying. It is very hard to get used to, and it leads to dialing down speed and feeds on NC tools so that they cut like conventional tools."

Informants from companies who reported using the best machinists for NC operators, usually specified their jobs as including setting up the machine prior to operation, inspection of tools, adjusting tools for wear, proofing and editing tapes, and inspecting the first part produced with a new parts programme. Such activities, apart from proofing and editing are, of course, identical in conventional or NC machining.

That the NC skill component, apart from programming, proofing or editing, is largely monitoring is also suggested by two other themes in my informants' discussions of NC skills. First, many informants referred to the need for mathematical and conceptual skills. This was most positively affirmed at a jet engine fabrication and repair shop. According to its supervisor of engineering their NC operators "...need to have rather different skills from conventional machinists. They need higher education concerning engineering principles, they have to be smarter in the head rather than smarter in the hands. This means that NC operators have a <u>different</u> set of skills not lesser skills." However, NC operators at this plant were characterised as semi-skilled; their machining skills were tied to one machine, rather than being all round skills; apart from knowing how to proof the parts programmes, they were not permitted to alter speeds and feeds or undertake any programme alterations. The operator's knowledge of tooling, metallurgy, and machining dynamics were held to be important so that they could identify and report problems clearly back to the programmer. This theme of knowledgeable watching - "they have to know what the v.d.t. means in machining terms," "they have to understand what's going on at the cutting point," "they have to understand what the control settings mean for the machining process" - was the predominant response to questions asking for characterization of the specific skills and abilities required of NC operators.

What emerged from these responses was a picture of NC operation (as opposed to programming) as fundamentally a monitoring and loading job. This is supported by a second theme in these responses -- the degeneration of conventional machining skills among machinists who specialise in NC machining. The steel plant shop foreman noted this problem. "We realised that NC is not everything and that it had its own problems. Because the machines are smart, they duplicate human skills. You can have a deterioration of human skills in the shop so that if you have a special job requiring work on conventional machinery it won't be as high quality as it should be. So we try to keep people rotating between NC and conventional machines, and also try not to use the NC machines where conventional machines do the job." A machine shop supervisor at a flight simulator manufacturing plant suggested that this was especially a problem with average rather than the best machinists. "A fine conventional machinist operator will turn out to be a fine NC operator. But sometimes a not so good conventional machine operator will turn out to be a very good NC operator. But if you took that NC operator and put him back on conventional machining, he will have lost what conventional machining ability he had."

All of the programmers with machining experience, and the few NC machinists with conventional machining backgrounds I did manage to interview, agreed that NC machining was simpler and that, unless you were allowed to program and enjoyed it, was less interesting and involving than conventional machining. As one who had been promoted to process planning pointed out, "Conventional machining is more satisfying because you control not just the feeds and speeds but the sequences and techniques used." An ex-toolmaker, now manufacturing director in a precision machine shop, was even more pointed in his comments on the technology which he claimed he had boosted in the early days of his tenure with his firm. "NC technology relies very heavily on process planning which is the area of technical management's responsibility. And the use of NC really shows up any shortcomings and ignorance in the office; you can't blame the poor bugger on the floor, he doesn't know what's going on with this machining technique. The NC operator is a captive to the machine, paid for the responsibility of watching over an expensive machine. He doesn't really have to know about feeds and speeds, although he does have to know the tools, their cutting characteristics, chip quality, sounds, and be able to judge the appearance of the cut and surface finish. But it's really a watcher's job - it needs alertness, basic intelligence, not the old craft skills of the conventional machinist or toolmaker." Of course, this and the other ex-machinist comments on NC operators were made by very skilled and upwardly mobile individuals who might be overemphasizing the gap between NC and conventional machining skills.

In those instances where NC operations were clearly "push button" applications, management judgements of NC operator skills were unequivocal. As a pump and valve firm's manufacturing engineering manager put it, "NC workers are no different from other workers in the sense that they don't really have to have any special skills or aptitudes. We have operators of NC equipment with both machining background and no background at all; a couple are just guys straight off the street. Our NC operations are almost entirely loading and unloading. The operators have to inspect the parts so they have to be able to use gauges and do the basic math involved in that kind of measurement. We do have a couple of guys who can work any machine in the shop. We also have some more who can only work NC and can't use conventional equipment at all."

Sheet metal firms were very clearly cases where operator skills, whether on conventional or NC presses were not very extensive. Two owner-managers' statements indicate this situation very clearly. The first, commenting on the labour force in sheet metal generally said, "This is an area where jobs are 'grunt jobs,' so we get people with less than high school graduation. You can't move up beyond lead hand in most small firms, and in sheet metal most are small. So we have problems in getting all types of labour. It's very hard getting people with skills, training and motivation to work and stay with the company. People are much more for themselves and not interested in working for the company."

The owner-manager of a much larger firm, reported to be among the technical leaders among sheet metal plants in Montreal, characterised his experience with obtaining and training NC operators as follows, "We have no great difficulty in training NC operators. Basically we take guys out of school or off the street and work with them, showing them how to load programmes, load the stock, work the CRT (cathode ray tube) display, etc. It's mainly a case of showing them the right buttons to push at the right moment in the production movement. It's best to take young guys from the street and teach them how to push the buttons. You don't want people who are too educated or too intelligent because they won't stay with the job. But they have to be responsible because it easy to do damage and produce a lot of scrap in a short time, so they have to pay attention."

Labour Force Skill Training

During the course of discussing the labour aspects of nc technology many informants spoke of labour shortages and current problems with skill training arrangements. Informants from 33 companies (55% of my sample) mentioned that they were currently experiencing labour shortages. Seven larger companies pointed out that any labour shortages experienced in the past had been "solved" for the foreseeable future by the recession and lower market growth rate of the eighties. Two informants from these companies, however, foresaw difficulties at some point when significant numbers of their current skill complement reached retirement age.

Table 8 (p. 302) presents these responses in terms of

Table 8: Firm Size and Skilled Labour Shortages

Firm Size	N	No. of Firms Reporting Labour Shortages	
		In the Past	Currently
Large	16	1	7
Medium	23	2	9
Small	21	2	17

current and past labour shortages and firm size. It clearly shows that labour shortages increase greatly the smaller the size of the firm. Small firm managers were acutely aware of their predicament. According to the production manager of a small precision machine shop whose labour force was primarily made up of recent Portuguese immigrants, "We are a small company and don't pay top wages. So we lose people or are not applied to by the best workers in the field." The inability of smaller firms to either attract workers or to retain them for long was a common complaint. Thus the owner-manager of a small precision machine shop doing largely aerospace subcontracting, "It's hard to get all categories of labour. No one seems willing to take unskilled jobs. The government makes it too easy to stay on U.I.C. and welfare. The semi-skilled and skilled people we train to do a variety of machining, and as soon as they think they know something they leave." This and the comments of the owner-manager of the sheet metal firm on the selfishness of contemporary workers are typical of the outlook of owner managers of small enterprises I interviewed.

Non-owning management in small firms, and larger firm management, however, attributed labour shortages to other factors. Manpower training was viewed as a significant problem by Quebec respondents but not so by those in Ontario. Several of the former pointed to a combination of historical and political factors which have contributed to this. According to a printing machinery plant manager, "Personnel and skill problems are persistent in Quebec for two reasons. One is the very low levels of education of the population. It is slowly improving with the C.E.G.E.P. system but it's still way below the general levels of shopfloor personnel in the Midwest let alone the U.K., Switzerland and Germany. This is reinforced by language barriers. Engineering is English language dominated - we're so close to the U.S. this would be the case anyway. The language laws impose costs not borne by anyone else in North America." (3)

The English educated NC department director at a large satellite communications firm saw the major labour problem for his firm as the "terrible provincial shortage of skilled machinists, tool designers and programmers." Three informants with experience in the United States characterised on the job training by Canadian companies as inferior to that of the United States. There was wholesale unanimity that no training programme in the province matched those producing European tradesmen. Experiences with C.E.G.E.P. students appeared to more negatively viewed than experiences with C.A.T. students in Ontario firms, although no one seemed able to explain exactly where the problems lay.

Tables 9 and 10 (pp. 306-307) present the rank order of skilled labour group shortages and the rank order of engineering and metalworking sectors reporting shortages. Even though my interviews focused on NC technology and its labour implications, the overwhelming labour shortage perceived by management was that of skilled conventional machinists. All of the NC related categories together (programmer, NC operator, NC maintenance) were mentioned only half as much as the need for machinists. Overall non-nc related skilled labour was mentioned far more than NC related skill problems. This pattern suggests that NC technology is not currently either a skill demand generator or a skill displacing technology. The weak effects of NC technology on the demand for skills is further evident in the sectoral pattern of manpower shortages. Those sectors using high level tradesmen -- mould and die, and agriculture and lumber equipment firms -- uniformly experience shortages of these skills. Sectors characterised by small firms with

Table 9: Types of Skilled Labour in Short Supply Currently

Skill Type	No of Mentions
Skilled Machinists	19
NC Programmers	4
Skilled Labour in General	3
Tool and Diemakers	3
Maintenance Men for Conventional Equipment	3
Experienced NC Operators	3
NC Machine Maintenance	2
Press Brake Operators	2
Welders	1
Tool Designers	1

Table 10: Rank Order of Current Skill Shortage by Sector

Sector	Firms Reporting Shortages	Total in Each Sector	Percentage of Firms With Shortages
Mould and Die	6	6	100%
Agriculture and Lumber	4	4	100%
Aerospace	9	15	60%
Pumps and Valves	3	5	60%
Sheet Metal	3	6	50%
Industrial Equipment	4	10	40%
Electrical	3	8	37.5%
Transportation	1	6	17%

lower pay scales such as aerospace, pumps and valves, and sheet metal also have a high proportion of firms experiencing labour shortages. Sectors characterised by larger firms paying higher wages and using smaller proportions of skilled labour in conjunction with semi-skilled operative, experience less intense levels of skill shortage.

