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Craft skills in flexible manufacturing systems

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CRAFT SKILLS IN FLEXIBLE MANUFACTURING SYSTEMS

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LIST OF ABBREVIATIONS

AEU	Amalgamated Engineering Union (formerly the Amalgamated Union of Engineering Workers - Engineering Section)
AGV	Automatic guided vehicle
AMT	Advanced manufacturing technology
ASP	Automated Small Batch Production (Committee of the British Government's Department of Industry)
AUEW	Amalgamated Union of Engineering Workers - Engineering Section
CAD	Computer-aided design
CADAM, CAD/CAM	Computer-aided design and manufacture
CNC	Computer numerical control, computer numerically controlled (of machine tools)
DNC	Direct numerical control (of machine tools, etc)
DTI	Department of Trade and Industry
EBQ	Economic batch quantity
EITB	Engineering Industry Training Board
ERU	Ejector release unit
FMS	Flexible manufacturing system
GT	Group technology
MDI	Manual data input (to CNC machine tools)
MIS	Management information system
MRP	Materials requirements planning
MTTF	Machine Tool Task Force
NC	Numerical control, numerically controlled (of machine tools)
NEDO	National Economic Development Office
SDEU	Shop data entry unit
TASS	Amalgamated Union of Engineering Workers (Technical and Supervisory Section)

UK	United Kingdom
VDU	Visual display unit.
WIP	Work in progress

SUMMARY

The importance of engineering craft skills is often believed to be under threat because of the advent of flexible manufacturing systems (FMS), on important component of the so-called "automatic factory". FMS is thought by many analysts, such as the "labour process" and "regulationist" schools, to possess the capability to incorporate, and thus render obsolete, machinists' skills. Other writers, notably those proposing manufacturing strategies of "flexible specialisation", argue that craft skills must be combined with technological changes to respond to more fragmented product markets. A study of fifteen British FMSs confirms the continued role of traditional engineering craft skills in commissioning and operation of such systems. As the "flexible specialisation" thesis finds, responses to demands for overall manufacturing control, productivity and production adaptability tend to be better where FMS operators have greater autonomy and discretion in system intervention. Yet managerial FMS job design preferences still tend to restrict operator intervention in programming and determination of working methods, while permitting flexibility between FMS servicing and ancillary functions. How far managers acknowledge requirements for relaxation of labour controls, however, depends upon wider institutional cultures and labour relations policies, and the types of flexibility and benefit sought from FMS.

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CHAPTER ONE: Introduction

i) The context: the "automatic factory"

The metalworking engineering industry world-wide is now in a state of flux after several decades of relative stability. Markets are becoming more fragmented; to serve this changing pattern of demand a growing variety of increasingly differentiated products are manufactured, each produced in smaller batches; numbers employed are falling rapidly both relatively and absolutely in most industrialised countries, while simultaneously manufacturing industry appears to be an increasingly unattractive working environment for workers with remaining needed skills.

In recent years there has been a growing belief in many managerial, engineering and sociological circles that technological changes based upon microprocessors and information technology in production processes, and generically known as advanced manufacturing technology (AMT), contain the promise of solving these problems. The key to this lies in the levels of reprogrammability, integration, and technical flexibility available from computerised manufacturing technologies at a decreasing cost. The advantage of lower purchase prices is further enhanced by such equipment's potential for savings in directly productive labour. Some writers now talk confidently about the realisation of this dream in phrases such as the "automatic" or "unmanned" factory, or the "factory of the future" [1]. This is visualised as being akin to the high levels of automation characteristic of continuous flow process industries such as oil refining, where production is largely independent of direct human intervention. In the "automatic factory" production can be quickly switched between batches of different components which are made only in the quantities the market demands. After the design of any component little human intervention is required to aid its rapid progress through the shopfloor to final assembly. Parts are transported through the factory by mechanised transfer devices, such as automatically guided vehicles (AGVs), to various locations, at which fabrication, assembly and other operations are carried out under computer instruction. The sequence of operations and performance of the entire process is predetermined by overall computer control.

Studies of plants into which AMT has been introduced [2] find a number of differences between AMT and previous technologies. These include a higher capital investment per employee, fewer workers responsible for each part of the production process, a greater sensitivity of output quality and quantity to human knowledge, and more interdependence of work activities. Malfunctions - where and when they occur - tend to be more costly and to spread more rapidly throughout the production process because of this interdependence and capital intensity.

Yet how will the nature of the remaining production workers' jobs change as a result of the introduction of these new advanced technologies, and what factors will determine the shape of those jobs? In recent years considerable speculation has taken place about the likely content and future evolution of such jobs under changing economic and technological conditions. At issue firstly are the skills that will be exercised. Specifically: how far these consist of new areas of expertise; and to what extent traditional craft skills are still required (if at all)? And, leading on from these points: are divisions of labour allowing the possibility for skill retention on the shopfloor likely to materialise in actuality; and what are the main factors enabling, or restricting, the formation of work roles with such features? These are the questions to be answered in this thesis.

ii) The crisis in engineering: Fordism and beyond

To understand the tentative nature of existing discussions of the current changes in the employment and skill structures of the engineering industry it is necessary to appreciate the wider background to the present period of industrial transition. Until recently the dominant ethos was that of mass production or "Fordism", which found its apex in Henry Ford's manufacturing methods for the Model T Ford. These innovatory techniques were characterised by particular forms of market structure, product profile, production processes, and labour inputs. Markets were large and undifferentiated, products standardised, production processes used highly mechanised but inflexible dedicated machinery to exploit the possibilities of huge economies of scale, and the labour necessary to tend this machinery was largely semi-skilled, requiring minimal training to perform a very limited repertoire of tasks.

In their pure form the diffusion of these techniques was not as extensive as has sometimes subsequently been claimed, even in so-called mass markets. For instance, Tolliday and Zeitlin (1986, p6) note the extent to which British volume car producers, not least because of the smaller size of the domestic market, pursued variations on these techniques involving a greater variety of models and more adaptable capital machinery. Writers associated with "dualist" theories, such as Berger, Piore and Sabel, argue that mass production only triumphed to a limited extent over sometimes very specialised forms of batch production in most industrial nations, and even in the USA [3]. This was partly because the giant mass production industries presupposed the parallel existence of many small firms making a wide range of specialised capital machinery by means of general purpose machine tools (Piore and Sabel 1984, p26). More importantly, in view of our subject matter in this thesis, the diverse and relatively limited markets for most capital goods (such as equipment for mining, construction and power generation) rarely permitted the diffusion of Fordist techniques in detailed form.

The continued dependency of engineering on small-batch production can be illustrated by various estimates which reveal that the majority of discrete products manufactured in the engineering industry are produced in such a form. The Production Engineering

Research Association (1969) reports that 86% of metal parts by number are machined in batches of less than one thousand; while another estimate (Anon 1980) suggests that as many as three quarters of all components are produced in a batch size lower than fifty. And a recent National Economic Development Office (NEDO) report believes that 70% of UK engineering output consists of medium-volume, medium-variety batch production (NEDO Advanced Manufacturing Systems Group 1985, p2) [4]. This form of manufacture brings about a need for frequent and lengthy changeovers of machines to produce new batches of components, resulting in a large proportion of available time being spent in skilled setting-up of machine tools rather than actually machining parts.

Fordist techniques did however appear in outline form. It was to the Fordist "model" that managements even in small-batch engineering aspired, pursuing standardisation, mechanisation, rationalisation and sub-division of tasks as far as was possible. Other Fordist conventions that have percolated widely into engineering include: justifications for the purchase of new machines in terms of labour cost savings; and an emphasis on intensification of production through reducing the time taken to perform individual operations. So the use of the term Fordism as a characterisation of the era of mass production and consumption, and of the ruling orthodoxy among production techniques, is accurate enough.

As we said at the beginning of this chapter, since the mid-'sixties the Fordist system has been pitched into deepening crisis by adjustments in each of the factors that previously gave it its stability. Firstly, increasing fragmentation has affected both consumer and capital good markets. One report summarises this trend, and the implications for manufacturers' responses, thus:

> Although conventional batch production is relatively inefficient, difficult to control and expensive, it is likely to grow as a percentage of total engineering manufacture. This is because both industrial and consumer markets increasingly demand a wider choice of products and a higher rate of product development and innovation. Thus the traditional response by companies to increasing competition, that is to maximise volume and minimise variety in order to reduce conventional production costs, may no longer be an adequate option. (NEDO. Advanced Manufacturing Systems Group 1984, p2).

Secondly, the products to be manufactured are themselves becoming more differentiated, variegated and complex as a result of these market changes, resource scarcities and a tendency toward the elimination of fitting and assembly labour. The Machine Tool Task Force (1980b, pp 28-29) study identifies trends towards the use of a wider range of materials, the design of more complex single parts to replace multi-part assemblies (which must therefore be machined to tighter tolerances), and a higher proportion of thin and light components which will be more difficult to machine because of their lack of structural strength. These developments require that production processes should be able to cope with improved accuracies and a wider universe of machining demands [5].

To these problems must be added an increasing resistance by labour to accept the highly prescribed and sub-divided labour processes resulting from the application of Ford's principles. To minimise high labour turnover and training costs managements have also had to consider ways in which to improve worker motivation in order to retain expertise. So we see that conditions of economic recession, resource scarcity, and changes in social expectations have caused the development of more competitive, constricted and rapidly changing markets more subject to customer influence. The features of these are said to include shorter production runs, lead and resetting times, and perhaps more flexible labour also. All of these factors call into question the continued appropriateness of dedicated production equipment. Thus in the automobile industry traditional high volume transfer lines are becoming increasingly inappropriate as volumes decline while markets dictate more regular modifications to designs (Abernathy 1978).

If Fordism is in crisis, and increasing flexibility of labour and of production are now the watchwords, how are these goals to be achieved? Moreover, can they be achieved within a framework still basically compatible with Fordism? Two influential schools of thought which believe they can, advanced by writers at opposing ends of the political spectrum, agree in according a central role to recent changes in available production technologies in this.

Influential policy-making managerial and engineering authorities, such as the National Economic Development Council's Advanced Manufacturing Systems Group, have argued that the inherent flexibility in microprocessor technologies enables:

> a series of technological solutions to what have so far been considered to be organisational, managerial and business problems. (NEDO. Advanced Manufacturing Systems Group 1984, p2).

These novel technical characteristics are believed to extend the benefits of Fordist economies of scale (such as high machine utilisation, rapid throughput times and low levels of work in progress) to mid-volume, mid-variety batch machining, while finally overcoming the disadvantage of lengthy and expensive changeover times between the manufacture of different products.

Further, the incorporation into software databases of the human skills hitherto necessary to cope with the variety of small-batch work will lead to the "automatic factory" (Slautterback and Werther 1984). On the political Left some (but by no means all) of the "regulationist" theorists proposing the transformation of Fordism into a form of industrial structure they term "neo-Fordism" also see these technologies as critical in allowing the extension to small-batch engineering of Fordist forms of labour input and structures of control.

One of the problems with the concept of neo-Fordism is the definitional uncertainty with which the term has been employed by different writers to denote changes in (variously) labour utilisation, production methods, markets and industrial structure. As far as we can ascertain, the term "neo-Fordism" was originally used in the first of these senses by the French Marxist Palloix (1976). For Palloix, neo-Fordism seems to consist of no more than the attempt to reorganise workers' task structures on assembly lines by means of job enrichment. Thus he sees neo-Fordism as an essentially conspiratorial and "purely formal attempt to abolish the collective worker" while still maintaining the Fordist system of control; merely a more refined method of exploitation and control over a basically unchanged labour process (cf. also Brighton Labour Process Group 1977).

In Palloix's account automation, by which he means most specifically the development of continuously-fed multi-machine systems, causes a polarisation of skills and results in the operator becoming the unskilled "minder" of several machines. Kelly (1978, 1982b) expands upon this latter development, interpreting it in terms of a capitalist need for the intensification of labour. Kelly stresses the need for work roles to be enlarged if the remaining "operators" of semi-automatic machinery are to be fully employed. In this context the adoption of greater labour flexibility than was the case under Taylorism and classical Fordism is necessary as technological developments reduce the need for direct human attention to machinery.

Another French Marxist, Aglietta (1979), develops Palloix's approach, albeit rather inconsistently. Aglietta (1979, pp 122-130) follows Palloix in defining neo-Fordism as a combination of the "automation" of control over production and the recomposition of work roles. Later, however, Aglietta claims that the real significance of neo-Fordism lies in the extension of these techniques into new industries and services previously impervious for technological reasons to the diffusion of Fordist forms of organisation in order to resolve what he sees as a crisis of the accumulation of capital (Aglietta 1979, pp 162-169).