Engineering and metalworking is characterised by quite intense business cycle fluctuations, organizational instability (4) and variable levels of employment. Several informants noted these as factors which made skill shortages inevitable in their industry. The railroad freight car project manager argued, "Any difficulties in labour supply is related to the boom and bust nature of this industry. Everything else is incidental. When times are good everyone in Hamilton is looking for experienced workers. When times are bad you can't keep everyone on and we lose good people. So shortages are just part of the cycle." However, most of the larger companies who mentioned significant layoffs of their skilled workers between 1982 and 1984, also said that many of these had either been recalled or were maintained on waiting lists should the company expand the labour force. The small and medium firms were not able to do this - for them, the loss of experienced workers was permanent, and replacements at an equivalent level largely a matter of luck.

Despite the unsatisfactory nature of skilled labour supply, less than a quarter of my sample (14 firms or 23% of the total) were operating any formal training programme. This is shown in Tables 11 and 12 (pp. 310-311). Six firms, all large, had discontinued apprenticeships and other formal programmes with the onset of the 1982 recession. Small firm informants argued that their size mitigated against the organisation of training courses. However, several small precision machining shops and mould and die firms did emphasize informal, on the job training of a systematic sort, and appeared concerned to ensure that their workers obtained all round machining experience. One ten man firm set aside one day a month as a designated teaching day; and two others arranged evening sessions when workers and technical management discussed technical production issues such as tolerances, edm work, etc.

All of the large firms characterized their training programmes as involving only small numbers of trainees, and focussed on very particular areas of skill. (5) The steel company was one of the first to drastically reduce its

Table 11: Formal Labour Training by Sector

Sector	No. of Companies Reporting Formal Training Arrangements: Currently	Discontinued	No. of Firms in Each Sector
Aerospace	3	1	15
Electrical	2	1	8
Sheet Metal	1		6
Mould and Die	2		6
Pumps and Valves	1		5
Agriculture and Lumber	2	1	4
Industrial Equipment	0	2	10
Transportation	3	1	6

Table 12: Current Training by Firm Size

Firm Size	No. of Firms Reporting Formal Training Arrangements	No. of Firms in Size Group in Sample
Large	9	21
Medium	2	23
Small	3	16

apprenticeship programme. This occurred in 1970, in the midst of skilled labour shortages and the move to adopt NC technology in order to reduce subcontracting. However, it was argued that the labour costs after the 1969 strike settlement had increased substantially and the apprenticeship programme was one area where reductions could be made without further labour strife.

Most medium and large companies exhibited a highly cost conscious attitude toward labour training. Informants from these companies claimed that informal training by pairing off lead hands or experienced workers with less experienced workers and putting them on a particular job together was the most efficient, flexible and inexpensive system. While several informants regretted immigration regulations which had stopped the inflow of European tradesmen, no one proposed that Canadian government and business should develop an extensive formal apprenticeship system. In the current economic climate of high risk and low growth, the general position on skill training was one of improvisation with the resources at hand and not any initiative requiring major resource commitment.

Conclusion

By probing labour deployment issues I intended to discover whether or not the spread of NC technology was associated with patterns of manning indicating the replacement of highly skilled workers by less highly skilled workers. Several findings emerged which are difficult to interpret in terms of the labour process theory. First, no single pattern of skill deployment was found to be associated with NC use. Generally, high skill operations such as tool and die and mouldmaking used NC as an extension of craft skills, while low skill operations such as sheet metal stamping used NC as another variant of semi-automatic machinery tended by semi-skilled operatives. Larger firms in particular used lead hand-follower or setup machinist-machine operator skill subdivisions to enable NC machines to be operated by less skilled workers. However, such shopfloor arrangements originated with conventional machining and has been continued with the use of NC equipment. The evidence suggests, then, that the spread of NC technology throughout engineering has not been accompanied by a homogenization of shopfloor skill levels.

Second, there was considerable disagreement among my informants about how much skill was involved, and what was the nature of the skill associated with NC operations. However, those informants who characterised NC operation as relatively unskilled did emphasize that workers with a high sense of responsibility were required because of the sensitivity, complexity, and expense of NC equipment. This is an aspect of changing labour force requirements which is often overlooked by labour process writers. It is important because the need for employee responsibility in relation to expensive capital equipment undermines the relevance and effectiveness of authoritarian management practices and also gives labour some bargaining power.

The third labour deployment aspect analysed was that of skill shortages. nc technology did not generate significant skill shortages. Nor did it solve traditional engineering skill shortages of welders, toolmakers and skilled machinists. This suggests that the technology is not, and probably cannot be, introduced to decrease the engineering and metalworking industry's dependence upon various categories of skilled labour.

A labour process writer might respond to the foregoing analysis by arguing that the impact of NC diffusion has been limited because of the strength of the unions in Canadian engineering firms and also due to strong shopfloor resistence to technological change. The evidence for this argument is explored in the following chapter.

Footnotes

1. In the absence of a European style industrial apprenticeship system, the criteria of skill level in engineering and metalworking were often quite vague among my informants. Some informants with European training dismissed all Canadian metal-workers as semi-skilled. Others proposed four to six years on the job experience as their bench-mark without specifying what the content of that experience should be. Still others suggested two years trade school or community college shop courses combined with three to five years job experience as their criterion defining skill. The distinction between unskilled and semi-skilled work was also hard to pin down. Semi-skilled work was often identified less in terms of skill level than as a certain minimum standard of responsible and conscientious behaviour. In analysing the responses to my questions about skill levels I used the following delineations: NC operators described as having no machine shop experience, or as being hired straight from vocational high schools, CATs and CEGEPs, I categorised as unskilled; operators described as "skilled machinists," "experienced machinists," "experienced NC operators," or as "tradesmen," were categorised as skilled; operators described simply as "operators," "one machine specialists," "not the best machinists," etc., were treated as semi-skilled.

2. Much of the skilled machining in this plant involved the fabrication of many different types of gears. This is a specialised branch of machining which has only recently witnessed the development of NC tools. Prior to this development, gear making was most certainly a high skill area of machining. Even with this development the machining involved in gear box and transmission assemblies for aircraft is a high

precision process and, because of the complexity of assembly of the entire unit is likely to remain one in which skilled labour is prominent.

3. Two Francophone informants also suggested that Quebec's language legislation added unnecessary costs to engineering businesses in the province. One pointed out that English language competence was an entrance requirement for the engineering graduate programmes at most ~~major~~ French universities. The other maintained that French technical literature was too obscure to be used in Quebec because of the acceptance of American-English terminology. An Anglophone informant said, "Sure we have a language problem; most of our people don't speak either English or French!"

4. 9 of the firms in my sample either had experienced or were undergoing major organizational changes such as denationalization, takeover by another firm, major rationalization of production, appealing for government funding to ensure survival, and close escapes from bankruptcy. 30 firms had had to lay off workers during the 1982-84 recession.

5. Most often mentioned training areas were welding and tool and die work. Only two companies mentioned some organised training of NC operators beyond the on-the-job systems described here.

Chapter 8: NC Technology and Labour Relations

Introduction

Braverman's labour process theory is intended to explain the design of modern production organization and the effects of technological change in terms of management's concern to weaken the bargaining power of labour. As a Marxist he views industrial relations as an arena of class conflict. However, his primary aim is to document the underlying class rationale in management ideas and actions and he does not investigate labour reactions to changes in the labour process (1). He believes though that "... the hostility of workers to the degenerated forms of work which are forced upon them continues as a subterranean stream that makes its way to the surface when employment conditions permit, or when the capitalist drive for a greater intensity of labour oversteps the bounds of physical and mental capacity." (1974, p. 151).

For Noble, Wilkinson and Shaiken also, the adoption and diffusion of NC technology is inextricably linked to industrial conflicts arising from labour's attempts to gain autonomy in the work process and management's attempts to control it. While Noble emphasizes the most dramatic trades union actions in defence of established work routines, job classifications and pay systems, Wilkinson and Shaiken explore a variety of cases of less dramatic disputes over the deployment of new technology which continually modify the "frontier of control." If the labour process theory is correct, then, it is probable that the diffusion of NC technology has generated some significant industrial conflict. The evidence presented in this chapter, however, does not support the labour process theory, for while some industrial conflicts have occurred they have been neither as intense nor concerned with the issues which would be predicted by labour process theory; issues such as the retention of NC programming as part of the NC machine operator's responsibility, for example.

My interviews sought to probe for the management awareness of various kinds of labour reactions to the adoption and utilisation of NC technology ranging from formal union actions through informal problems of individual unwillingness to retrain or to transfer from conventional machinery. Apart from receiving the occasional National Citizens Coalition style sermons on the evils of trades unions and the welfare-support system from some owner managers of small shops, I found the rest of my informants discussed labour relations issues frankly and with equanimity. The following rather tranquil picture of labour relations in relation to changing technology is assumed to be, then, an honest reflection of industrial relations in the engineering and metalworking industries and not a distorted, purely managerial image (2).

Unionism in the Subsectors of Engineering

Tables 1 and 2 (p. 320) show the levels of unionisation (in terms of proportion of firms with unions) within each subsector and according to firm size. Unionization was directly associated with firm size. Hence, those subsectors with large plants (over 500 employees) -- transportation, agricultural and lumber equipment, and electrical products -- had higher proportions of unionised plants than sectors characterised by small and medium firms such as sheet metal, pumps and valves, and die and mould shops. Table 3 (p. 321) is a list of the 8 of the 36 unionised firms where some form of labour resistence or dispute occurred in connection with the use of NC equipment. Most of these disputes concerned issues of job classifications and job responsibilities; none involved any significant outbreak of industrial conflict.