Blackburn et al (1985, pp 104-106) have attempted to synthesize the above themes to produce a definition of neo-Fordism having three main features. Firstly, there are the above-mentioned technological developments enabling a weakening of "the link between mechanisation and scale". Secondly, organisational (or labour utilisation) changes favour the adoption of multi-task occupational roles. Both of these factors are said to be dependent upon informational changes, which enable many of the supervisory and decision-making roles within the production process to be assumed by new computer-based infrastructures rather than a extensive hierarchy of indirect personnel; as was the case in Fordist production processes. Thus control of labour is built into semi-automatic equipment, and is now enabled by technical rather than hierarchical means.

Like Aglietta, Blackburn et al wish to emphasise the relevance of this emergent neo-Fordism for new sectors of the economy such as small-batch engineering, which they consider to be in transition from a craft to a neo-Fordist labour process. Unlike the French Marxists, however, they argue that the need to utilise the increasingly capital-intensive production technology efficiently makes the employment of skilled workers desirable (Blackburn et al 1985, p145). Also, they see neo-Fordism as constituting a qualitative break with Fordism.

Another, rather different, interpretation of neo-Fordism to those above is offered by Sabel (1982), who refers to it in the context of forms of adjustment to changing market conditions on the part of industries hitherto organised on a Fordist basis. An advantage of Sabel's approach is its stress on the role of specific management policies and strategies for accomodation to changed markets in which particular firms and sub-sectors of industry may use means other than the exploitation of more flexible technology. Hayes and Wheelwright (1979, p138) illustrate this choice with the following example:

> For a given product structure, a company whose competitive emphasis is on quality or new product

development would choose a much more flexible production operation than would a competitor who has the same product structure but who follows a cost-minimizing strategy.

In some senses these different sets of objectives are mutually incompatible and demonstrate what Abernathy's (1978) study of the automobile industry referred to as the "productivity dilemma". This argues that incremental increases in manufacturing process efficiency, and thus of productivity, presuppose a reduced competitive emphasis on major innovation of new products to respond to changes in market demand. Developing this approach, Piore and Sabel (1984) propose two possible responses to the dilemma in which firms find themselves. They suggest that such firms will be forced to choose between two strategies. Firstly, they could preserve volume production techniques by attempting to extend penetration into new global areas in order to recreate a mass market on a new basis. Alternatively they could adopt more flexible production strategies in terms of their use of labour and technology to accommodate to and exploit these market changes [6]. Piore and Sabel call this latter policy "flexible specialisation".

Flexible specialisation is based upon the use of adaptable, general purpose machinery combined with the expertise of skilled craft-trained workers, who are granted considerable autonomy and discretion. It also demands a close harmony between manufacturing capabilities and marketing strategy, to permit rapid switching of production in line with market demands [7]. "Flexibility" is measured according to this ability to allow more rapid changeovers between products. Historical evidence (Sabel and Zeitlin 1985) suggests that recently developed versatile production technologies are not an essential ingredient of flexible specialisation. However, the ability to pursue a strategy of flexible specialisation is considerably enhanced by the development of production technologies which allow the advantages of mechanisation at lower scales of production and employing a greater degree of flexibility than previously possible.

The consequences for labour of flexible specialisation, as interpreted by Piore and Sabel, has recently come under attack from radical critics. Shaiken et al (1986) find little evidence of the development of flexible specialisation in case-studied companies that might have been regarded as propitious for such a strategy. Instead they argue that the application of flexible production technologies has enabled the compatibility of managerial goals of incorporating product design changes and increasing management control over labour. Increased worker flexibility reflects the intensification of labour through the agglomeration of semi-skilled, mostly machine-paced, tasks rather than a return to craft autonomy. Thus, they conclude, market structure has very limited implications for the organisation of work; and the current restructuring of production is making batch manufacture "more like mass- than craft-production." (Shaiken et al 1986, p181).

Some commentators on the left have recently gone even further to equate flexible specialisation with neo-Fordism (Murray 1985, followed by Gough 1986). Murray does this by adopting a remarkably loose definition of flexible specialisation, which owes little to Piore and Sabel. Indeed, for Murray, flexible specialisation appears to be interchangeable with Aglietta and Palloix's conceptions of neo-Fordism. Murray and Gough thus argue that flexible specialisation is little more than a modification of Fordist methods of labour control enabled mainly by technological changes, which are seen as increasing exploitation and deskilling. On this view, what is called flexible specialisation by Piore and Sabel is compatible with the manufacture of non-standardised products using low skilled labour. It is argued in this thesis that this might be possible within a neo-Fordist strategy, but it is certainly not flexible specialisation.

Most of these interpretations of neo-Fordism contain conceptual difficulties which reduce their usefulness as theoretical frameworks. There is a tendency to undervalue the importance of particular management manufacturing and marketing strategies at the micro- level, which will affect the manner in which labour and technologies are deployed. Secondly, the idea of neo-Fordism tends to conflate the use of the concept of "control" in two senses. New computerised technologies are believed to enable tighter control over the production process while allowing greater production flexibility. From this it is thought to follow that tighter control of labour in detail ensues, which is assumed to be entirely compatible in turn with greater labour flexibility in such systems.

Against the first difficulty it can be argued that these varieties of "regulationist" approach overlook the manner in which eventual operating arrangements and organisation of labour in a given advanced manufacturing system are decided. Arrangements are conditioned both by particular and varying production objectives (which affect the dimensions of technical flexibility that may be sought) and by pre-existing labour control policies (which affect the dimensions of labour flexibility sought and achieved).

We wish to argue instead that the relationship between control of the production process and control of labour, and between measures of technical flexibility and labour flexibility, is by no means as straightforward or technically-determined as the neo-Fordist approach would suggest. It is agreed that the technical flexibility of computerised manufacturing systems can be interpreted ultimately as affording greater management control over production. However, it is unclear whether the achievement of greater control can be extended equally to labour. It seems possible, as some commentators have already suggested, that the exploitation of the potential for production flexibility of automated manufacturing systems is likely to require compromises between the needs for management control of labour as against the delegation of workgroup autonomy to optimise operations (Senker and Beesley 1986; Susman and Chase 1986). In other words, is it the case that the manufacturing flexibility implied by advanced production systems requires a loosening of

What did you like about the session?

What did you dislike about the session?

What changes would you suggest?

Was there anything missing from the session or which could have been left out?

Any other comments?

Please return to CLAIRE DEEMING.

control over labour?

iii) Background to the study

A considerable body of literature has been produced in recent years (discussed in Chapter Six) on the labour implications of the relatively numerous examples of two generations of stand-alone computerised machine tools, known respectively as numerically controlled (NC) and computer numerically controlled (CNC). This interest derives in large part from Braverman's (1974) seminal Marxist work on the labour process Labour and Monopoly Capital, in which NC is cited as a prime illustration of his theories of deskilling of craft workers, and the removal by managers of their control over the labour process. The debate engendered by this work (discussed further in Chapter Four) is indeed important as a precursor to themes that will be raised again in discussion of the "automatic factory". Also, Aglietta (1979, p125) and Palloix (1976, pp 54-56), use their interpretation of the labour process surrounding NC as principal items of evidence in their theory of a transition to neo-Fordism.

For writers such as these French Marxists, however, the increase in machine pacing and deskilling of machinists they attribute to NC is merely the prelude to what will happen under more advanced forms of mechanisation involving linked machine systems. A further empirical study of stand-alone computer-controlled machine tools was considered of little use, therefore, on the grounds that this technology does not necessarily involve the more sophisticated automatic transfer of parts and control of several operations implicit in the much-heralded "automatic factory" concept, and that the labour effects of NC and CNC were by now fairly well known (see Chapter Six).

Much of this earlier research demonstrates the continuing importance of many traditional craft skills with numerically controlled machining (Jones 1982; Sorge et al 1983 inter alia). Significantly, though, this research (largely of necessity) remains agnostic in its conclusions regarding whether this craft role would diminish with the development of more advanced forms of computerised automation. This study therefore investigates the research questions raised in the above sections by reference to applications of a major component of the technologies subsumed under the rubric of the "automatic factory".

A reading of the above research suggested three preliminary working hypotheses. Firstly, it was thought that the possibilities for workers, their organisations, and designers to influence the skill requirements for, and work organisation surrounding, such systems can be identified. Secondly, it was believed that the reasons why such possibilities have remained untried in Britain are institutional and political, as opposed to technical. Finally, it was hypothesised that the most advanced forms of automation, at present in formative phases, will be more susceptible to attempts to adopt skill-maximising forms of work organisation [8].

The most advanced machining technology operational to date in the small-batch engineering sector is the so-called flexible manufacturing system (FMS). This incorporates both the additional transfer and control functions of the kind proposed in the "automatic factory" (see Chapter Two for a full definition of FMS) [9]. There is now a considerable literature on FMS, as Senker (1985, p37) also notes, but this has overwhelmingly been of a technical or normative nature. Because of a lack of such installations until the very recent past, in-depth empirical case studies of labour roles in such systems were almost non-existent at the time this research project commenced. A notable exception was the work of Blumberg and Gerwin (1981), which referred mainly to relatively early (and unreliable) FMSs in the USA. There was no parallel coverage of the sprinkling of British systems existent in 1983 other than sporadic, rather superficial, and often exaggerated or inaccurate, articles in managerial and technical journals [10]. FMS was therefore felt to be the most appropriate test case to establish the veracity of existing theories of changes in labour roles resulting from current upheavals in technology and industrial structure.

iv) Overview of the thesis

The thesis is presented in the following manner. Chapter Two gives our definition of a flexible manufacturing system and provides the historical background to the development and diffusion of the technology in Britain. It also shows how the fifteen FMSs studied for this project relate to the total population of such systems, and explains how the fieldwork for the research was conducted.

In Chapter Three it is argued that there are three main dimensions to "automation" in production techniques: mechanisation of the transformation, transfer and control processes. Of these, control mechanisation now possesses the greatest potential for future development. Its importance in this thesis lies in the fact that control mechanisation is now believed to enable the encapsulation of much of the expertise and ingenuity formerly the monopoly of human skills.

Chapter Four therefore investigates the question of the relationship between mechanisation and skills. It proposes that some previous influential approaches to this question, notably the "labour process" and what I call the "technicist" views, have been flawed because they have ignored or underestimated the fact that outcomes for skill changes depend on the division of labour. A distinction is thus drawn between technically-determined tasks and work roles, which depend on additional factors. The "sociotechnical" approach acknowledges this distinction, but simplifies the process whereby expanded work roles can be adopted to mere managerial choice. I argue that, although managerial preferences for labour control are probably the most important determinant of work roles, product and labour market factors, and inherent task variability are also independent influences. The other main theme in Chapter Four is the importance of workers' tacit skills, which are difficult to automate out of the production process. Their often unacknowledged but vital role allows production workers to continue to exercise a measure of control over the production process, even despite mechanisation.

Applying the above grounding to the machining labour process in the small-batch engineering industry, Chapter Five discusses the nature of craft skills and control. The reasons for its persistence, despite management attempts to rationalise production, are discussed with reference to the factors affecting work roles introduced above. It is argued in conclusion that, using conventional technology and functional organisational methods, managers have been unable to achieve the high degree of production flexibility required without sacrificing goals of productivity and control over the manufacturing process (which has been surrendered in part to craft workers).

Chapter Six looks firstly at the recent organisational changes (group technology) and technical innovations (numerical control), which jointly form the basis for flexible manufacturing systems, that have been proposed to harmonise these three manufacturing aims. It finds that, applied singly, these innovations have not been able to achieve the three objectives simultaneously. In particular, fragmenting product markets have resulted in more complex production demands and increasing variety. These factors, coupled with the complexity of the new innovations, have often resulted in more local desion-making by machinists, and hence higher levels of skill and control. Secondly, FMS is located within a continued concern to enhance productivity, manufacturing flexibility and control simultaneously in batch engineering. The preliminary evidence indicates that a choice must still be exercised between which of these benefits are sought. Also, the meaning of "flexibility" in FMS is found to be extremely varied and ambiguous, and seven definitions uncovered of the term are given.

Chapter Seven applies the earlier discussion on tasks, skills and work roles to the FMSs studied. The types and levels of skill are discussed from an analysis of those remaining human task functions. Much of the confusion in the literature about the effect of FMS on required skills is ascribed to the fact that expertise appropriate to process, mass- and craft production can all be found in some measure. The continued role of traditional engineering craft skills is confirmed. Finally, an overview is given of the changes in work roles that occurred at the systems studied. Horizontal labour flexibility and vertical mobility between FMS servicing and ancillary functions (such as inspection, loading and toolsetting) are found to be common, but there is less evidence of flexibility between crafts (most notably between production and maintenance) or of operator intervention in managerial functions, above all in programming and determination of working methods.

Chapter Eight investigates the reasons for what seems to be the relatively restricted incidence of extensive flexibility, and the virtual absence of autonomous workgroups (as proposed by sociotechnical authors). It shows that job design in FMS is normally treated as a belated adjunct to technical criteria, and informed by wider institutional cultures and labour relations policies. Given the nature and size of most of the plants visited adopting FMS, work organisation policies tend on the one hand to have the effect of undermining craft control by favouring a restriction of operator intervention in methods decisions and promoting a higher degree of task flexibility than elsewhere on the shopfloor. On the other hand, a tendency to permit FMS operators some genuine autonomy in system intervention and performance of their tasks is noted. These latter features are more pronounced at greenfield sites and smaller plants less hidebound by previous demarcations. A case study of one plant, where explicit plans for an autonomous workgroup were reversed as a result of the adoption of more tradional labour management policies, underlines the influence exerted by plant-level institutional constraints.

Chapter Nine tackles the question raised by the debate between "regulationist" and "flexible specialisation" approaches of whether, and how far, different frameworks for job design and managerial labour control preferences can affect the achievement of overall manufacturing control, productivity and production adaptability. It also questions the extent to which a role for labour autonomy is recognised by management. It finds firstly that the paucity of managerial expertise in FMS process technology, coupled with a reliance on informal, on-the-job learning, in Britain has resulted in the tacit knowledge of FMS operators becoming crucial in making FMS operational. This is confirmed by an almost ubiquitous management preference for the recruitment of craft-trained machinists as FMS operators, whose tacit skills and ability to intervene autonomously to solve production problems allows them a measure of control in the manufacturing process. I produce evidence to show that managers are sometimes still unwilling to cede such control, especially in system programming. The price of such reluctance, however, is often reduced productivity and restrictions on the ability to switch between products and expand the part spectrum machined.

The main conclusion is that in many respects there is still a vital role for traditional machining craft skills in flexible manufacturing systems, as FMS is still basically a technology for machining (albeit a sophisticated one). The expertise conferred, particularly by the tacit element of these skills, has allowed craft workers to exert a pivotal role in the commissioning and operation of FMS. Craft skills allow the absorption of unfamiliar technology with minimal organisational dislocation and enhance the ability of FMS to respond to new market requirements, and greater production flexibility above all. This disproves the "deskilling" claims of many "regulationist" analyses.

Despite the importance of craft skill, managerial labour control preferences, informed by pre-existing institutional and relations contexts, tend in many plants to discourage the exercise of craft autonomy. Work roles adopted are indeed more flexible, but normally limit operators' intervention in determining production methods. Advocates of sociotechnical job redesign and "flexible specialisation" have failed to take these contextual constraints sufficiently into account. Experience suggests that *de facto* relaxation of labour controls occurs to the extent that craft skills are proved necessary to solve machining problems and enhance the production capabilities of the technology.

CHAPTER TWO: Flexible manufacturing systems: the research project

i) Defining FMS

This study follows the definition of FMS adopted by the British Government's Department of Trade and Industry (DTI) in its guidance notes for companies applying for financial support for the introduction of such technology [1]. This definition is appropriate as it has been very influential in Britain, mainly because most of the FMSs installed to date have benefited from grant aid awarded subject to conformity with the DTI's definition of FMS. The FMSs studied in the research were among these beneficiaries. The Department of Trade and Industry (1984) states that:

> Flexible manufacturing is a system which combines microelectronics and mechanical engineering to bring economies of scale to batch work. A central on-line computer controls the machine tools and other work stations and the transfer of components and tooling. The computer also provides monitoring and information control. This combination of flexibility and overall control makes possible the production of a wide range of products in small numbers.

Although we talk of flexible manufacturing systems in practice we shall be referring exclusively to flexible machining systems.

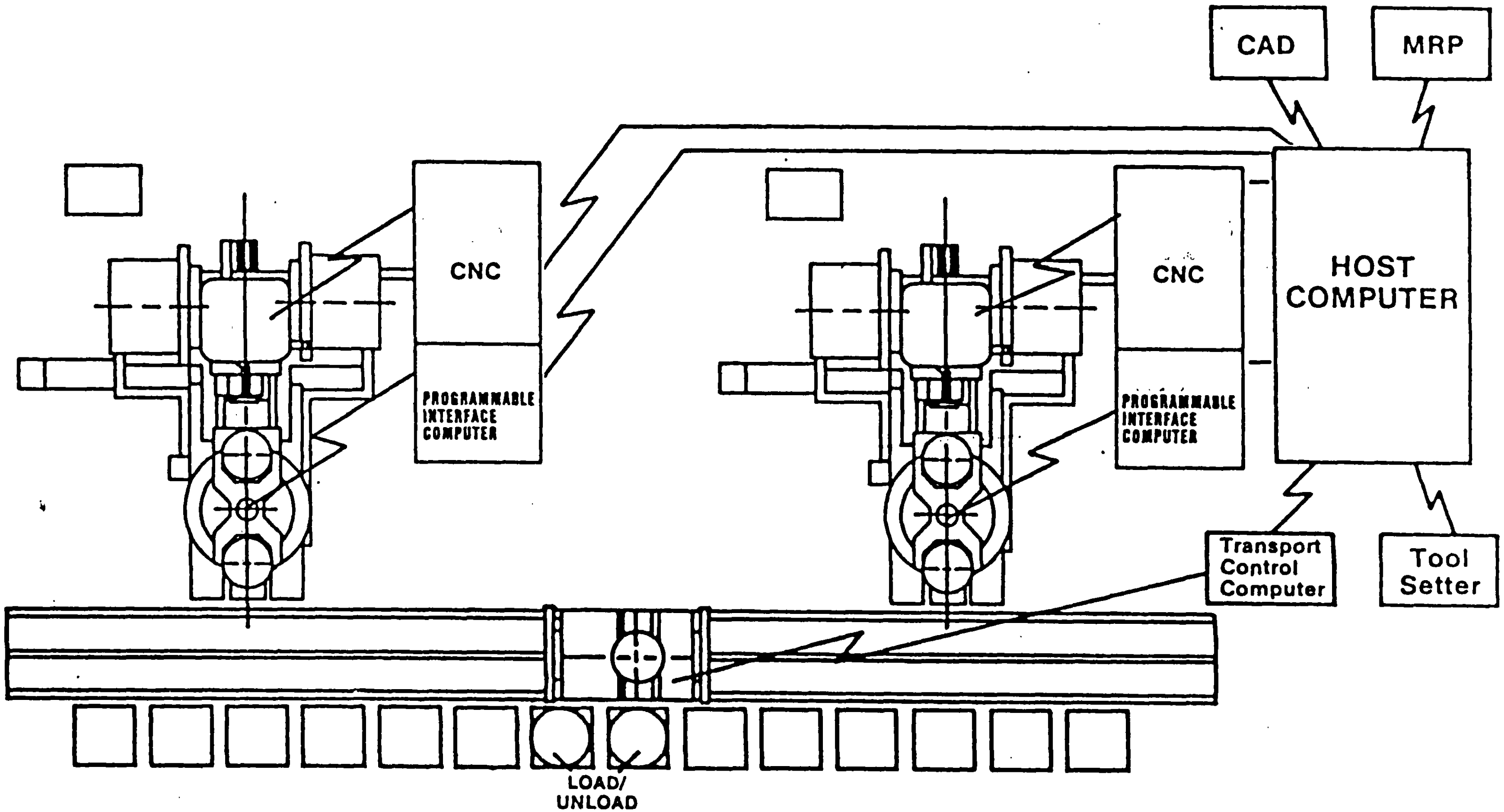
Because of the current paucity of non-machining applications (and the fact that only machining systems were studied in the project fieldwork) we shall continue to use the term "flexible manufacturing system" to refer to machining systems in the present context [2].

As a technical concept FMS is based upon the combination of the organisation of parts into families of like components (as proposed by group technology (GT)), the numerical control of machining, and the overall computer control of activities introduced by direct numerical control (DNC) (see Chapter Six). Some restriction on the range of parts which can be machined on an FMS is necessary in order to try to balance the levels of utilisation of the work stations in the system, and to put a practical limit on the number, variety and complexity of hardware and software features required. An FMS is therefore used to machine families of parts of similar size and shape requiring the same sorts of machining operations (Ross 1981, pp 32-33). An example of this would be a set of valves, each of slightly different sizes but all requiring the same kinds of consecutive milling, drilling and boring operations.

In at least two ways FMS comprises a technical advance on the separate application of group technology and stand-alone numerically controlled machine tools. Firstly, unlike most GT applications, materials transfer to different machines within the system boundaries is mechanised, usually being performed by means of robot, automatic guided vehicle or rail-guided truck. Setting-up for an entire sequence of operations only needs to be performed once initially, and can now be carried out remotely from the machine tools. This relieves the need for repeated manual setting of parts on each individual machine in FMS, thus eliminating a major cause of machine downtime. Secondly, all the major elements within an FMS (that is, the transport system, machine tools and overall system management) are now subject to direct numerical control from a supervisory (or "host") computer. This enhanced control facilitates the improved central coordination of workflow, enabling more accurate information on, and better control of, components in the system, improved utilisation of technical resources, and faster throughput. A typical FMS is illustrated in Figure 1 overleaf.

ii) <u>The development of FMS in Britain</u>

Machining systems described and commercially operated as FMS first appeared in the United States in the late 'sixties to early 'seventies, although none of these were really flexible in terms of numbers of different parts processable (Harrington 1973; Ingersoll Engineers 1982). Yet it was a British maker of tobacco-processing machinery which in fact pioneered the flexible manufacturing concept in the late 'sixties. The firm, Molins Ltd., dubbed this first FMS System 24 [3]. This system, as explained by one of its principal designers, Theo Williamson (1968b), was intended to automate and integrate the machining and control aspects of a group technology cell in order to manufacture a wide variety of



Full FMS

FIGURE 1

A TYPICAL FMS

(Reproduced by permission of Kearney Trecker Marwin Ltd.)

components with a minimum of human intervention. The overall manufacturing concept and technical design of the system were indeed revolutionary for batch manufacture at this time, the system's ability to break with the past helped by the fact that the firm was aided by government finance and able to install System 24 in a new building.

Unfortunately for Molins, System 24 as a whole was too premature to meet with commercial success, although a number of the machine tools were marketed (Anon 1969). Conceived of prior to the advent of the microelectronic era, the relatively unwieldy and primitive generation of computer power available in the 'sixties meant that software and controls were unequal to the extent of the tasks expected of them. Molins' ideas were too advanced for the technology available at the time, and the firm subsequently abandoned machine tool manufacture. Combined with the problem of a lack of sufficient finance to further the system's development it only ever ran on a demonstration basis (Jablonowski 1985b, p131) [4].

The manufacturing concept embodied by System 24 did provide the foundations on which further development of FMS could take place. The immediate initiative for innovation moved abroad however. In some advanced countries, notably Japan, this was encouraged by coordinated programmes of targetted state aid aimed at developing the ability to automate batch production (Hutchinson 1979). Domestic FMS impetus after the demise of System 24 only resumed in the mid-'seventies when the Labour Government's Department of Industry, concerned at lagging British performance in the field, set up a body known as the Automated Small Batch Production (ASP) Committee. As had also been the case with System 24, this originally comprised a series of research projects to develop redesigned machine tools capable of running with considerably reduced need for human attention (National Engineering Laboratory 1978).

This programme was viewed initially as a large scale mechanical engineering concept (although with relatively limited state funding). However, it became rapidly clear during these initial projects that these aims were too grandiose in scope for the smaller-scale potential applications more likely to be useful in British batch engineering. Also it was discovered that a considerable number of the features deemed necessary to facilitate the level of machine tool automation proposed already existed in a workable form (Anon 1981a) The ASP Committee's emphasis therefore changed to reduced scale projects with individual firms applying for help. For the later projects it was intended that to qualify for government grant aid in developing FMS each scheme financed must represent an increasing level of automation in some way on its predecessors (Hollingum 1980).