Table 1: Unionization by Engineering Subgroup

Subgroup	Number of Unionized Firms	Number of Non-Union Firms	Percentage of Union/Non-Union
Aerospace	8	7	53%
Electrical	6	2	75%
Sheet Metal	3	3	50%
Mould and Die	1	5	16,6%
Pumps and Valves	1	4	20%
Agriculture and Lumber	3	1	75%
Industrial Equipment	6	4	60%
Transport	6	0	100%

Table 2: Unionization by Firm Size

Firm Size	Number of Unionized Firms	Number of Non-Union Firms	Percentage of Union/Non-Union
Large	15	1	94%
Medium	15	8	65%
Small	4	17	19%

Table 3: Firms Experiencing NC Related Labour Unrest

Type of Firm	Labour Dispute
Large steel producer	Initial concern over skill level of NC workers, manning ratios, who would program, rights of older workers. Currently manning ratios are up for renegotiation. All issues in the past settled by negotiation.
Medium sized sheet metal plant	Initial concerns over potential layoffs, job descriptions, who would program, rights of older workers. Some labour shifted to other departments, informal and flexible programming allocations. All issues settled through negotiation.
Medium sized industrial conveyor manufacturer	Initial concerns over NC machining job description as a non-bonus payment job. Resolved by negotiation resulting in upward revision of base pay for NC work.
Small pump and valve component firm	Initial concern with rights of older workers to remain on conventional machining jobs.
Large aerospace firm	Union has always expressed concern that NC technology part of a labour saving strategy on the part management. In fact employment has grown continuously despite the 1980s recession.
Small jet air engine parts and repair plant	Union insists on strict job classifications and has resisted any moves to enlarge NC machinists' responsibilities to include programming.
Large aircraft engine manufacturer	Shift to a more sophisticated programming language led NC workers to demand additional training. The trades union did not support this demand, the company moved slowly to meet the demand. Dissatisfaction persists over the elementary level of the training provided.
Large sheet metal and pipe plant	Union reported to be very active in "policing" job classifications whenever new equipment is introduced. Such issues have been resolved by union-management negotiations.

Three of the disputes were not satisfactorily settled, or were only precariously resolved and could emerge as the source of future conflicts.

In the preceding chapter I discussed the considerable variation in NC operator involvement in editing and programming. Manufacturers and vendors of NC equipment have consistently emphasized "programme integrity" (i.e. programming as an "office" and not a shopfloor function) and therefore management control as a positive aspect of the technology because it increases management and engineering control of the actual movements of the machine tool cutters and potentially requires less skilled operators than conventional machining. In practice, however, such a clear division of labour between shop floor and office has not emerged, and a variety of compromises with shopfloor programming have developed. For the labour process writers, control over parts programming was at the heart of most disputes over the deployment of NC equipment. I too found that programming responsibility was the most controversial issue, but the disputes simply did not conform to the labour process descriptions of managerial attempts to control programming confronting labour's attempts to evade or to impose their own controls.

I have cited the steel company's process of NC adoption in detail. My informants in that plant pointed out that the initial adoption occurred shortly after the resolution of the 1969 strike and was met with some suspicion on the part of the union. The planner indicated, "The major problems have focused on job definitions and manning. The latter has been less of a problem because so far we have held to a one machine-one man policy consistently, although we may be forced to change this with the continuing tough times. Each new machine was explained to the union when we were considering its installation. We were lucky in that our NC programme took place during a period of an expanding market and growing workload, so there were no problems with the union around this."

The initial concern of the union was that NC machines would lead to a dilution of the machine shop's workforce with semi-skilled operators, and union representatives demanded that both operating and programming be consolidated as the operator's responsibility and that the operators be skilled machinists. After some negotiating which, as was indicated in Chapter 6 was made easier by management's own tentative position on NC deployment, it was agreed that NC machine tools would be manned by skilled conventional machinists, but that programming would be a staff function, carried out by personnel recruited from machinist ranks.

Subsequent NC acquisitions followed with routine union-management consultations. The last acquisition -- a CNC lathe -- reinforced the management's view of the need to retain control of programming. "Our last NC machine, a shaft lathe, had a built in processing post so that it raised the question once again whether it should be programmed by the operator or by staff. We didn't feel comfortable about the operator controlling the machine productivity we had paid for. But we did an extensive survey of various engineering plants to see what happened when operators programme. We found that where workers programmed they programme the machine for far lower feed and speed rates than the machine's optimum. We also found that in all production situations, post-processing was not used for programming, which was done off the floor so that the production was controlled. But in small shops with lots of short run custom jobs, where workers were very close to the management, shop floor programming made sense. Ours is a massive plant with a lot of production at stake, so we went the production route."

The steel company informants were acutely aware that their NC policies had worked out well because the equipment had been installed during a period of great demand pressure, and at the same time to ensure greater self-sufficiency from subcontractors. This meant that it was easy to sell to the union as a job saver even should times get harder. "When we made the decision to go NC nobody was thinking of personnel reduction. It was an expanding market. We were overloaded with work, but we also wanted to reduce our subcontracting by bringing work in house. This was similar to a lot of other firms going NC at the time. Now conditions are different and labour shedding is important. We are probably in a good position to cope with labour by attrition. But this leaves two problems: one, everyone is frozen in the position they hold now, so there's little advancement open; second, later on due to the age blocks we have, attrition may not be possible. The other personnel consequence of NC is that we use our older workers and those experienced but with health problems better in set up operations, tool inspection, and maintenance." The last reference to the deployment of older workers was interesting because a recurrent theme in my informants' discussions of the labour aspects of NC was the problem of older workers who were reluctant to learn to work with the new machines.

Management in larger firms with union protection for long service employees often mentioned this as virtually the only real personnel problem they had experienced in connection with nc adoption and use.

The experience of the steel company contains almost all of the labour related NC issues I discovered in my sample -- job classification, programming responsibility, the future of older workers, and whether or not NC technology would lead to layoffs. While job classification disputes occurred, in no instance were such disputes particularly intense. As the production manager of a large steel fabrication plant using NC punch presses observed, "We usually have arguments over job classifications every time new technology is introduced, but nothing really serious and it's usually resolved through a management-union committee process. With our union we have normal conflict, nothing more."

This aptly sums up the job classification disputes I was referred to. Thus the NC shop supervisor at a custom sheet metal factory found that NC disputes tended to decline with management and labour experience with the technology. "In the early days there was a lot of trade union suspicion about NC machine tools. Both management and workers were new to it and didn't understand the technology. A lot of false claims were made that NC machining was pure button pushing. The unions thought these claims were a snow job and weren't happy about losing programming. We 've all found out that more manual skills are required for nc operation anyway, and this has made things easier about the programming issue." Earlier this same informant had characterised programming as a "grey area" in his plant where most jobs were centralised in the office, but small jobs were done on the shopfloor. Again there were some manpower deployment problems arising from the use of NC equipment. "Some of our oldest workers were sometimes reluctant to get involved with mere push button operations. This, combined with union insistence on protecting seniority criteria, meant that it was sometimes hard to fill jobs. But generally labour deployment hasn't been a frequent or repeating problem here."

While the labour process writers describe many instances of workers fighting to retain control of NC programming, I found two instances where the union was either opposed or indifferent to this control. The former case was that of an aircraft jet engine parts fabrication and repair plant. "The union hasn't been opposed to technical change such as nc as such. Probably because it's not a production instrument and so it isn't job threatening. On the contrary we couldn't survive in today's market without it. What they are strict about is keeping to the agreed upon job description. The programmer here is a good case in point. He was hired as an experienced NC machinist and after probation became a lead hand. He knew more about programming than anyone on the shop floor and was the only one we allowed to edit programmes. But this violated the machinist's job description so the union stepped in and told him either to be a regular machinist like everyone else or else become a programmer. Rather reluctantly he got into the programming end and has done really very well for us" (3).

This aircraft plant used semi-skilled operators on its nc machines so it might be argued that the union supported classification code reflected the interests and concerns of operators rather than skilled tradesmen. However, another aircraft plant, manufacturing transmission drives and components tried to expand the responsbilities of skilled gear grinders by giving them programming responsibilities when CNC gear grinding machines were installed. Although the programming was relatively simple the operators tied up the foreman with questions and checks so that he couldn't do his job properly. Consequently shop floor programming was ended. The union was passive throughout this experiment. "The union didn't raise a peep either way -- when we included programming with grinding, and when we took it back." A similar "job enrichment" incident where programmable inspection devices were introduced into the inspection department also failed, again with no activity either in support of or in opposition to it by the union. My informant suggested that the reasons for these failures were related to the size of the plant. "It would have worked out differently in a small shop where management is really almost part of the shopfloor team and the atmosphere is different. Our plant is too large, so everybody just gets by and does his job and no more."

One other instance of some labour unrest about a company's policy on NC programming might be interpreted as a case of craft consciousness. A major builder of engines for helicopters and small commuter aircraft changed from an older, manual-based parts programming system to the industrial standard COMPAC II three years ago. The latter works from parts geometry rather than the earlier system's method of calculating all major dimensions for each operation. COMPAC II is faster, much easier to programme, less error prone, and excellent for families of parts, nesting parts, or complex contours, according to the programmers I interviewed. But it is very analytical and requires learning the programming language in order to understand it. According to one programmer the operators found they could no longer understand what was going to happen at the machine. They were extremely uncomfortable with ~~this~~ and tried to get the union to support their demand for management to arrange programming training for them. However, the union did not support this demand on the grounds that programming was not part of the operator's job description. A year passed by before the company provided a course for the operators on the basics of COMPAC II programming. According to the programmer, "By then the smart guys had figured it out anyway."

Somewhat divergent accounts of this episode were given to me by a staff programmer, a foreman who was an ex-shop steward in the NC machining section, and an ex-nc machinist recently promoted to the Process Planning Department. The programmer and machinist suggested that the changeover in programming methods had generated a lot of dissatisfaction among the NC operators to which the union refused to respond at all and management only slowly. The foreman agreed that while there had been anxiety and unease with the changeover, this was not the main source of the problem. He suggested that the dissatisfaction was greatest with the programming course provided by management. Both the foreman and the ex-machinist had taken the course and agreed that it was so simple every NC operator had already learned more in the course of the year merely by running the machines. What frustrated the operators was that the course did not adequately explain the programming language. However, since the union would not get involved the frustration never crystallised into any organised shop floor action. Again this case is interesting in that the union operated with a rigid adherence to the negotiated job classification arrangement while the NC operators were uncomfortable with the narrowing of their job activities which occurred with the change to COMPAC II (3).

The Reasons for Industrial Peace

I should like to conclude this chapter by discussing why NC technology has diffused in my sample with relatively little labour resistance or turmoil.

Probably the major reason why the spread of NC technology in Canadian engineering and metalworking industries has produced so little labour unrest is that it has not had any major labour displacement effects. My informants were unanimous that product demand was overwhelmingly the most important determinant of employment in their industries. In only three cases was there any reference to labour reductions following the adoption of NC equipment. A large industrial valve manufacturing manager estimated that "...perhaps 3% (i.e. nine employees) of our labour force were affected. But there were no layoffs; we just moved them to other operations." The manager of planning and development at a railroad freight car fabricating plant argued that, "...there is a definite reduction in labour required for production. But the major labour demand effect is rehiring fewer people after the downturn due to lower market demand. A recession outweighs technology in producing unemployment." Finally, the perforating department supervisor at a sheet metal plant thought that NC had reduced his firm's labour requirement "by a small amount."

In contrast to these cases, the majority of the sample's response was similar to the programmer at another sheet metal firm who in expressing surprise that there were no layoffs after the NC equipment was installed noted, "I thought the higher productivity would surely reduce the work force required. But it's a growth cycle. You put in nc, you get more contracts, you need more workers of all kinds."

Many informants pointed to NC technology as having increased labour demand because it made the plant more competitive by improving product quality, increased capacity to handle more contracts, shifted the company into a more complex line of parts, etc. Four managers in medium and larger firms thought that there were probably "hidden" labour increases in their companies as a result of the adoption of NC machines. That is, as the company used the NC equipment various pressure for more materials to be supplied to them, greater maintenance requirements, more programming support, subtle changes in manufacturing and design, gradually involved adding one or two people to several departments. Since these additions occur over some length of time and their relation to NC acquisition may not be directly apparent, their real source in the use of NC tends to be overlooked.

Three informants did discuss the possibility of major technologically related layoffs in connection with their plants. Two managers in two different agricultural equipment firms speculated that the severe depression in their industry would, in the longer run lead to the development of manufacturing systems which were less dependent on high labour input. Specifically they foresaw robotics technology as having a major impact on employment because their industry had certain major areas of production such as welding, grinding and spray painting which had been successfully robotised by the automobile industry.

Finally, the print machinery plant manager saw a potential reduction of about 20% in his plant's labour force if a major machine tool acquisition programme were undertaken. This, however, was not an NC related potential reduction but, "...because so much of our machinery is old and should be scrapped. We need so many skilled people to maintain it, to make it machine to a reasonable standard, and to fit the pieces together which won't fit without further work because the machines are so old." With an NC equipment acquisitions programme combined with what he considered proper preparation and reorganisation for effective NC use, this informant thought that a 40% labour force reduction should be possible in theory. However, the rest of the plant's management were not so enthusiastic about change on this scale, so this manager doubted that any of these reductions would come to pass.

In the preceding chapter I showed that NC technology has had negligible impact on employment levels within engineering and metalworking plants in which it was installed. This would account for the typical response to my question about there being any union resistance to the installation of NC equipment. One exemplar of this response was, "There has been no union objection at all. Nc production is only a part of the total operation with no major effects on deployment or employment, because the NC department does small runs, and NC has not developed into a mass production operation. In fact the increased production from applying NC has increased our need for maintenance men and for assemblers and packers." As well, NC technology has not radically altered the basic organisation of work or drastically reduced the demand for conventional skills which have been in short supply such as welding or toolmaking. Any initial fear of possibly dramatic changes in manning practices and employment levels have proved groundless so far. As all my informants said it is the level of demand for engineering products which determine employment levels and not technological changes.

Part of the reason for the level of industrial peace that I found may well have been the recency of the economic recession. There is some consistent evidence that industrial disputes decline during recessions and increase with recovery (Ashenfelter and Johnson 1969, Reese 1960, D. Smith 1972 and 1976). In this context two managers made interesting observations about the impact of the recession on their workforce. A plant manager at a medium sized steel fabrication shop in Montreal observed that during 1983 when there was a 60% reduction in the work force, "The men had an interesting reaction to the general insecurity. They worked harder than normally, Our productivity probably went up to 110%. I would have expected them to work less, to spread out the work, make it last longer and so keep their jobs, but they did the opposite." Clearly the recession and layoffs induced considerable anxiety on the part of the labour force, and each man operated as a "good," "conscientious" worker in order to reduce the risk of layoff. This behaviour occurred at a unionised plant and reinforces the interpretations of aggregrate strike data in relation to economic cycles which point out that recessions are not the time when strike activity is a rational response.

The NC shops supervisor at a flight simulator plant, also a unionised shop and in Montreal, observed that the recession had consequences for his workers' interest in NC training. "I have people demanding and waiting to be trained for nc. They have different reasons for it. Some have a real desire to know how to do it. Others see it as a way to get ahead if they have to leave this plant. Others see it as job security. This is because during the '83-'84 layoffs I retained the NC lead hand over several senior people and the NC machines were always operating while some other work stations weren't." Interestingly, this occurred at the only plant where the union was reported to be consistently suspicious of NC as a labour reducing technology. The shop supervisor's description of his workers' interests in NC training suggest that there might be a gap between the union's concerns and those of the membership.

The question remains why such factors are apparently less effective in the United States where, according to Noble and to a lesser degree Shaiken, there is considerable industrial conflict associated with NC technology. It is possible that the relative strength of the unions is greater in Canada than in the United States (Huxley, Kettler and Struthers, 1986). Consequently the greater level of unionization inhibits the utilization of NC equipment in ways which would produce significant labour redeployment or reductions. Three managers in larger firms maintained that they could maintain current production levels with labour force reductions ranging from 20% to 40%. However, they all indicated that any move to do this would be disruptive to labour relations at the plant. As the NC department director at a major aircraft manufacturing plant pointed out, "We couldn't take things that far because even before the union starts making an issue of it, funny things start happening on the floor. Mistakes get made, accidents happen, and the operators say, 'See what the machine made me do?'"

It is possible that if the persistence of slow economic growth rates and intensifying competition alters the past application methods, NC could emerge more evidently as a labour saving technology. This could, in turn, alter trades unions' attitudes towards nc. Several informants saw robotics technology, rather than NC as having more serious labour force reduction consequences. However, they also pointed out that current robotics devices are extremely expensive, and that the scale of investment necessary to produce significant labour saving effects is prohibitive precisely in a period of slow growth and uncertain economic outlook. Such conditions also inhibit the investment in the most complex forms of computer automated manufacturing.

While managers also referred to the difficulties and reluctance of older workers in adapting to NC machining, they consistently pointed to the willingness of younger workers to learn NC operations. The manager of a small precision machining shop observed that, "Younger people with technical school background are willing and interested, and want to work with NC equipment. They are taught that it is what they will be doing, and they seem to be taught that there is a prestige associated with it." An owner-manager of the shoe mould firm said that, "There is no friction or resistence to new technology. Most workers are young, in their twenties and thirties, so they expect to see changes on the shopfloor and expect to have to adapt." Other observors said that the younger workers are comfortable with video screens and electronic equipment and have an ease and familiarity with computer technology whereas older workers are most comfortable with mechanical equipment and uneasy with electronics. It is probable, then, that the wider social acceptance and uses of computers and electronic leisure devices render younger workers in engineering and metalworking at ease with and accepting of NC technology. These broader social factors were repeatedly referred to as a condition facilitating the use of NC technology on the shop floor.

Footnotes

1. Braverman's exclusive focus on managerial strategies has produced much criticism from fellow Marxists and other left-wing scholars. See, for example, Friedman (1977) and Heron and Storey (1986, Chapter 1). Wilkinson's work (1984) is also presented as a critique of Braverman through an analysis of the impact of worker-management struggles on technological change.

2. Daniel and Millward (1985) found considerable congruence between management and labour perceptions in their survey research on British industrial relations. The major area of divergence appeared in evaluations of the effectiveness and utility of grievance procedures which were most favorably viewed by management (1985, Chapters VI and VII).

3. Next to owner-managers, the technician group was the most overtly hostile to trades unions. Critical comments focussed mainly on job classification restrictions, which were viewed as obstacles to mobility through learning new skills.

Chapter 9: Conclusion

As outlined in Chapter 2, my research originated from certain dissatisfactions with both the labour process analysis of nc technology and orthodox economic innovation-diffusion interpretations of technological change. Both theories involved a one-dimensional or unilateral conception of technological adoption and use -- profit expectations for innovation-diffusion analysis, and managerial control of the labour process for the labour process school. Each theory drastically simplifies the process of management decision making in relation to technology and overlooks the constraints to pure profit maximising or labour control strategising. Each theory overlooks the complex variety of pragmatic and operational factors which management take into consideration with respect to technological adoption and use. The aim of my study was to document the existence of these constraints and pragmatic factors in order to contribute to a more adequate behavioural understanding of technological diffusion. In this chapter, then, I shall review my findings and discuss the implications they have for the analysis of technological diffusion.