Little hard evidence can be found to suggest that the ASP initiative encapsulated a coherent national manufacturing strategy. At one point the Committee's chairperson was reported as recommending the use of "very high technology to manufacture low technology products cheaper than the rest of the world" (Anon 1982a, p34) - in other words, offsetting the disadvantage of high British labour costs (in comparison with newly-industrialising countries) against low unit capital costs enabled by overall economies of scale. This, of course, is classic Fordism! Yet the above statement is not matched by the reality of subsequent developments. As we shall see, few British FMSs fit this criterion (although penetration of FMSs into manufacture of low-value goods such as gears and valves has recently begun to accelerate). This is in large part due to the untargetted nature of government finance towards any specific industrial sectors. Instead, FMS developments by firms in Britain have by and large assumed the form of *ad hoc* responses to immediate commercial pressures (Hatvany (ed.) 1983; Jones and Scott 1985, pp 150-151).

The most recent direct form of government aid has centred upon a FMS support grant scheme enabling firms to recover up to half of the costs of a feasibility study for, and a third of the costs of, installation of an FMS (Department of Trade and Industry 1984; Sims 1983), although this was only initiated as late as mid-1982. An overall allocation of £35 million was fixed and was rapidly exhausted, being replaced with an Advanced Manufacturing Technology Scheme of somewhat wider scope (Kochan 1984b; Sim 1984). Other forms of financial support common to other purchases of capital equipment may of course also be available.

Sim (1984, p136) states that thirty three FMS installations received government aid under the FMS Support Scheme, sixteen of which were in companies employing less than five hundred workers. Since the exhaustion of government aid a slower but still steady trickle of new schemes not receiving grants have been announced and installed. In total, evidence from this research suggests that some fifty-two projects conforming to the DTI's definition of FMS have been completed or are still being installed at the time of writing. This means that Britain is now becoming a comparatively large user of FMS in European terms, being on a par roughly with West Germany (Kochan 1984b, 1985). The above figures probably slightly understate the full position owing to the likelihood of some planned projects remaining unreported in the technical and trade press. The FMSs can be classified according to industrial sector as shown in Table 1 overleaf.

Table 1 shows that FMSs are in fact being applied in extremely heterogeneous manufacturing applications, encompassing relatively high volume consumer products (like automotive parts), very low volume production such as die-making, and much in between. Capes (1985), in a thumbnail sketch of the pattern of FMS adoption in Britain, also finds such a diversity [6]. He interprets this in terms of existing flexible manufacturing systems having been installed for two conflicting reasons. Either firms have wished to maximise productivity by using FMS to produce a very narrow variety of parts; or it has been intended to produce a large number of dissimilar parts in sets.

TABLE 1

BRITISH FMS PROJECTS PLANNED OR OPERATIONAL AS OF JUNE 1987 [5]

SECTOR	NO. OF COS.	PROJECTS
1) Aerospace	5	10
2) Machine tools	6	8
3) Diesel engines	4	6
4) Earthmoving equipment and vehicles	4	6
5) Compressors, pumps, valves unaccounted for elsewhere	4	4
6) Misc. automotive	3	4
7) Automotive components	3	4
8) Misc. capital goods equipment and industrial machinery	3	3
9) Mining machinery	2	2
10) Tool and die manufacture	2	2
11) Marine engineering	1	1
12) Domestic heating appliances	1	1
13) Turbines and electrical power generation equipment	1	1
TOTALS	39	52

Thus we must distinguish between two broad concepts of FMS application in Britain. On one hand, FMS can be conceived of as one method whereby manufacturers in industries still producing at relatively high - albeit reduced - volumes (such as motor vehicles) may respond to more differentiated and competitive product markets. Some commentators, such as Goldhar and Jelinek (1985), have argued (perhaps rather overoptimistically) that, for such applications, FMSs are now capable of superceding the "productivity dilemma" identified by Abernathy (1978) in the car industry whereby increasing efficiency is directly related to less innovation. As Senker (1984, p135) notes, for relatively large volume producers (such as automotive manufacturers) FMSs may be more expensive than the traditional transfer lines but the superior productivity and flexibility of FMS may well result in their becoming more economic for such applications, especially as FMS can be turned to alternative uses if necessary rather than simply scrapped. Edgehill and Davies (1985) demonstrate further that many "flexible" manufacturing systems world-wide do not possess the ability to process wide part varieties at low volumes (as the DTI definition of FMS would suggest). Rather, these FMSs merely modify the main features of the Fordist type of automation (through producing in reduced, but still high, batch sizes, for example).

Alternatively it is possible to view FMS in the sense suggested by the DTI definition. This sense suggests the use of FMS in capital goods manufacture to more economically produce wide varieties of components (subject to their formation into part families) in low batch sizes, or even in sets, as and when required.

FMS - in common with other forms of AMT (Anon 1986; Harrison and Dunn 1986; Ingersoll Engineers 1985) - is not yet particularly widespread in Britain when set against its total potential for applications in batch engineering, despite the now discontinued state financial help (see also Kochan 1984a; Pullin 1986a). Indeed, investment in such systems is now claimed to be falling (Anon 1986). It also seems likely that the relatively high diffusion of FMS in sectors such as automobiles, machine tools and aerospace has been speeded by factors inapplicable to other parts of batch engineering. In the automotive sector and its component suppliers (classified under headings 3), 4), 6), and 7) in Table 1) take-up of FMS and other automated equipment has been encouraged by some of the most competitive product markets. For machine tool producers, as Kochan (1984a) says, the conditions for investing in FMS are "somewhat false", being also concerned with demonstrating ability as an FMS supplier to potential customers. And availability of the necessary finance appears to be a lesser problem in the highly capital-intensive aerospace industry than in other sectors.

A recent survey (Pullin 1986b) of advanced manufacturing technology in batch engineering companies provided a number of reasons for this lack of diffusion, which are reinforced by the evidence of other studies. All of these reasons have been applied specifically to the lack of FMS take-up [7]. The principal reason given for a lack of adoption of such technologies is the belief that products manufactured are too varied to permit the feasibility of automation. A second reason is a lack of finance, sometimes coupled with an inability to financially justify the necessary investment according to a payback period of typically two to three years [8]. Thirdly, it is suggested that firms' awareness of advanced manufacturing technology is not matched in many companies by possession of the necessary in-house expertise and skills to install and operate such equipment. This is further exacerbated by insufficient planning, development and training time for new innovations being made available by senior management (see later chapters for an applied discussion of these points). Particularly in the case of FMS, its complexity is a significant barrier to more widespread adoption, especially if firms have little or no prior experience of CNC, or unhappy histories with previous computerised technologies [9]. One recent claim also suggests that machine tool suppliers are now becoming disenchanted with offering FMS projects due to their complexity (Holland 1986b).

It is of course quite possible that companies may well be addressing their production problems with different and less complex solutions than FMS. Indeed several management commentators claim that many FMS benefits are in fact obtainable by changes in the preparatory organisation of the manufacturing methods rather than the technology itself (Dempsey 1983; Small 1983). Bessant and Hayward (1986b) even conclude that in some cases the same benefits that firms hoped to obtain by adopting FMS technology would have been realisable by the alternative (but less popular) route of reorganising production methods.

iii) The case studies

Fifteen plants (Plants A-R) were studied in the research. It is therefore believed that this survey is the most comprehensive to date on social aspects of British flexible manufacturing systems. These fifteen plants were owned by the same number of companies, which represent a sub-set of the thirty-nine companies believed to have introduced FMS in Britain (see Table 1). The plants concerned were located throughout the country between the south coast and Tayside and variously employed from twenty to one thousand direct workers, although medium to large companies were more common in the study. Importantly a considerable variety of capital equipment (such as mining machinery) and consumer goods (such as passenger car gears) were manufactured in the companies studied, thus giving access to several different industries, product markets, and manufacturing requirements, and hence to examples of both the concepts of FMS application identified above. These plants include the locations of eighteen out of the estimated current total of fifty-two FMSs. Thirteen of the FMSs studied were running on a production basis by the time of final interview. This study includes a wide cross-section of British FMSs in terms of size, cost, machining application and complexity.

The sample possesses the added advantage that nearly half of the companies known to be introducing FMS during the period of fieldwork were studied. Thus the results obtained can be justifiably considered as representative of the limited total population of FMSs in Britain. Further details of the FMSs studied can be found in Appendix One. At least one firm each in sectors 1)-9), and the firm in sector 11), in Table 1 is included in the study. We are therefore in an authoritative position to discern the development of any national trends in patterns of labour utilisation and skill requirements in British FMSs.

A number of other plants first approached (Plants T-Z) proved unsuitable for the study. This was because - despite first reports (and often press claims too) - the machining systems being introduced did not fit the DTI definition of FMS; or because plans to introduce FMS were abandoned (Plant T) during the fieldwork period, or subject to reconsideration at the time of interview (Plant X). These plants did however provide some very useful information on aspects of the usage of stand-alone CNC machine tools, which both complements and contrasts with research published elsewhere. Details of these plants are included in Appendix Two. Separate reference to some of the information from these plants has been also included in the body of the thesis where appropriate for comparative purposes with the more integrated FMS systems described.

Although the decision to introduce FMS makes these plants atypical of small-batch engineering as a whole the wider context in which these investment decisions occurred is probably quite typical. In nearly all cases the companies concerned had suffered falls in output and sales of varying degrees of severity as a result of the recession in British manufacturing industry of the early 'eighties. Several of the worst-hit plants were those of the mature industries in the survey, most of which were also located in regions badly affected by recession, such as the Midlands, North-West and

Scotland. In response to the recession the plants concerned had cut capacity and costs, notably through attacking staffing levels. In those firms outside the aerospace sector (which had suffered proportionately least) it was far from uncommon for the workforce to have been roughly halved in the approximate period 1981-85 with direct labour bearing the brunt of these losses. In these firms adoption of FMS was part of a continuing process of readjustment to changing manufacturing conditions and modernisation of technique and working methods.

Only two of the FMS companies studied had expanded their business during the recession and taken on workers (although it may be significant that both these companies were planning to use FMS to reduce their need to hire additional labour to accommodate increased demand). These were Plants G and K, which - perhaps also significantly - were two of the three small companies visited installing FMS.

FMS development on greenfield sites only occurred in the cases of Plants P and R. These two plants were the earliest and most experimental systems in the study, and greenfield sites had been chosen mainly because of these factors. The possibility of installing FMS on separate sites was discussed at a number of other plants (such as Plants A, B, and C), but ultimately rejected on the grounds that it was thought important to acclimatise the workforce as a whole to major technological innovation.

iv) Methodology

In common with much previous research in this subject area a qualitative methodology was adopted (Buchanan and Boddy 1983; Buchanan 1985; Cockburn 1983; Jones 1982, 1985b; Pendleton 1986; Wilkinson 1983; Wilson 1985 inter alia) [10]. Data was gathered by means of semi-structured interviews with relevant personnel in the case study plants [11].

Fieldwork was carried out between March 1984 and August 1985. Access was gained via production engineers or middle managers responsible for the introduction of the plants' FMSs, who were interviewed in the first instance [12]. In most cases, two visits were paid to each of the plants, during which time interviewees were broadened to encompass FMS technical, supervisory and operating personnel as available. A small number of the FMSs exhibiting particularly interesting features for the purposes of the research were selected for more detailed study. These were visited at least three times. Interviews with further personnel were conducted in these cases. The longitudinal element in many of the case studies was valuable as labour policies were frequently found to be subject to amendment between visits.

The approach developed in this research project assumes that the skills required, and forms of work organisation adopted, in flexible manufacturing systems can only be understood in terms of the wider context of employment, market, and production developments within the plants concerned. Firstly, therefore, information was sought from production engineers and managers on the history, markets, and particular production problems of the company; and such background details as the numbers employed, relationship with the parent company (if appropriate), and details of the sites on which the company operates. These sources were supplemented by literature published by the companies concerned, and relevant press articles.

Specifically as regards FMS, production engineers and managers were asked about reasons for adoption; benefits intended; problems encountered in development and use; anticipated and actual effects on skills and working practices; procedures for programming, tooling, fixturing, inspection, supervision and maintenance; criteria for the recruitment and selection of FMS personnel; and FMS training programmes. Technical information about the configuration, operation and capabilities of the FMS was also obtained.