NC and Labour Process Analysis

Labour process analysis has undergone much modification and emendation since the publication of Braverman's work. Much of the subsequent work has been designed to elaborate the "counter tendencies" which operate to limit the capacity of management to control the work process. Thus Wilkinson (1982) pointed to the way unanticipated technical problems with new machinery open up opportunities for shopfloor workers to "claw back" control over the production processes intended to be diverted to engineering management or to automatic control; Friedman (1977b) found periods of relaxation in management controls alternating with periods of struggle to control the labour process corresponding with changes in market conditions; Shaiken (1986) discovered cases of industrial processes which were too complex or variable to be routinised in preparation for automation or computerisation; finally, Noble (1984) found cases where union insistence on established job classifications and manning arrangements thwarted management plans for systematic automation. All these cases are brought forward to explain why deskilling and labour displacement are not as prominent a tendency in industry as Braverman's theory predicts.

However, as was pointed out in Chapter 2 none of these authors is able to present compelling evidence that industrial management generally operates with a self-conscious strategy of deskilling or labour displacement. Several aspects of my study suggest that, at least in engineering and metalworking firms in central Canada, no such strategy exists. These aspects include: i) management's reasons for adopting and using NC technology ; ii) management evaluations of the technology's impact on labour productivity employment and patterns of deployment or manning associated with NC technology; iii) management's estimates of areas of labour shortages. iv) finally, there is the evidence of shopfloor and trades union response to technological change.

i) With regard to adoption and use decisions my interviews with managers indicate that labour concerns of any sort were overwhelmingly secondary to technical concerns. That is, in all branches of engineering, and in all ranges of firm size, NC machinery was primarily acquired to solve problems of working to particularly precise tolerance levels, for coping with complex geometric contours, working with recalcitrant materials, or to overcome bottlenecks in production. Other considerations might be labelled market concerns where NC machines were installed in response to contractor demands, to satisfy changing customer requirements, to shift the company to a higher scale engineering market, to reduce scrap levels, to improve product quality, etc.

ii) Where labour concerns were mentioned (in 7 firms in connection with the initial acquisition, in 6 firms at the point of second acquisition) these were related to labour shortage conditions which made it either very costly or very difficult for the firms to expand production by using conventional machine tools. In only two cases was NC equipment explicitly installed in the hope of reducing the company's dependence on skilled labour. In both instances the "deskilling tactic" proved to be a technical failure and in short order more skilled workers were shifted to the NC machines.

Another aspect of the diffusion of NC technology which is pertinent to an evaluation of the labour process thesis is the impact of NC on employment in the plants where it is adopted. While there was a universal acknowledgement of the productivity gains inolved in using NC tools, the predominant element in this evaluation was with reference to qualitative aspects such as increased precision, complexity, high tolerances etc., rather than solely to production volume. Only four references were made to NC equipment permitting productivity to rise without corresponding increases in plant employment. In fact the weight of opinion was quite the opposite, with the bulk of the informants suggesting that because the adoption of NC operations improved the company's market position, there was an increase in the workforce required.

Moreover, these managers estimated that NC equipment involved some increased employment of skilled maintenance personnel, of parts programmers and machinists. Even at the least skilled end of the spectrum -- NC sheet metal punch press operators -- managers in such plants felt that recruitment of operators required more care to ensure a higher quality of labourer who would exercise greater responsibility in working with the more expensive nc machines.

Braverman's theory of labour force deskilling hypothesizes a homogenization of the work force as skills are fragmented and compressed to ever lower levels. While my data are at best retrospective but not chronological and therefore cannot adequately evaluate this historical hypothesis, they do suggest that, after two decades of NC diffusion, this technology has not yet become associated with a standardised labour deployment pattern (1).

There was a great variety of manning patterns associated with the use of NC tools in my sample. At the high skill end of this spectrum were NC toolmakers in tool and die shops, and NC diemakers operating NC machines, both of whom were responsible for programming and operating the NC machines. The next highest skill level were polyvalent or general machinists running NC equipment in agriculture and lumber equipment firms, some electrical goods, industrial machinery and a few aerospace plants. These workers undertook the tasks of editing and proofing programmes, worked closely with programmers in the development of programmes, and at times did programming themselves. In all these cases the products were small batches of complex units, with many subcomponents requiring strict accuracy for problem-free assembly and functioning. The programming office existed to ensure that engineering specifications were strictly adhered to.

At the next skill level, that of specialised machinists, the shift system operated where the more experienced first shift operators set up the machines and did the tape proofing and editing for the second shift operators who then only had to load and unload the machine. There were several variations of this system, including lead hand-follower, buddy systems, etc., most of which were quite informal. In these situations control over machine programming was a grey area. Where parts were judged to be simple and with tolerances relaxed, programming often occurred on the shop floor by the more experienced machinists. Where parts were complex, used expensive materials, or were part of a very restrictive contract, company technicians in the Process Planning or Programming Departments controlled the programming. However, in several instances I found illicit shopfloor programming despite management's expressed policy of "programme integrity." In all these cases, ex-machinists or toolmakers had been promoted from the shopfloor as programmers and maintained "collegial" relations with shopfloor machinists so that knowledge of programming was widely diffused.

At the least skilled level -- operators in sheet metal, pumps and valves and certain large batch airframe manufacturing plants -- no programming or editing by the NC operator occurred.

Such deployment patterns suggest that there is no common manning arrangement required by NC technology, and that management have not used the spread of the technology to impose one ; that plants with concentrations of highly skilled workers such as tool and diemaking will continue to employ such workers in conjunction with NC machinery, while sheet metal and other plants with low skill workers will continue hiring at this skill level for NC operators. The existence of illicit arrangements undermining "programme integrity" provides yet another reason for thinking that the formal principle of managerial control over this key part of the NC labour process is not an inevitable accompaniment of the spread of NC.

This lack of management control, moreover, probably owes its existence and likely persistence at least as much to inefficiencies and costs of strictly imposing the policy as to craft consciousness of metalworkers. Future research, then, may discover deskilling at the formal organisational level represented by management rhetoric, flow charts and organizational definitions, while skills at the shopfloor levels may have continued at the same level or even expanded.

iii) The persistence of engineering management's references to shortages of particular categories of skilled labour suggests that NC has not reduced the demand for the traditional groups of metal working skills such as welders and toolmakers. Moreover, the spread of NC has not generated much demand for new skill categories such as NC programmers or NC operators. While the intensity of labour shortages varies with the business cycle in engineering and metalworking, and is felt most by smaller firms less able to provide premium wages, it is the traditional metalworking skills that remain in short supply. If deskilling were a product of technological change one would expect the disappearance of such skill demands.

Interestingly enough, the firms in my sample have not made either significant capital or "human capital" investments to overcome these shortages. These firms have not introduced capital equipment to reduce their complement of skilled labour, nor have they developed training programmes and apprenticeships to overcome skills shortages. Far from having any strategic approaches to the labour force, my sample of management tended to "muddle along" and just cope with labour shortages, training deficiencies and deployment.

iv) This lack of strategic orientation was adequate because the labour force itself did not pose any significant challenge to the "right to manage" in connection with technological change. The installation of NC did not generate any major disruptions to labour-management relations. In only 8 firms did the introduction of NC create any labour relations issues at all. No significant conflicts emerged in relation to job skills, although minor frictions did occur in relation to job classification. All of the incidents of labour-management friction were characterised as "normal" by management and none involved major objections to NC installation and use. The bulk of my informants suggested that NC technology was accepted by the labour force and, indeed, working with it had definite attractions for younger metalworkers. Management does not need strategic plans to deal with worker resistance to technical change because such resistance rarely occurs.

All these responses suggest that: first, in the adoption of NC technology, labour deskilling concerns are not salient among management, although labour shortage problems were occasionally a factor; second, in the eyes of management NC is not a labour-saving technology either in terms of significantly reducing overall levels of employment in each plant or in terms of reducing the proportion of skilled workers required; third, even where NC is used in combination with unskilled workers, more rigorous recruitment and selection of the labour force becomes necessary so that there is actually an increased dependence of the management on the responsibility and trustworthyness of the labour force.

NC and Innovation-Diffusion Analysis

Introduction

The relationship between my findings and innovation-diffusion analysis is rather more complex than their largely disconfirming relationship with labour process analysis. The concern of many economic writers on innovation and diffusion is to establish the endogeneity of technical change (Stoneman 1983 , Chapter 4) , to develop measures of the rate of technical change (Romeo 1977) , and to specify the direction of technical change in terms of type and amount of factor bias (David 1975, Habakkuk 1962). While there appear to have been significant advances in extending formal, quantitative economic models to the analysis of innovation, diffusion and technical change there is still considerable dispute over the empirical adequacy of these models (Stoneman 1983,Chapter 5). Thus Gold and others have argued that most economic analyses of innovation and diffusion operate at too high a level of aggregation, ignore the variety of factors affecting management decisions about productive technology, and minimise the obstacles to optimization in the adoption and utilisation of production technology. Consequently, the complexity of innovation and diffusion processes, involving the interaction of firm characteristics and differences in managerial risk evaluation, tactics and strategies is overlooked.

Endogeneity and NC Diffusion

As Noble's history of the origins of NC makes clear (1984 Chapter 4), this technology originated with the "exogenous" requirements of the United State's Defence Department. The initial users of NC machinery were major aircraft and and missile manufacturers whose equipment was heavily subsidized by the United States' Airforce, at the time the sole customer for NC products. However, the spread of jet technology to civilian air transportation opened up a broader use for NC equipment, although still within the single confines of the aircraft industry. The late nineteen fifties and early sixties, in particular, was one of both expansion of demand for civilian air transportation and the replacement of the last generation of propellor driven aircraft by jet turbine powered craft. This period, then, saw the development of the first generation of commercially available NC machine tools designed to fabricate airframe and engine parts for jet aircraft.

By the late nineteen sixties the aircraft market had been saturated, and replacement parts rather than fleets of planes were more in demand. At the same time the performance capabilities of NC machine tools in aircraft manufacturing were publicized in trade and engineering journals. Thus machine tool manufacturers were being forced to look to new markets at a time when information about the new technology was beginning to become widespread across the engineering and metalworking industries. Changes in raw materials used, increases in the price of conventional machine tools, and skilled labour shortages all played a part in causing some engineering managers to consider the potential of NC technology for their industries. The late 1960s and early 1970s, then, witnessed various firms working with NC manufacturers to develop machinery applicable to specific manufacturing processes, and the development of simpler, easier to programme NC tools such as drills and lathes. These processes generated a second generation of more widely applicable machine tools involving simpler computer programmes and controls.

By the mid-1970s onward, changes in microelectronics began to transform the entire computer-control aspect of NC technology by rendering programming and control of NC tools vastly simpler, more flexible, cheaper and more reliable. At the same time European and especially Japanese machine tool builders began to compete with the established American firms, introducing smaller machines and the more versatile machining centre. Both the changes in the electronic controls and in machine size and designs rendered NC machining accessible to an even broader range of engineering and metalworking firms. At the same time, engineering design changes, the use of new materials, and the rise of new industrial procedures, together generated demands for machining techniques capable of producing engineering parts to refined tolerances, of great geometrical complexity, from difficult to machine materials. The combination of the changes in computing and controls, and these broader changes in engineering practices and products led to the emergence of the third generation of NC machine tools -- versatile, general purpose tools capable of many manufacturing applications, controlled by shopfloor microprocessors or by direct computer link.

The origin and diffusion of NC machine tools, then, was a process of "endogenization" from the original exogenous requirements of the United States' Airforce. The development of NC technology involved lengthy trial and error searches in which the American government and then the aircraft industry bore the "burden of the first user" (Dosi 1984, p. 71). Each stage of diffusion involved a movement away from a situation of exploratory technology and uncertain markets to progressively more established and familiar technology with ever broader applications.

Information Gathering

Despite much analysis of the vagaries of information in many other areas of economic decision making (Machlup 1984), diffusion writings tend to use economic models of firm behaviour assuming rational decision making based upon adequate information. For example, Mansfield's model of diffusion assumes that firms make correct assessments of (i.e. they know) the profitability of particular innovations. However, my findings suggest that knowledge of new technology is imperfectly distributed across engineering firms; can be gained only with some effort and therefore cost which only some firms can or want to incur; and that the adequacy or reliability of that knowledge changes with the spread of technology and in conditions associated with that spread.

Thus with respect to information gathering in relation to general monitoring of production technology and to acquisition-related information, significant imperfections and costs are found. All firms tend to use the cheapest sources of information in monitoring the general state of productive technology. But when planning equipment purchases, larger firms are able to incur the larger costs involved in reviewing wider sources of information. With greater resources, they are able to seek out information and, especially, to check on counterpart installations. As well, they possess enough engineering management personnel to carry out systematic pre-adoption studies without loss of managerial input to regular production. Small firms are dependent on fewer, more accessible sources, and are more concerned with the price of machine tools and quick delivery of equipment to facilitate contract bidding. Consequently, small firms are more susceptible to accidental rather than systematic choice processes.

All of these patterns can be accounted for by orthodox cost minimising, optimizing models. However, their are important constraints on optimising technological choice. These constraints are particularly marked in the case of small firms which are most dependent upon the least costly of all sources of information -- salesmen and their brochures, most isolated in terms of resources drawn upon to make acquisition decisions, most vulnerable to cost and supply considerations, and to haphazard selection processes.

Over half (35 out of 60) of the sample of firms experienced problems in the course of adopting NC tools in their plants. A major element of these problems was unrealistic expectations and sheer ignorance of what to expect when using NC tools. Experience with the technology -- learning by using -- was a major factor in the development of realistic evaluations of the utility of the technology. Two processes were associated with this learning by using. The users developed a more precise sense of how the technology could work profitably for them. The machine tool builders could then redesign and modify their products for a better fit between users' requirements and specifications as the latter experience and record their problems. However, these learning processes were often lengthy and costly. In 7 cases (6 pre-1974 installations and 1 post-1974 installation) major errors in machine tool choice or severe difficulties in machine performance and reliability occurred. This group included firms of all sizes drawn from in most of the branches of engineering and metalworking. Some of these kinds of problems still exist in sheet metal because of the recency of computerisation in that field. But the period in which major difficulties occur is now a matter of months rather than years as was the case with early nc users.

The problems of availability and reliability of information thus diminish with the spread of the technology and the development of a better fit between machine tool builders' designs and users' requirements and specifications. However, the process of improvement in machine tool designs introduces a different kind of uncertainty in technological adoption decisions -- that of deciding whether to adopt sooner or wait for further improvements.

In the face of uncertainties of performance and lack of extensive information, the initial adoption of NC thus tended to be of a risk-minimising character. In other words, NC adoption was often tied to a specific contract which would cover the purchase price of the machine ; or the machine tool was adopted to solve a very specific production bottleneck in the context of rising demand. In the case of the aerospace industry large contractors often guided small subcontractors in the initial acquisition of the technology, so that some of the risks associated with inexperience were largely eliminated.

The Supply of Technology

Diffusion analysis has tended to emphasize innovating firm behaviour, or characteristics such as size, market position, management education, etc., leading some firms to adopt innovations before others, i.e. the demand side of technical change. Recent writers, especially Gold and Rosenberg have tended to emphasize the supply side aspects of diffusion -- the conditions under which technology itself changes so that it has wider applicability; the impact of learning by using on the diffusion of technology; the coming together of diverse streams of technical changes merging to produce novel techniques, and so on. An older literature on the machine tool industry in the United States also suggest that slumps in the demand for manufacturing equipment forces machine tool builders to develop new machines with improved designs and wider applicability in an attempts to revive sagging markets for their products (Brown, 1957; Wagonner, 1966, Chapter 2.)

My interviews indicate that the spread of NC technology in Canada is a result of the interaction of several such factors including supply and demand. The supply of NC technology altered in the late sixties with the end of expansion of aerospace demand for NC tools and the rise of Japanese machine tool exports. The end of the aerospace market expansion led machine tool builders to cultivate other sectors of engineering and metalworking as potential NC users. The Japanese machine tool industry accelerated the diffusion of NC outside aerospace by introducing smaller and more flexible machines adaptable to a wider range of production applications. A major breakthrough occurred with the coupling of micro- computers with NC machine tools which vastly simplified and speeded up the preparation of machining programmes and made a wider range of programmes possible.

While these changes in the supply of NC technology took place, changes in engineering product designs and materials altered the demand for NC machining. These changes required higher tolerance machining and/or machining of more recalcitrant materials than used hitherto, both of which were suited to nc manufacturing. At the same time these shifts in the demand for engineering and metalworking products took place occurred in a general economic context of expansion, relative ease of capital funds, and labour market tightness, all of which were positive influences on NC adoption.

The Economic Context of Diffusion

Changes in the latter conditions, and particularly the 1982 recession and heightened international competition in industrial products, have probably slowed down the overall rate of adoption (Canadian Machinery and Metalworking, March 1983). However, in certain industries such as agricultural equipment and automobiles, the resulting market pressures have led to the need for greater variability in product lines, shorter lead times, and greater responsiveness to shifts in market demands. In the search for more variable and flexible manufacturing systems, then, some mass production industries are trying to incorporate NC technology in order to obtain greater flexibility in their manufacturing systems. In other industries, NC technology is being reconsidered as a potential future labour saving technique to reduce the need to expand the core of skilled labourers required when demand increases again; while in yet others NC is being abandoned as large and medium firms rationalize their operations by specializing in mass production and subcontracting out the variable, small batch runs to smaller enterprises. NC technology is also being used by firms that are responding to market pressures by moving "upscale" to higher precision engineering product markets. This was a response found particularly in a few medium size sheet metal shops and small general machine shops. The latter, along with edm die shops have also developed a strategy of identifying very particular niches in the engineering product markets with limited competition and accessibility to small firms with limited financial resources.

Technology and Management Strategy

In Chapter 3 I suggested that my interview responses could indicate whether industrial management might have a strategic orientation to technological change. For labour process writers technical change is part of a strategy to control and subordinate labour; for innovation and diffusion writers technical change is the result of management's optimizing choices between different factor combinations. With respect to the latter, Freeman (1982, pp.169-183) and

Gold (1978, pp. 185-186) have argued that optimising may be pursued by using different technological adoption strategies ranging from pioneering innovation to laggardly imitation. At the level of management I interviewed, technological adoption and utilization decisions were largely conceived in operational engineering and production terms rather than in any broader strategic ones. From an operational perspective profits were seen as an automatic byproduct of good engineering practice or successful solutions of engineering production problems. That is, optimal cost-profit estimates were assumed to correspond with optimal engineering specifications.