Operating personnel were asked questions about their former working background, their recruitment to and training for the FMS, their job responsibilities and particular problems encoutered in their work. They were also asked to expand on their subjective feelings on the advantages and disadvantages of work on such systems compared to their previous work experience, with particular reference to the changes in skills and autonomy they experienced. Union representatives were asked about labour relations policies generally within the company; and about policy issues in relation to the FMSs, such as what negotiation took place over introduction and their attitudes to demands for greater working flexibility.

CHAPTER THREE: Understanding "automation" in manufacturing

i) Introduction

According to the Oxford English Dictionary something that is "automatic" works "of itself, without direct human actuation". Hence "automation" consists of "automatic control of manufacture of product through successive stages; use of automated equipment to save mental and manual labour." On this view "automation" consists of changes in technology, whose distinguishing features are that (unspecified) functions formerly undertaken by human worker are now performed by machine.

The superficial plausibility of this definition conceals a number of problems, which we intend to clarify in this chapter. In the first place the breadth of our definition of automation must depend in turn on how we define technology. Secondly, when humans work they may be undertaking several different kinds of mental and manual activity, some of which are more complex than others and therefore require competences (or skills) that are different in extent and kind. Simply being told that a function is being removed from the worker leaves unanswered the important question of what kind, what order, of human function in terms of mental or manual activity we are talking about. Here we shall first establish what we mean by technology before going on to consider how changes in technology relate to automation.

Some definitions of technology are very broad, encompassing far more than simply machinery. Winner (1977, pp 8-12) defends a wide-ranging definition of technology, which he takes to include what he calls "technique" (skills, methods, procedures, etc), varieties of social organisation such as factories, and communications networks as well as technical apparatus. Similarly Hill (1981, p86) suggests that a definition of technology should encompass "all forms of productive technique" (including the unaided human hand and brain), the physical organisation of production, and the notion of these aspects being the product of conscious human design and direction.

The danger of definitions this wide is that they become too unwieldy to use as precise analytical tools. One of the purposes of this thesis is to suggest that technical apparatus may be used in manufacturing activities to produce several different outcomes for skills and methods of working dependent upon factors extraneous to the apparatus itself. For example, it might be reasonable to suppose that developments in apparatus are interrelated with changes in production methods (such as work study techniques). It seems wrong, however, to obscure these relationships between essentially different phenomena by subsuming them all under the heading of "technology". By way of brief illustration of this point let us examine Hill's definition of technology. In referring to the necessity of considering the organisation of production as part of technology Hill describes the former as implying "the division of labour and work organisation... <u>built into</u>, or <u>required</u> for efficient operation by the productive technique." (Hill 1981, p86 -

emphases mine (PJS)). This claim gives unwarranted credence to the idea (argued to be erroneous below) that work organisation is determined by the choice of productive technique. To sidestep such problems this study follows Rose et al (1986, p19) in adopting the restricted definition of technology as comprising machine hardware and software.

ii) Main trends in manufacturing production processes

Woodward (1965) identifies three main types of method which have evolved over the last two hundred years for the manufacture of goods, each of which has successively demonstrated the use of a greater degree of technology in the production process. In their order of development she calls these unit or small-batch production, large-batch or mass production and continuous flow process manufacture. Small-batch production of discrete components in factories, developed after the eclipse of the artisan during the industrial revolution, has proved the most persistent of these forms. By the twentieth century the expanding market for certain types of consumer goods caused this to be complemented (but crucially, not supplanted) by the extremely inflexible form of batch production known as mass production for manufacture and assembly of large numbers of a small variety of discrete components. Finally the manufacture of non-discrete goods (such as chemicals and metals) was transformed from a batch to a continuous flow process. Today all three of these forms of production co-exist but the relationship between them is becoming increasingly blurred.

To understand this claim it will be necessary to briefly investigate the evolution of these different production processes.

In the period preceding the industrial revolution items were normally made individually by craft workers. An individual would take responsibility for the complete manufacture, assembly and even the sale of the chosen article. Hand tools were used to fashion the product. Because of the expertise demanded by this method of manufacture, the rudimentary nature of most of the technology involved and the low division of labour it is the accepted wisdom that this system eventually broke down because of an inability to manufacture quickly enough by these techniques to satisfy the expansion of market demand for the products. Certain radical critics of this view, notably Marglin (1978), have however maintained that inability to maintain control over labour was the main reason for the breakdown of this system.

Initially coexisting with and finally almost completely replacing the above system was the factory based system of "machino-facture". Workers were gathered together in factories to use general purpose machines to produce items in batches. Batch production based on similar principles continues to the present day, as there are countless examples of products with levels of demand insufficient to allow other methods of production to become economically viable. However, by the nineteenth century there were also many products for which an emerging mass market would facilitate an increasingly high sub-division of labour based around the development of new types of specialised machinery allowing repetitive manufacture. Unlike the artisanal system "machino-facture" gradually enabled the production of large numbers of parts at much lower unit costs.

Nevertheless such machinery was normally too inaccurate to achieve the production of parts without the need for considerable subsequent hand fitting work in assembly. Until about 1880 it was only in the American government armouries that such a standard of precision was regularly achieved. In the USA this form of manufacture became known as the "American system", which evolved initially because of the need to produce large numbers of interchangeable parts for armaments. The requirement for interchangeable parts to counter the assembly bottlenecks otherwise remedied by hand fitting only became really pressing in the minority of industries manufacturing at very large scales of production and so did not diffuse widely (Hounshell 1984) [1].

The next major development came during the early years of the twentieth century when Frederick Taylor introduced his work study doctrines. These were intended to improve productivity in a number of factories undertaking large-batch and process production (such as the iron and steel industries) by eliminating inefficient labour and management practices. To do this it proposed the accumulation and systematisation of working knowledge in the hands of management, thus substituting defined procedures and "science" for the variability of the "rule of thumb" (what Taylor referred to as finding the "one best way" to perform a given task) (Taylor 1929).

It also proposed an increase in the efficiency of labour by substituting less skilled (and therefore cheaper) for skilled workers wherever possible. Taylor's scientific management doctrine was not therefore a technological development in the sense we have defined the term so much as a methods and work study exercise (Hill 1981, p27). Nevertheless, as part of the process of optimising procedures, Taylorism did for example lead to the introduction of new coolants and high-speed steels to facilitate faster metal-cutting, (Taylor 1929) [2].

The intermeshing of organisational methods with technology was not long in coming, however. Around the time of the First World War the emerging Ford Motor Company introduced an advance on Taylorist production principles in its American factories. This heralded an era of "mass" production on a hitherto unimaginable scale of vast numbers of identical consumer goods. At the level of production techniques Fordism combined interchangeability of parts, line balancing and scheduling methods, and work study techniques with certain technological concepts. This combination could be achieved because Taylor's "scientific management" simplified the production process into a series of fragmented and specified routines, thereby laying the basis for the subseqent possibility of automation. Ford's innovations went beyond Taylor's ideas by building control over the speed and intensity of work into the machinery itself. As Sabel (1982, p236, note 5) says, because the "Fordist system of special-purpose equipment" accomplished "partly by mechanical means what Taylor wanted to do through administrative control....

Taylorism presupposes Fordism and Fordism implies Taylorism."

Ford developed single purpose machine tools, which were only capable of each producing one fixed type of component, but the potential disadvantage of this inflexibility was outweighed by the fact that they were intended to be in constant use. The "technical control", as Edwards (1979) has described it, was achieved by adding the concept of mechanised transfer lines, which carried components to the workers at specialised work stations at a speed predetermined by management. The remaining crucial innovation of Fordism was the extension of these principles to the assembly process. Drucker (1967a, pp 19-20) notes that little if any of the technology used by Ford was novel. The originality behind Ford's production process lay in the systematisation and integration of existing technologies (such as the special-purpose machine and the assembly line) and the organisational concepts described above. This automation (known as hard or Detroit automation) was dedicated to manufacture of a product of fixed design, and difficult if not impossible to adapt to other purposes. However, it did enable the manufacturer to benefit from great economies of scale and hence sell products at low costs to large markets [3]. The approach still remains influential to this day.

By the mid-twenties the heyday of this rigid form of automation had passed at Ford, although the basic features of the system were still to become far more widely diffused in the motor and other consumer goods industries in the next thirty to forty years. The main disadvantage of the early Detroit approach was the rigidity of its product lines and of the machinery to specific production, which were the principal factors contributing to a lack of product differentiation. The resulting saturation of the market caused by the very success of these mass production methods made it difficult to continue to generate sufficient sales to allow the necessary high levels of equipment utilisation (Hounshell 1984).

The development of a limited degree of production flexibility permitting minor product differentiation was employed by rival car manufacturers (initially under Alfred Sloan's influence at General Motors) with some success. The main disadvantage of this latter approach, irresoluble in mass production until recent years, was the expense of providing the technical flexibility to diversify production at scales of output still so high. The costs included those of the redundant machine capacity, work in progress, high stock levels and - most importantly - the long lead times necessary to change over dedicated lines to manufacture of even a slightly different product.

The advent of the early generations of computers in the years after World War Two provided a new and powerful boost to the ability to automate other, new, areas of manufacturing. In particular it now became feasible for certain non-discrete products hitherto made in batches to be manufactured as a continuous process. Initially this affected those industries where the product was in liquid or gaseous form (such as oil refining), for in such cases the automation of the handling and transformation of the raw materials, which could often be completely enclosed, was technically simpler by such methods (Noble 1984, pp 58-59). More novel, however, was the fact that computers were now also applied to the regulation and control of these continuous manufacturing processes. Importantly, such applications demanded little flexibility in terms of the end product manufactured so, at least in this respect, the nature of the production process did not differ significantly from the inflexibility and high volumes of the mass production industries. The application of this degree of capital intensity to the production of discrete items (whatever the batch size) has however remained a technologist's dream until recent years with the advent of the microprocessor.

iii) Categorising "automation"

The above section described the development of the main types of manufacturing production process from the middle of the last century to the present with particular reference to the changes in technology involved. The common thread in each of these different production processes is a tendency for increased capital intensity substituting for human labour. It is this that is often characterised as "automation". It is believed that the term "automation" was first used in connection with the transfer mechanisms used by the Ford Motor Company (Winch 1983a, p2). But, as Bell (1972) and Cohen (1975) point out, the word has also been employed to refer to mechanisms equipped with control feedback facilities, and also more diffusely as a metaphor for any activity occurring without a need for human intervention. If we hope to assess the effects on labour of particular forms of automation further preservation of such ambiguities will be a source of confusion (Bell 1972; Coombs 1984). It is clear that the types of development described have in common the fact that they replace a human input to the production process. Therefore the problem is that, as Coombs (1984, p148) observes:

> Any technical change which replaces a human activity, particularly with some skill or mental component, becomes a candidate for description as automation.

This "definition" may well encapsulate the popular view of what constitutes automation but is inadequate as a theoretical basis on which to proceed, because the kinds of human input being superceded are actually widely different. We must therefore arrive at a usable definition.

The first influential attempt to categorise "automation" can be attributed to J R Bright. Bright defines automation simply but tautologically as "something significantly more automatic than previously existed in that plant, industry or location" (Bright 1958, p67). It follows that he sees automation as being an evolutionary process. Despite the deceptive simplicity of his definition, however, he develops a scale of automation comprising seventeen levels of mechanisation in which the major dependent variable is the degree of control over the performance of the production process built into the machinery as opposed to the human operator. Thus, beyond a fairly elementary level of interaction of the worker with a single power-assisted machine, it is proposed that the ascending levels of automation represent an increasing atrophy of the function of control over the production process performed by the human being. For a long time this linear scale of classification represented the only serious attempt to categorise "automation", and its influence should not be underestimated. This is particularly noteworthy in view of the fact that Bright's taxonomy is adopted uncritically by Braverman (1974, pp 213-223) as a basis for his thesis that the prime purpose of machine design under capitalism is to wrest skill - meaning essentially control over the labour process - from the worker and incorporate it into the machine (see Chapter Four).

Although Bright's scheme has a certain plausibility this type of definition is problematic. It views automation primarily as the degree to which machine control processes are mechanised. This approach is best suited to the level of "automation" of a discrete machine. Because of this classification's lack of attention to the manner in which materials are moved between different parts of the total production process it is unable to cope with the "automation" of production <u>systems</u> (Coombs 1984, p148). Its uni-directional nature prevents it being used as an analytical tool to explain differing types of labour required as a result of "automation".

Faunce (1965, pp 150-151), on the other hand, provides the germ of a method to rectify this shortcoming. He refers to four basic and distinct technologies as together constituting "automation". These are power technology, processing technology, materials handling technology, and finally control technology [4]. He claims that technological developments may occur independently in any of these but that "a certain level of development of each is a necessary condition for further development of the others." Thus automation can proceed in a number of different and semi-autonomous directions, yet still be subsumed under the same generic term.

Faunce did not pursue the development of this more complex definition, however. This task was left to Bell, who develops the work of Bright referred to above (whilst seemingly being unaware of Faunce's contribution). Like Faunce, Bell criticises previous writers on automation for conflating changes occurring in three separate types of technology. These he terms (presented here with Faunce's terminology given in brackets afterwards where different) the technologies of transformation (processing), transfer (materials handling), and control. Respectively these refer to the way in which the raw material is fashioned into finished product, the way the material is carried between stages in the production process, and the manner in which the overall process is controlled. Bell describes automation as a "three-dimensional space" in which the extent of "automation" is determined by the different and almost certainly varying degrees to which the three component parts are mechanised. Bell's purpose was to demonstrate that differing extents of automation in these three areas will have dissimilar effects on the numbers and type of labour employed in systems of production. We shall discuss this in the next chapter.

Kaplinsky (1984, pp 24-27) acknowledges the importance of Bell's contribution, but argues that the work of such writers as Bright and Bell is incomplete because it only refers to the activity of one particular sphere of the productive process, that of manufacture. Kaplinsky argues that industrial enterprises consist of three spheres of activity (design, manufacture, and overall coordination and control) which have become increasingly compartmentalised since the industrial revolution. A central feature of "automation" in these three spheres to date has been the development in each of numerous (and usually incompatible) databases, thus hindering the breadth of automation possible. For Kaplinsky the unique feature of new microprocessor-based technologies lies in their ability to (re)integrate these distinct spheres (see also ACARD 1983; Ingersoll Engineers 1985).

Therefore automation can be viewed as consisting of three distinct levels, dependent on the degree of integration of production activities enabled. These types of "automation" are: a) individual activities within a sphere, such as CNC machine tools (intra-activity automation); b) the integration of a number of hitherto separate activities within a sphere, such as FMS (intra-sphere automation); and, c) the integration of hitherto separate activities in different spheres, as in the development of a common database for all manufacturing activities (inter-sphere automation). This definition is useful in some respects because it extends the discussion of automation to encompass all aspects of the production process within the enterprise, and points the way to future technical developments. However, as Kaplinsky's account makes only too clear, "automation" has but recently begun to progess as far as the intra-sphere category. To date developments are most advanced in the area of manufacture (which helps to explain why previous theories of automation have concentrated on this field), beginning with the transfer line but only recently finding broader application in linked systems such as FMS. Kaplinsky's approach to classifying automation is undoubtedly helpful in disentangling the various component activities in the "factory of the future". However, his definition is too broad for our use because our study is basically only concerned with automation within the manufacturing sphere according to Kaplinsky's definition.

More promising is an even more rigorous application of Bell's typology devised by Blackburn et al (1985, pp 28-29). The following analysis draws principally on their classification. They suggest that the dominant pattern of development of these three technologies since World War Two has tended to lead those seeking to define automation into a cul-de-sac. This is because each historical phase of "automation" (as described above) has actually emphasised the development of different types of mechanisation. For this reason Blackburn et al argue that it is misleading to speak of "automation" as such, preferring to drop the term altogether. Against this one might raise the objection that "mechanisation" can be viewed as the replacement of human physical effort while automation represents the substitution of human mental effort, and thus the latter presumes the existence of some form of internal control feedback. This cannot be sustained, as examples do exist of innovations (such as the self-acting mule) which replaced both human physical and mental energies, but contained no means of feedback (Council for Science and Society 1981, pp 17-18) [5].

To bypass such confusions Blackburn et al prefer to speak of three overlapping types of mechanisation, which consist of what have been in turn the dominant forms of what has been referred to as "automation". These they call primary mechanisation (the automation of material transformation in the production process), secondary mechanisation (the automation of material transfer in the production process), and tertiary mechanisation (the automation of control and coordination of the above activities) in order of the approach of each of these dimensions toward maturity.

These different trajectories can be inferred from the discussion in section ii), in which it became clear that the three main forms of production described have tended to exhibit varying extents of these three kinds of mechanisation. Thus small batch manufacture has displayed considerable mechanisation of the means of material transformation for many years, but little in the way of the other types until recently (see later chapters). On the other hand, the distinguishing feature of early mass production systems was that they complemented this first type of mechanisation by seeking to mechanise the means of material transfer between work stations. Whereas control of labour in this system is partially built into the machinery, control over the process itself was heavily labour-intensive and remained largely unmechanised during the heyday of the transfer line. By the time of the rapid development of continuous flow process technology the emphasis of technical development had shifted to the mechanisation of the control process (whereas transfer and transformation were almost completely automated). Transformation and transfer technologies are now relatively mature and tend now to be characterised by merely incremental innovation. By contrast the era of tertiary mechanisation is yet young and now contains the greatest potential for future development by means of capturing the information databases upon which control functions are based (Coombs 1984).

Within the concept of control mechanisation it is increasingly important to draw a distinction between "hardware" and "software" forms of control as a result of the increasing power and flexibility of microprocessor-based forms of technology. Any control system contains a tangible hardware aspect which simply consists of the equipment enabling the store of information to be processed and transmitted (such as the human brain or a computer). It is also important to realise that the necessary information itself can also be hardware-based, for example in the form of a cam, template, or punched tape (Bell 1972). The disadvantages of encapsulating information in this form are its inflexibility - it is not particularly easy to adapt or edit - and it tends to become more inaccurate with use as it wears out. Also the fashioning of templates, and so on, to act as a "pattern" is usually a complex and skilled task and therefore very labour intensive in its own right. Information which is likely to be subject to rapid change or obsolescence is therefore rarely suitable for expression solely in such a form.

By contrast software-based control information such as digitally-encoded data within a computer is extremely flexible, being readily amended. The transformation from "hard-" to "soft-wired" control systems as a result of the development of microprocessors and digital information processing has led to a qualitative increase in the importance of control technologies in terms of the range of production activities which can now be expressed in digitized form. Some, such as Morris-Suzuki (1984, pp 112-113) have gone so far as to suggest that "knowledge", particularly in the form of software, has now been separated from labour and machinery to such an extent that it now represents "an independent commodity and element in production." On this argument the disembodiment of knowledge and its consequent objectification as a commodity results in a loss of control for workers occasioned by their possession of this previously irreproducible know-how. However, the intention of separating the conceptual knowledge in the production process from those who are to execute it is not the same as achieving this separation. We shall discuss this further in Chapter Four.

iv) Conclusion

This chapter has used historical evidence of the pattern of development in industrial societies to assess the relative merits of a number of theories of automation. On the basis of this analysis it becomes apparent that the confusion surrounding discussion of "automation" can be resolved by accepting that three different trajectories of mechanisation are in fact involved. These, following Bell (1973) and Blackburn et al (1985), we term transformation, transfer and control mechanisation. These trajectories are characterised by varying levels of maturity.

Of these, it was demonstrated that control mechanisation now possesses the greatest potential for future expansion because it objectifies human mental rather than physical capabilities. An essential difference was drawn between control mechanisation and the other, more mature, types of "automation". Unlike these latter, control mechanisation is now basically concerned with the automation of the "soft" information databases and decisions on which all production databases are dependent. It is believed that microprocessor-based and information technologies now contain the power to store such data in hitherto impossible quantities, and the flexibility and reprogrammability to switch rapidly between different functions. Hitherto these capabilities have been believed only feasible in many productive activities by the uncertain application of human skill. As will be discussed in Chapter Four, these questions relating to the displacement of human conceptual knowledge are at the core of many of the discussions about the automation of human skills.

CHAPTER FOUR: Mechanisation, skills and the division of labour

i) Introduction

The exact nature of the effects of technical changes on skill requirements has been intermittently debated in recent decades. Despite the amount of discussion, the various debates' most striking feature has been the absence of any unanimity on what the relationship between skills and mechanisation might be. Bright (1959) answered in the negative to the title of his article "Does automation raise skill requirements?" Taking the opposite view, the early 'seventies saw other authors, such as Bell (1973), predict the emergence of a "post-industrial" society, which would be partly facilitated by the computerisation emerging at this time. Bell correlates the greater number of years being spent in formal education with a generalised demand for higher skill levels as a result of changing technology. By the mid-'seventies the pessimists were once again in the ascendant under the influence of renewed economic recession, the theoretical guidance of Marxist-inspired critics, and (latterly) wide-ranging changes in the numbers and nature of jobs as a result of the application of microprocessor-based technologies.

These disparities suggest that the classical debates on this question mistakenly assumed (as do some more recent approaches) a more or less direct linkage between changes in skill requirements and whatever they chose to define as mechanisation. In this chapter we wish to question the adequacy of existing influential approaches to skill and technological change. The differing conclusions of the above approaches suggests that additional variables intercede between mechanisation and changes in skills and work roles. In discussing the debates on the classical theories we shall introduce additional factors which some authors have proposed as potential variables. Particularly we stress managerial intentions, but we argue further that inherent task variability, and product and labour market factors also exercise influence over the relationship between mechanisation, skills and the division of labour.

ii) Skill

Having discussed mechanisation in Chapter Three our first task here must be to define our concept of skill. A considerable debate has opened up in recent years as to how skill should be defined [1]. Littler (1982, pp 7-11), in a useful exposition of skill definitions, identifies three broad basic meanings which stress respectively measureable competencies, control over one's labour process, and the "social construction" of skills for particular bargaining ends [2].

The first approach suggests that skill has a real, objective basis, which consists of particular physical and mental competencies, and techniques normally acquired through a period of training. This definition is the most restricted interpretation of what constitutes skill. It sees skill as a personal property comprised of categories such as motor or manipulative skills, perceptual skills, and conceptual or intellectual skills. These are necessary for the performance of given tasks but, in this definition, they are internal to the worker and can exist largely independently of external factors dependent upon the division of labour. This definition is most frequently associated with occupational psychologists and others concerned with the training of employees (Engineering Industry Training Board 1971; Hazlehurst et al 1969; Seymour 1966), who have attempted to devise methods for the measurement of these skills [3].

This limited definition, adopted by More (1980) in his study of the engineering industry, is superficially attractive. However, as Rolfe (1986, p40) points out, the definition of skill according to measureable psychological criteria, while always inadequate for work with a high conceptual (and therefore "invisible") content, is also of limited application to manual work. This incompleteness results from Polanyi's (1958, 1962) recognition that the skill involved in humans' use of tools is essentially an experiential process which cannot be formally articulated or codified, although it nevertheless exists as a subsidiary form of mental awareness. Polanyi calls this "tacit knowledge". Studies of training techniques such as the Engineering Industry Training Board (1971) and Seymour (1966) have acknowledged the difficulty that tacit skills pose to the formal transfer of knowledge. They found that the more intellectual, planning and adaptive skills employed in jobs with a wide variety of tasks and high conceptual content are too elusive and suject to variability to be formalised as highly specified and proceduralised rules applicable to every circumstance. The importance to our study of the concept of tacit skill is such that we shall refer to it separately below.

A second school of thought, most prominently but not exclusively associated with labour process studies of (mainly) Marxist origin, agrees that skill has an objective basis in the possession of particular abilities, but argues that the indispensible element is control and autonomy over one's own labour process, which is best illustrated in the notion of "craft"-type work. This definition emphasises additional notions such as "autonomy", "discretion" and control over the labour process. In an extreme version of this argument, which begins to overlap with the third definition below, Blackburn and Mann (1979) and Oliver and Turton (1982) see "skill" as comprising not competence but mainly behavioural, attitudinal and motivational factors influencing the recruitment of personnel for particular jobs. For Blackburn and Mann (1979, p292), in their study of the labour market in Peterborough (where, it might be noted in view of later discussion, a very high proportion of jobs are for semi-skilled rather than craft workers), skill constitutes a position of discretionary "trust... within which decisions, whether routine or complex, could be taken by the worker himself..."

This approach also has its drawbacks. Concepts like autonomy and discretion are both relative and subjective, and therefore difficult to measure, although undeniably present in jobs. Moreover, to apply such concepts to the jobs of individual workers presupposes a parallel consideration of the manner in which overall responsibilities are subdivided between workers. Notions of autonomy, discretion and control are therefore dependent upon analysis of the extrinsic variable of the division of labour.