The consistent emphasis throughout my sample of informants was the mundane one of getting the job done most efficiently (in a satisficing sense) and of meeting the contract quality and deadline requirements. Strategic thinking in terms of systematically attempting to be a technological pioneer, or of following a pioneer to minimise the risks of innovation etc., were absent in all but a few large aerospace and telecommunications firms. Hence the justifications for adoption of NC were overwhelmingly technical and operational, and, they varied with batch size and characteristics of the product manufactured. Consequently, respondents from larger firms emphasized NC's advantages in terms of minimising down time, respondents from pumps and valves and sheet metal firms emphasized the need for quality improvements in the products, while die and mould and aerospace firms' respondents point to design complexity and recalcitrance of materials as major factors in NC adoption in their sectors.

Apart from unrecognised gaps between satisficing and actual NC use (for example, as in those plants where illicit shopfloor programming breached management's "programming integrity" ideals), many informants openly admitted that their utilization of NC technology was less than optimum. The worst case was that of the printing plant (discussed on pp. 197-203), but others included an agricultural equipment plant unable to replace its aging equipment because of severe market decline; a situation which had led to plant closings and the accumulation of an increasingly heterogeneous miscellany of obsolete equipment in the surviving plants. Other cases ranged from a large telecommunications firm in which a plant manager had purchased equipment at bargain prices which, in the long term had proved increasingly expensive to maintain, to a small, highly specialised aerospace firm which had had to purchase a particular milling machine hurriedly in order to get a contract, only to find that many of its design features were seriously flawed. Yet the firm could not afford to purchase a subsequent model without most of these flaws. In all these cases problems were "coped" with and solved on a day to day basis and the suboptimality of the situations were accepted as an inescapable burden in the situation.

In general, a commitment to NC operations did not necessarily involve continuous upgrading to keep up with the rapid changes in nc technology. NC equipment was amortised on the same basis as conventional machine tools, with the tool's life averaging 5-8 years' of service in production. Consequently NC machine tools' production lives exceeded that of their "design lives" (2) to a far greater degree than was the case with conventional machinery. However, most of the upgrading in NC technology has centred on programming and the control systems while the mechanical hardware has altered much more slowly. Even so, a few firms, including some in the aerospace sector have retained manual programming and punched tape controls virtually unaltered since the early 1970s.

Throughout the entire period studied, patterns of adoption remained conservative. The predominent pattern was one of "one step at a time" installation of a single NC machine tool to solve a specific bottleneck in production, or to meet a particular contract,etc. In all these ways NC machine tools existed as a specific solution to a specific technical production problem. Wholesale equipment upgrading, or the assumption that NC was the "wave of the future" or other forms of speculative pioneering with NC technology occurred only in exceptional and isolated instances. Nor did NC replace traditional mass production technology. In several plants it remained an isolated application in a mass production operation. In at least two cases companies were eliminating their NC operations and contracting out the variable production operations for which nc was required. In these cases specialisation in mass production rather than increased flexibility was the strategic response to market uncertainty.

Conclusion

The most general finding which I would like to emphasize is that the term "NC technology" as a homogeneous and static entity covers up the real diversity and complexity involved in the adoption and use of NC machine tools. In over two decades of diffusion in Canada, NC technology evolved from a largely aerospace related technology, characterised by cumbersome controls and difficult to use computer programmes, to a general metalworking technology controlled by increasingly flexible, easy to use computer systems. In evaluating its potential management in different branches of engineering and metalworking used different operational criteria to assess it. NC tools became used in a great variety of ways ranging from very special purpose, virtually automatic mass production operations to very flexible and diverse applications in custom and prototype precision machining. Long term patterns of intra-plant diffusion also varied enormously from isolated application to very particular, unchanging production tasks, to creeping displacement of conventional machining. My sample also included firms with "stalled" applications of NC tools, and mixed successes and failures with different NC machine tools, as well as a few cases of retreat from NC to conventional mass production techniques.

Close attention to the characteristics of the technology of production in engineering and metalworking is necessary to understand such diversity. As the technical requirements of different engineering firms vary, so do the reasons for adopting and using NC equipment. Traditional diffusion analysis has not investigated production technology in enough detail and while it can model rates and patterns in the aggregate it is less able to explain interfirm differences in adoption and use of new technology. Future diffusion research, then, will have to be more precise about industrial technologies, in order to understand the range of "technological expectations" (Rosenberg, 1976) which affect management, and the range of technological practices within industrial sectors.

A second implication of this diversity for research and theorizing about technology is that technological changes probably differ considerably across different industries, and that the characteristics of technological change have to be empirically investigated for a variety of industries rather than generalized from a narrow range of industries. Labour process writers, in particular, have tended to commit this error -- Noble using the defence aircraft industry as his model, and Shaiken using the the automotive industry -- although Gold has pointed to this as a problem in economic diffusion research also (1977, p. 189).

A third implication for research and theorizing is the need to take account of shifts over time with respect to the diffusing technology. As a new technology spreads, learning by using occurs which is communicated back to to the equipment manufacturers, and through a variety of interfirm contacts. These experiences and communications result in improved machine designs, and the accumulation of experience resulting in better and more diverse utilization of the equipment. Associated with these changes, maintenance and other adjunct operations also tend to be improved, lessening the costs and obstacles to diffusion even further. The result of all these developments is to broaden the market for the equipment and to usher in more rapid diffusion, and to shift from highly uncertain conditions of technological choice to conditions of much greater certainty. However, these changes do not affect firms in the same way or at the same time. Thus large firms could bear the burdens of programming complexity associated with the first generation of nc equipment. But having established programming departments they were not interested in the latest generation of NC equipment which have micro computer controls built into them so that they can be programmed on the shop floor. However, tool and die shops were very much attracted by these models and became prominent new consumers of nc technology.

Accompanying this spectrum of use is a geat variety of manning patterns ranging from skilled "NC toolmakers" responsible for programming as well as operating NC tools to semi-skilled or unskilled machine operators responsible only for loading and unloading NC tools. This variety undermines those theories which argue that micro-electronic technology is one with significant deskilling consequences (Braverman, 1974, pp. 196-206, 244-245 ; Greenbaum, 1979). From the management reports I received NC technology appears not to have eliminated the need for highly skilled work, nor to have caused significant shifts in the skill composition of the engineering and metalworking industries' labour force. Moreover, the diffusion of NC technology has not yet increased the size of the "industrial reserve army" by creating technological unemployment. Unemployment is much more intimately connected with the state of the markets for engineering products than with technological change.

The range of managerial evaluations, NC machine tool production applications, patterns of intra-firm diffusion, and deployment or manning patterns, present a picture of diversity and complexity which cannot be adequately encapsulated in the unitary conceptions of technological change currently circulating among those writing about "the computer revolution" or "the microelectronics revolution." As was seen in Chapter 4 the evolution of computer technology interacted with different technical and market developments in each branch of engineering. NC technology developed in the context of ever changing technical needs and market demands specific to the diverse branches of engineering and metalworking. There was no single, unified or homogeneous technology which was exploited throughout engineering to solve identical problems of manufacturing. Rather, NC technology was itself changed rapidly as it was adopted at different times, under different market and technical conditions, to perform different tasks or to solve different production problems. Consequently general models of diffusion or of the impacts of diffusion (as in the deskilling hypothesis) drastically oversimplify the actual conditions and processes of technological change in the economy and obscure those changes which are of such central concern today.

Footnotes.

1. It should be emphasized that labour process writers do not have clear evidence of deskilling. An excellent critique of Braverman's treatment of skill is found in.

Lee (1980). A recent collection of labour process essays does concede that the deskilling model is far too simple to account for changes in the nature of work Canada. See Heron and Storey (1986), Chapter 1.

2. By "design life" I mean the period during which a machine tool's design is stable. While changes occurred in subcomponents between 1920 and 1970, the basic configuration of the lathe, horizental and vertical mill, and radial drill remained unaltered. During the 1970s independently powered double chucked lathes, multi-tabled milling machines and machining centres were introduced as part of the changes associated with the development of NC. These were fundamentally new machine tool configurations, and not just changes in subcomponents of a stable overall tool design.

Appendix A

The Sample: Basic Characteristics

Sector	Location Ont.	Location Quebec	Firm Size 100	Firm Size 100-400	Firm Size 500	Unionized Yes	Unionized No	Period of First NC Acquisition Pre-1974	75-80	1981+	Number of NC Tools 1985-86: 2	5	10	20	20
Aerospace (15 firms)	5	10	7	4	4	8	7	11	4	0	2	1	4	5	3
Electrical (8 firms)	3	5	1	3	4	6	2	6	1	0	0	4	1	3	0
Die & Mould (6 firms)	3	3	5	1	0	1	5	1	2	3	2	3	1	0	0
Sheet Metal (6 firms)	5	1	2	4	0	3	3	4	1	1	3	2	1	0	0
Pumps/Valves (5 firms)	3	3	4	1	0	1	4	3	2	0	0	1	3	1	0
Transport* (6 firms)	5	1	0	3	3	6	0	4	1	1	1	1	1	1	1
Industrial Equipment (10 firms)	5	5	2	6	2	6	4	6	3	0	2	2	5	1	0
Agriculture and Lumber (4 firms)	4	0	0	1	3	3	1	2	1	0	0	0	1	1	2
Totals	33	27	21	23	16	34	26	37	17	5	10	14	17	12	6

* One automotive plant was planning to install NC equipment on the assembly line, but had no NC tools in use at the time of the interview.