Studies of skills at the levels of work tasks holding to the above definitions have been criticised by some sociologists. These writers argue for a more "ideological" definition of skill based on power relations in the workplace on the grounds that skill has little objective basis [4], but rather labels of "skill" are socially constructed by workers and employers in order to try to further their own interests. For these writers the study of skill should consist of investigation of this process.

This approach amplifies the sociological aspects of skill implied by the idea of control over the labour process. It sees "skill" as a bargaining process; a category based on power, on which basis particular groups may be selected for, or excluded from, certain categories of work. For Penn (1984, p129) the central feature of skilled manual work is "some form of social exclusion." This view originates in Turner's (1962) research in the cotton industry. He disputes that the jobs are skilled in any objective sense but notes instead the use of the term in cases where workers have been able to artificially restrict the supply of labour into the industry by means of trade union action or period of apprenticeship [5]. Other forms of social construction than by union action have since been identified. Feminist writers studying the undervaluing of women's work (Phillips and Taylor 1980, p79), and changes in the printing industry (Cockburn 1983), contend that the labelling of jobs as "skilled" is used as a weapon by male workers to deny female workers either access to particular kinds of employment or adequate recognition of its value and skill content.

At various points this study refers to the idea of skill in each of these three senses, but the primary emphasis is on the first two. Our main focus will be on changes in the nature of the specific skills required and the redivision of work tasks as a consequence of technological changes. However, we shall refer to the ideas of "skill" and "control" as separate categories to avoid contributing further to the confusion caused by their frequent conflation in much of the literature reviewed below. It is necessary to draw this distinction for, as Rolfe (1986, p41) says, it does not necessarily follow that the possession of skill will lead to control over the labour process or vice versa [6]. In this thesis we are particularly interested in craft skills and, by extension, it may become relevant to consider the social construction of skill Turner believes to exist through the mechanism of craft control. We shall make it clear when skill is being discussed in this sense.

iii) "Labour process" analyses and the "degradation of work"

One of the most influential approaches in recent years to the question of skill has considered its most important aspect to be the idea of control over one's labour process. Kelley (1984) defines any labour process as consisting of three elements: a set of related tasks that need to be performed to achieve a particular purpose; technical means (tools); and a body of knowledge necessary to effect the transformation (skills), which in turn implies a given degree of complexity in planning and implementation tasks, and a knowledge base of a certain breadth on which it is necessary to draw. One occupation may encompass an entire labour process, in which case it may be described as a craft.

This idea of craft or artisanal production as the very embodiment of skill underpins in particular the influential Marxist approach popularised by Harry Braverman. In his view: "For the worker, the concept of skill is traditionally bound up with craft mastery..." (Braverman 1974, p443, see also Hinton 1973), central to which is the ability to visualise how the product will appear in its final form (Braverman 1974, p444). Implicit in Braverman's concept of a craft is the idea that the worker has autonomy and discretion in decision-making regarding the organisation and performance of his or her work resulting from the possession of these particular competencies [7]. The notions of discretion in deciding the pace, content and planning of work derive mainly (but not exclusively) from Marxist approaches to the question of skill. The emphasis on autonomy stems from the Marxian concern with the division of labour and, in particular, the notion that its developed capitalist form requires the separation of conceptual from execution tasks as proposed by Taylor. Braverman claims that the necessary physical prerequisites of skill are a less significant component than the ability to unify in one's work the conception and execution of tasks he believes to constitute the essence of craft.

For Braverman, the (largely pre-capitalist) era of artisanal production was characterised by workers who had served a lengthy apprenticeship in their particular craft, during which they developed the all-round knowledge of the techniques necessary for production of a complete item from start to finish. In such a case the labour process encompassed an entire occupation, and so the division of labour was minimal at this time. The beginning of the era of machino-facture, however, constituted a qualitative break with this period, and ushered in a more intensive division of labour. This division of labour developed at different speeds within different industries: indeed it is only recently that the craft basis of the printing industry has been seriously challenged. As a general trend, though, manufacturing and then assembly jobs became subject to sub-division and mechanisation. This process reached its apex with Taylor's scientific management techniques and Ford's assembly line, although it did not proceed very far in small-batch engineering (see Chapter Five).

Braverman therefore uses the concept of skill in a dynamic sense to theorise a process of overall deskilling during the twentieth century on the basis of the claimed fragmentation of conceptual and executive activities into separate jobs, each comprising an increasingly circumscribed variety of tasks. This trend is said to facilitate management's pursuit of accumulation of surplus value in two ways. Firstly, as most jobs now comprise a smaller number of simpler tasks, they can be filled by less skilled workers (in terms of the competencies required), who will therefore be cheaper to employ and to train. Secondly, the separation of conception from execution allows increased management control over workers' job performance, thereby permitting the intensification of labour and an enhanced ability to extract surplus value.

Braverman sees this process of deskilling as being initiated by the application of Taylor's methods rather than by mechanisation. The rationalisation of the organisation of the production process is viewed as first enabling the deskilling of work through its routinisation, and the subsequent ability to separate conception and execution. Only when individual jobs had become so routinised and deskilled that their automation was a technically unchallenging task, was machinery recruited to further the possible dimensions of what Braverman sees as a conscious management strategy. Thus he regards automation as essentially a more sophisticated (and, to workers, less ouvert) method by which managers may achieve a twin political goal of increasing their control over the production process by appropriating the skill formerly residing in the employee (see also Edwards 1979).

Braverman arrives at his concept of the relationship between automation and skill by marrying Bright's typology to Marx's theory of capitalist development. Braverman takes up Marx's claim that the essential purposes of the development of machinery under capitalism are the usurpation of human manual and mental control functions. In language later echoed by Taylor (see Chapter Three), Marx (1976, p508) refers to:

> the replacement of human force by natural forces, and the replacement of the rule of thumb by the conscious application of natural science.

Bright (1958), although certainly no Marxist, provides the second pillar for Braverman's argument. Bright, as we saw in Chapter Three, compiles a seventeen-fold classification of levels of "automation", which for him is characterised by an increasing order of mechanised control over production operations and decisions. As "automation" becomes more sophisticated so the conceptual skills required and discretion exercisable decline in proportion. Bright's purpose here was to argue that the skill requirements of automated machinery were being generally overestimated and that wage and training levels for those employed such equipment could be reduced accordingly. Braverman seizes uncritically on Bright's classification and assumptions to provide evidence for a claimed continuation through "automation" of the rationalisation process set in motion by Taylor and Ford.

In this approach, furthermore, it is believed that technology, taken as more or less embodying unambiguous management control objectives, will determine the structuring of work into hierarchical patterns. Forms of job redesign under such technologies as the assembly line and NC are viewed as no more than a confidence trick to obtain workers' continued consent, and enabled by the fact that the pace of work is now technically predetermined (Braverman 1974; Palloix 1976) [8].

The most significant criticisms of Braverman are that he underestimates actual and possible worker resistance to deskilling; that he assumes the universal adoption of one overriding management strategy based on Taylorism, which emphasises labour control above all other possible objectives; and that this strategy is being pursued to the exclusion of any possible others and is largely succeeding. Braverman's evidence of deskilling is derived primarily from secondary sources like the claims of equipment sellers and management consultants in a limited number of technological applications. Little energy is expended on study of the practical outcomes of the adoption of such systems [9].

Many subsequent contributions to the labour process debate have been concerned to redress these various shortcomings [10]. For us, the most relevant have been those contributions which propose the existence of alternative labour control strategies, some of which may allow groups of workers greater autonomy (Edwards 1979; Friedman 1977); those transcending this level to stress other, more primary, focii of management control objectives than merely labour (Buchanan and Boddy 1983; Cutler 1978); and those questioning the directness of the link between conception of a "strategy" and the ability to implement it (Rose and Jones 1985) (see also Child 1985, pp 108-110). We shall take up these criticisms again below when we attempt to draw together some conclusions on the relationship between mechanisation and skill. However, one particular body of thought on the inviolability of certain worker skills - the theory of tacit knowledge - is sufficiently important to the subsequent argument to merit separate discussion below.

iv) Tacit knowledge and mechanisation

Tacit knowledge consists primarily of the unformalised awareness it is necessary to possess in order to perform a task. Such knowledge is acquired through trial, error, observation, imitation and the accumulation of experience rather than formal instruction. But tacit knowledge implies slightly more than just the abstract possession of this ability. It also presupposes the ability to perform a task at the level of speed and efficiency of a practiced worker (this is called Experienced Worker Standard) (Engineering Industry Training Board n.d., pp 4-5). Although recent studies have concentrated on the presence of tacit skills in semi-skilled jobs (Kusterer 1978; Manwaring and Wood 1985) other research suggests that such skills are also important in craft jobs in order to successfully apply theory practically (Engineering Industry Training Board 1971; Seymour 1966) [11]. Here the concept of tacit knowledge has a two-fold importance. Firstly, it reintroduces a role for workers' subjective action in the production process that is discarded in Braverman's approach. Secondly, and bound up with the first point, the nature of tacit knowledge itself renders it difficult to translate into a formal body of expertise, which it is then possible to computerise (Bourne and Fox 1984, p80). The idea of workers' possession and use of tacit knowledge therefore throws doubt upon the extent to which their job knowledge and skills can be appropriated by management (Manwaring and Wood 1985). Let us look at these points.

As we saw above, Braverman claims that management's pursuit of Taylorite strategy is facilitating its monopolisation of job knowledge by separating conception from execution and extending the division of labour. This wrongly assumes that control (through the possession of job knowledge) can be seen as zero-sum: either possessed by management or workers, but not both. Management acquisition of the theoretical knowledge necessary for the performance of production tasks does not denote that they therefore monopolise such expertise, as the workers involved must also still possess the elements of this knowledge themselves (Burawoy 1984, p41; Kelly 1982b, pp 22-23; Wood and Kelly 1982, pp 78-79). Kusterer (1978), in a study of the tacit knowledge acquired on the job by semi-skilled workers to expedite or improve the precision of their work, argues (against Braverman) that the possession of tacit skill confers on workers a continued degree of control over the labour process. As Manwaring and Wood (1985, p184) argue, Kusterer may well overstate the degree of control workers are thereby able to retain. However, he rightly emphasises the continued dependence of management on workers' use of their subjective knowledge to facilitate the successful continuity of the production process. This dependence manifests itself in workers' often unacknowledged (and unofficial) interventions in the production process to compensate for variance [12]. Variances may consist of product- or process-specific factors (such as poor quality raw material or unreliable machinery). Through the use of tacit skill certain, possibly significant, decisions on work methods remain at the point of production rather than being transferred to production engineers, or mechanised so on. This latter option both creates delay in resolving production problems and relocates control over manufacturing decisions.

The difficulty of articulating necessary tacit skills as opposed to formal knowledge is the major problem in readily enabling the transfer of tacit expertise to management, should they wish to achieve this. In the case of machining, professional engineers' knowledge of the process is expressed in abstract terms of set methods, tables of feeds and speeds, computations of cutting forces, etc. For the machinist, however, metal cutting is experienced as the practical accumulation of physical working knowledge based on sensory intuition, and as the observed and "felt" behaviour of workpieces, tools and machines in combination with the human operator. Therefore the different cognitive structures of professional engineering and production jobs results in activities in the production process being "conceptualised in radically different ways" and articulated in different terms by practitioners of different departmental specialisms (Jones 1984b, p19). Workers possess necessary job knowledge in a much more direct and very different form. In everyday operation and in cases of minor innovation machine operators tend to pass on learning to one another on the job in an unstructured manner. Thereby their understanding of the detailed practicalities of job performance becomes considerably removed from, and improved upon, the structured means employed by the professional engineers.

These points can be demonstrated in an example of the employment of tacit skill in the control of variance in machining. When the machinist feeds the tool into an item being turned too fast on a powered lathe the resulting "drag" on the tool can be felt through the hands of the experienced machinist, who will then sense the need to modify the machine's operating values in order to avoid turning out a defective part [13]. The signals transmitted through the tool in this manner enable the immediate continuous compensation necessary to achieve satisfactory performance of the machining operation.

The only way of formally imitating these manual actions is through the recently developed, but imperfect, technique of adaptive control. This monitors the power consumption levels drawn by tools during cutting, and shuts the operation down if these levels exceed broadly-set pre-programmed limits. However, Larsen (1981) indicates that adaptive control does not appear in practice to have lived up to its theoretical promise to surpass the effectiveness of manual control, and fieldwork evidence demonstrates that adaptive control is at its least effective with those small tools which tend to break most readily in any case (see also Scott 1985). Adaptive control does not appear to compensate for machining variables as thoroughly or readily as the tacit knowledge of the human operator.