Appendix B

The Sample: Company Characteristics
:Agriculture & Lumber

Company	Product Line	Production Runs	Number of Employees	Employment of '82-'84	Impact Recession	Union Status	Date of First NC	Current No. of NC tools
1	Agricultural machinery, discs and forgings	Small batch	1,000	Peak of 1400 in 1980, declined to 750 in 1981-83		Union	1965	30
2	Agricultural machinery	Early 1980 medium batch, now small batches up to 15	2,500	Declined since 1982		Union	1974	24
3	Tree harvesting & pulp mill equipment	Small batch - 6-8 some parts large batch 1,000-5,000	250	Declined 1981-82, increased 1983 on		Union	1969	6
4	Saw chains & bars	Mass production	614	Peak of 640 in 1981, reduction of engineering staff since then.		No Union	1978	14

Appendix B

The Sample: Company Characteristics : Industrial Equipment

Company	Product Line	Production Runs	Number of Employees	Employment Impact of '82-'84 Recession	Union Status	Date of First NC	Current No. of NC tools
1	Specialized nc machines, adjunct equipment, software, testing equipment	Custom - 1-off	24	Gradual expansion since 1972 establishment	No Union	1972	5
2	Large mining machinery, hydro turbines & generators	Custom - 1-off	500	Stable since 1980	Union	1964	9
3	Plastic injection moulding machines	Custom to small batch - 1-10	400	Continual growth since 1980	No Union	1978	9
4	Swaging machinery	Small batch - 2-10	100	Return to 1980 level Declined to 32 in 1982.	No Union	1969	6
5	Printing machinery	Custom - 1-off	200	Slight increase since 1980	Union	1975	2
6	Sleeves, bushings and rollers	Large batches of bushes & sleeves, minimum roller batch of 100	100	Decline from 160 in 1980	Union	1974	2
7	Repair shop & toolroom repairs machinery, makes special machinery and spare parts.	Highly variable - 1 - 1,000	700 (tool-room) 1,000 (plant)	Down because of 1981-1984 layoffs	Union	1970	8

Appendix B

The Sample: Company Characteristics : Industrial Equipment

Company	Product Line	Production Runs	Number of Employees	Employment Impact of '82-'84 Recession	Union Status	Date of First NC	Current No. of NC tools
8	Elevator & conveyor machinery	Medium batches	300	Down from 800 in late 1981, but due to plant rationalization	Union	1970	9
9	Wood pulping machinery	Machines : 1-off Parts: small to medium batches	350	Decline since 1980	Union	1964	15
10	Precision gears for heavy industrial uses	Very small batch	43	Slight growth since 1980	No Union	1975	3

Appendix B

The Sample: Company Characteristics
: Transportation Equipment

Company	Product Line	Production Runs	Number of Employees	Employment Impact of '82-'84 Recession	Union Status	Date of First NC	Current No. of NC tools
1	Diesel locomotives, transit coaches & power units, repair parts	Small batch	500	Decline from 1978 peak of 1800	Union	1964	19
2	Pressure aluminium die castings mainly for the automotive industry	Small to medium batches	250	Growth from 90 employees in 1980	Union	1983	2
3	Automotive jigs, fixtures, machinery, replacement parts & repairs	Small to medium batches 25-300	18	Slight growth since 1980	Union	1964	9
4	Transmission parts & assemblies for cars	Mass production	1500	Decline since 1980	Union	Under Consideration	-
5	Railroad freight cars	Small-medium batch	200	Decline from 1980 peak of 1300	Union	1969	4
6	Railroad braking equipment	Small to medium batch - 20-500	220	Lowest employment level since 1968. 350 in 1980.	Union	1973	21

Appendix B

The Sample: Company Characteristics : Pumps & Valves

Company	Product Line	Production Runs	Number of Employees	Employment Impact of '82-'84 Recession	Union Status	Date of First NC	Current No. of NC tools
1	Pumps for pulp, paper & mining industries	Small to medium batch - 10-200	50	No information	No Union	1971	7
2	Safety release valves	Small valves:1-300 Large valves: 2-20	40	Stable since 1980	No Union	1976	5
3	Pipe valves & fittings	1-off to medium batch	40	Down from 60 in 1980 During 1982-84 down to 25	Union	1970	9
4	Vacuum & centrifugal pumps & parts	1-off to medium batches of pumps; parts in small to medium runs - 10-500	50	Stable since 1980	No Union	1975	8
5	Industrial valves	Small to large batch runs of valves - 5 - 10,000; mass production of some components	300	Stable since 1980	Union	1970	16

Appendix B

The Sample: Company Characteristics
: Sheet Metal

Company	Product Line	Production Runs	Number of Employees	Employment Impact of '82-'84 Recession	Union Status	Date of First NC	Current No. of NC tools
1	Metal furniture, cabinets, electrical housings	Small to medium 5-100	120	Grown from 80 in 1980 reduced to 60 in 1982-83	No Union	1972	5
2	Perforated sheet, grids and grill work	Small batch	140	Stable since 1980	Union	1975	4
3	Electrical and machinery housings, furniture, industrial doors, hatches	Custom, small batch. Occasional medium batch up to 200	35	Some layoffs 1981-83 Expansion since 1984	Union	1981	2
4	Electronic telecommunications equipment housings, industrial frames & cabinets	Small to medium batches - 2-300	75	Expanded since 1981	No Union	1968	1
5	Steel pipes, pressure vessels & fittings for food, beverage, brewing, petrochemicals, pulp and paper industries.	Mass production of pipes & fittings. 1-off to medium batches of pressure vessels	350	Reduced to 175 in 1983	Union	1965	1
6	Shelving, industrial cabinets, frames & hatches, electrical & communications equipment housings.	Large batches of shelving, small to medium other	210	Some layoffs in 1984	No Union	1969	9

Appendix B

The Sample: Company Characteristics
: Mould and Die

Company	Product Line	Production Runs	Number of Employees	Employment Impact of '82-'84 Recession	Union Status	Date of First NC	Current No. of NC tools
1	Makes and repairs automotive dies	1-off	25	Grown continually 1980	No Union	1978	3
2	Industrial dies	1-off, very small batch	16	Stable since 1980	No Union	1979	3
3	Investment costing moulds	1-off	10	Grown since began in 1979	No Union	1982	2
4	Shoe moulds	1-off, small batches	15	Slight growth since 1980	No Union	1981	3
5	Automotive stamping dies, plastic injection moulds	1-off	80	Declined from 110 employees in 1980	Union	1983	1
6	Blow moulds for soft drink containers	Small batch - 1-16 occasionally medium batch 45-100	100	Gradual expansion	No Union	1969	6

Appendix B

The Sample: Company Characteristics
: Electrical & Communications Equipment

Company	Product Line	Production Runs	Number of Employees	Employment Impact of '82-'84 Recession	Union Status	Date of First NC	Current No. of NC tools
1	Telecommunications switchgear	Small-Medium batch 5 - 5000 pieces	80	Slight growth since 1980	No Union	1975	5
2	Aircraft fuel control systems	Variable: ranged 20-4,000 average 100	120	Same as 1980 strength 1982-84 down to 120	Union	1960	14
3	Flight simulation equipment	1-off, custom production, rare small batch 10 items	2,600	Large layoffs in 1983-84.	Union	1969	12
4	Power transformers	1-off	330	Significant decline since 1980	Union	1974	6
5	Aviation telecommunications parts	Repeated small batches	2,000	Stable since 1980	Union	1966	11
6	Telecommunications equipment	Mostly small batch occasional runs up to 1,000	2,500	Declined since 1980	Union	1967	5
7	Transmission switchgear	Small runs up to 200 items	200	Slight increase since 1980	No Union	1970	5
8	Satellite transmission components and assemblies	1-off and small batch	850	Stable since 1980	Union	1973	4

Appendix B

The Sample: Company Characteristics
: Aerospace

Company	Product Line	Production Runs	Number of Employees	Employment of '82-'84 Impact Recession	Union Status	Date of First NC	Current No. of NC tools
1	Wing, hydraulic, motor components	Highly variable 1 - 50,000	40	1981 80 employees 1983-84 13 employees	Union	1977	2
2	Small precision machine parts	Small batch 1 - 1,000	50	1981 35 employees 1983 30 employees	No Union	1977	9
3	Executive jets	Small batch	5,000	1981 7,000 employees	Union	1963	35
4	Various small aircraft	Small batch	2,900	Current level a return to 1980 level after 1981-84 layoffs	Union	1968	17
5	Multitude of precision parts and assemblies	Single item, small occasionally medium batch	210	Grew through recession	No Union	1976	9
6	Small precision parts for air industry, surgical instruments other industries	Small batch	15	10 in 1980 9 in 1982	No Union	1971	9
7	Aircraft landing & other hydraulic parts for jets. Repairs for same.	Small batch	45 (in manuf. shop)	1980 35 employees 1983 25 employees	Union	1965	22
8	Gyroscopic camera mounts for surveillance and tracking devices	Custom 1-off.	21	Steady growth of employment	No Union	1980	1

Appendix B

The Sample: Company Characteristics
: Aerospace

Company	Product Line	Production Runs	Number of Employees	Employment Impact of '82-'84 Recession	Union Status	Date of First NC	Current No. of NC tools
9	Air & military precision machine parts	Variable - proto-type & custom to large batch	115	Growth since 1980 with 90 employees	Union	1968	14
10	Small hydraulic & pump parts of aircraft fuel systems	Average run = 50 pieces	100	Slight growth since 1980	Union	1965	4
11	Air & military small parts, new lines of surgical equipment	Air-defense parts small batch, sur-gical large batch	100	Firm split as a result of disagree-ment between 2 owners. Difficult to estimate recession's impact.	No Union	1965	15
12	Aircraft & helicopter engines	Prototype & custom to large batch	8,000	1981-82 large lay-offs; 1983-slow growth	Union	1963	91
13	Jet engine components & maintenance	Small to medium batches	105	1980 - 220 plant rationalization process	Union	1967	14
14	Aircraft trans-mission components	1-off to large batch	500	Stable since 1980	Union	1967	14
15	Airframe and wing parts	Medium batches	70	Stable 1980-84, grew 50% since 1984	No Union	1970	8

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