One objection to the above argument might be to acknowledge that tacit skill exists, but to propose that the central purpose of mechanisation (particularly of control functions) is to free the employer from dependence on operator control of compensation for variance in the production process. Zuboff (1982, pp 143-144), for example, makes explicit the argument that the purpose of computerisation is to formalise into software the tacit decision rules on which workers' control over the labour process is based:

> The purpose of the intelligent technology at the core of a computer system is to substitute algorithms or decision rules for individual judgements. This substitution makes it possible to formalize the skills and know-how intrinsic to a job and integrate them into a computer program.... For some jobs the word "decision" no longer implies an act of human judgement, but an information processing activity...

A parallel argument suggests that a change in technology will cause many or indeed all of the skills applicable to the operation of the technology replaced to become redundant. Braverman (1974, pp 224-227) argues that operatives in chemical process plants need now know nothing about the underlying process of chemical transformation occurring behind the lines of gauges in the control room. Likewise Palloix (1976, p55) (prefiguring some of the argument in Chapter Six) maintains that:

> (A numerically-controlled machine tool), though it involves less use of man-power, at the same time reduces even more the technical skills of the worker to the extent that the skills themselves increasingly disappear.

The view taken here is that these claims, which are again predicated on a zero-sum model of skill and control, are unfounded in most circumstances. To explain this, and to understand the reasons for the qualification, we shall draw a distinction between the form in which a process of transformation is being controlled; and the content of that transformation process. Modification of the form of control does not necessarily alter the underlying content of the production process concerned. The skills attached to the latter are therefore not necessarily displaced. This is best illustrated by way of two examples. Let us consider respectively a transition from conventional metal-cutting to electro-chemical machining and numerical control.

The skills appropriate to conventional metal-cutting of a component would be completely inappropriate to "machining" of the same part by electro-chemical methods, which are based on the principles of electrolysis. But (despite Palloix's claim) the same cannot be said of the replacement of conventional machining by NC. Why the difference? Our first example represents a complete change in the process whereby a piece of metal (a blank) is transformed into a finished shape. Electro-chemical machining is based on entirely different principles and methods of transformation and control to conventional machining. The means of control appropriate to the latter process are simply eliminated.

Numerical control is not akin to this. Under NC the content of the process whereby the metal's shape is transformed is identical to conventional machining. Here surplus metal is still removed by the motions of a tool relative to a workpiece by physical cutting (rather than electro-chemical) forces. The form of the system of control under NC is indeed different, being "hidden" in digitised form. But to understand the computerised cutting process one can only proceed by mental analogy of the conventional machining process (see also Canter 1985), for in content it merely tries to imitate the movements that would otherwise be made by a human. Success may not however be assured, because of the fact that numerical control dispenses with the direct body/brain/tool interaction that comprises tacit skill, and the compensation of variance it enables. Similar cutting errors are possible as a result of this identical means of material transformation, and thus the same skills for error avoidance are still required.

Thus, in such a case, skills are not lost per se. However, the question now becomes: who possesses the authority to control any variances that still arise in the production process? For there exists with the changed form of control a choice as to whether this function should remain at operator level (albeit exercised in a more conceptually-based manner) or become a management prerogative. The issue is not so much the loss of skills as the manner in which they are distributed throughout the labour force. This will be discussed further in Chapter Six.

Additionally, even advanced forms of mechanisation may not be immune from the influences of retained control through tacit skill. Piore (1968b) and Jones (1984c) offer evidence that the incremental tacit transference of job knowledge can still occur even when radically new technologies creating new types of job are introduced. In such cases, Piore (1968b, pp 441-443) notes, transmission of knowledge through on-the-job learning still takes place as production workers are familiarised with the new technology during its innovation and installation periods. During this crucial debugging phase the first generation of job incumbents develop their own body of knowledge and method of understanding the system requirements which they then teach to new workers.

Alternatively (but more rarely) the engineer responsible for the design of the system may become one of its first generation workers. Jones (1984c) stresses the importance of the continued everyday modifications to the operation of the technology by its workers once the phase of debugging or "productionisation" is past [14], regular working patterns become established, and the "new" technology becomes "old" technology. As time goes on the system operatives are increasingly less likely to be the same personnel as were trained for the system during the second stage, and will introduce their own new sets of subtle variations on the details of system operation. Tacit job knowledge and learning becomes a means whereby production workers can overcome a partial vacuum in management's process knowledge caused by unfamiliarity with the detailed workings of the technology.

In sum, then, tacit skill constitutes an often unacknowledged medium whereby production workers may be able to retain some control over the performance of their work through their monopoly of essential but unformalised practical "know-how". Managers cannot monopolise the knowledge of workers' productive technique through work study techniques (especially when work has a conceptual content), or through mechanisation when the same underlying principles of material transformation are retained. Paradoxically, the more innovative the technology compared to what currently exists in the plant (and can therefore be used as a comparator) the more likely it seems to be that, to get and keep the equipment running, spaces will be created for the *ad hoc* interventions of production workers, and the greater the possibility that production workers will be able to retain a pivotal role for their tacit skills in enabling the new equipment to function efficiently.

v) Technological reskilling and the "socio-technical" schools

Two schools of thought have developed which take a contrary view to labour process analysts of the relationship between mechanisation and skill. The first of these, which we shall label "technicist", retains the idea that a fairly direct linkage exists between technical change and skill requirements. The second approach is that of sociotechnical analysis. As Blackler and Brown (1978, pp 128-130) observe, sociotechnical theory shares the values and underlying assumptions of a transition to post-industrial society propagated by the technicist writers. However, it offers greater sophistication than the technicist approach because of its stress on conscious management policies as the factor determining the effect of mechanisation on job design and thus on skill levels.

In the "technicist" approach skill is defined similarly to Braverman. Blauner (1964), in his classic study of parts of the labour process in four industries, is a prime example of this. The work of the printer is considered as a craft "ideal", in which skill is exemplified by such factors as freedom from supervision, freedom to decide the pace of work and the quantity and quality of work, and:

> direct control over the technological environment by means of the manipulation of tools and materials. (Blauner 1964, p42).

This is contrasted to the worker on the assembly line, for whom "the technological environment" removes all such autonomy and discretion. The "technicist" analysis differs from Braverman and his disciples, however, by proposing that tertiary mechanisation (best exemplified by the continuous flow process industries developing after World War Two) will facilitate the re-emergence of craft-type control over production processes. Writers such as Kerr et al (1973) and Bell (1973) specifically relate rising skill levels to the emergence of a "post-industrial" society, which is less dependent for the creation of its wealth upon the elementary and highly sub-divided forms of manufacturing employment hitherto predominant. Such writers concur with the view that highly sub-divided work - symbolised above all by the assembly line - has led to de-skilling and "alienation" of the worker from industry (Blauner 1964; Williamson 1972 inter alia), but see this as the product of technologies prevalent in an era of industrialism now being superceded. For these writers the capital-intensive continuous flow process industries emerging in the post-war period symbolise the means whereby the reversal of the Taylorist division of labour will be attained. Continuous process manufacture seemed to writers such as Blauner (1964) and Bell (1973) to exhibit a low division of labour with a requirement principally for technically highly skilled workers exercising considerable autonomy (although arguably little discretion) in overall process control.

Because of the fact that the operator is now freed from the need to actuate and monitor individual machines it becomes possible (and indeed desirable) to decrease the subdivision of tasks. It is argued that the main feature of the jobs in process industries is the overall management, supervision and control of processes by means of sophisticated computer systems. These jobs are said to require the use of high level conceptual and perceptual, rather than manual or manipulative skills, because of the enclosure of the material transformation and transfer processes. This strain of analysis concentrates almost exclusively on the potency attributed to the technology of continuous process industries. In most of these commentaries the continuing existence of largely unautomated batch production remains invisible [15].

The technicist approach is perhaps less influential since the onset of mass unemployment in Western economies, which has overshadowed the presumed professionalisation of the workforce. A more sophisticated variant which has been much talked about in recent years - although practised considerably less) is so-called sociotechnical analysis. This is both applied at a more concrete level and (usually) less technologically deterministic than the technicist approach. Rather than broadly generalise about changes in societal skill structures sociotechnics concentrates its analysis at the level of the workgroup. In most versions sociotechnical analysis sees skills as relatively autonomous from technology, and affected more by managerial choices in the division of labour at this latter level. Thus it prescriptively applies a concept of "organisational choice" in job design in order to argue for a restructuring of labour roles. Sociotechnical writers propose that any organisation is an "open system" consisting of a mutually interacting "technical system" (the technology employed) and "social system" (the employees and organisation of their work). These are not in automatic harmony - indeed, they will conflict to a certain extent. Therefore it is not possible to optimise both dimensions simultaneously. However, it is proposed that each dimension should be consciously remodelled and harmonised as far as possible ("jointly optimised") with the goal of affording improved job content to the workers concerned.

For sociotechnical writers desirable criteria for job design include relatively higher decision-making ability, longer work cycles and a wider range of tasks than would be found under the Taylorite principles still assumed to be generally characteristic of industrialised society [16]. Central to the achievement of these sociotechnical goals is a requirement that workers become increasingly flexible between the different tasks to be performed. It is important to distinguish between a number of types of such flexibility between tasks that may be sought, as different forms vary considerably in the degree to which they extend the worker's role. The main stratifications can be divided into either horizontal or vertical categories (Connock 1985, p36; Incomes Data Services 1986, p9). Horizontal flexibility includes firstly job or task rotation. As Kelly (1982b) and other radical critics argue, these are not necessarily incompatible with continued Taylorism. By contrast job enlargement consists of the grouping in one job of additional (and hitherto separate) tasks at the same grade. This can include flexibility within the same trade, such as when a machinist becomes responsible for operating a number of different types of machine tool (see also Chapter Five). In the case of craft jobs horizontal flexibility may take the form of flexibility between different trades (such as between production and maintenance personnel), which is often known as multi-skilling. In this latter case craft workers may be trained in additional skill "modules". This form of inter-craft flexibility is still relatively rare in Britain, as craft unions have been largely successful in preserving the sanctity of the boundaries between different trades.

Vertical flexibility involves the worker taking additional responsibility for tasks of a lower or - more significantly - higher grade level (job enrichment). Here we are particularly interested in the addition to directly productive jobs of pre- and post-production tasks with a decision-making content. Prominent among these functions in engineering firms, for example, would be quality control, part programming, supervision, production scheduling and the overall management of production. The emphasis of sociotechnical writers tends to be a combination of the above categories of horizontal and vertical flexibility to produce what are known as flexible (or autonomous) workgroups. Here the focus of interest shifts from the individual to a distinct team of workers, who become jointly responsible for a set of activities, including managerial, work allocation, and decision-making functions related to the tasks concerned (Kelly 1982b, p61; Wall 1982, pp 11-12).

Many versions of sociotechnical theory claim to be agnostic regarding the appropriateness of different types of technology, including computerised technology, for the achievement of its job design aims. Cooper's (1972, p155) view is typical:

> Advanced automation... will not of itself provide a more congenial form of work for the human operator. It will, however, provide the opportunity for job enlargement based on combining attenuated operating functions with more complex maintenance requirements. Planned intervention will be necessary to make this a reality.

It is apparent however that certain sociotechnical authors lean heavily towards the position that only the sophisticated technology characteristic of the computerised control of processes is able in practice to facilitate an enhancement of jobs and skills (see for example Davis 1971; Davis and Taylor 1979; Hirschhorn 1984). Hirschhorn argues that the high level of sophistication of the most advanced current "automated" control systems denies professional engineers the ability to foresee all possible modes of failure. For Hirschhorn, therefore, authority should be devolved to autonomous workgroups organised on sociotechnical principles in these environments and circumstances. This will enable the flexibility to learn about, and respond to, unpredictable contingencies that occur outside of the parameters for which computerised control systems have been programmed, and to react to changing market conditions.

Both of the approaches described in this section are flawed. The technicist approach, based on inferred transformations in skills and employment structures within continuous process industries, has been subject to considerable methodological criticism. For example, Blauner's methodology and conclusions are questioned by Gallie (1978), who notes that similar French studies have arrived at opposite conclusions; and Nichols and Beynon (1977), who draw attention to the continued existence of low-skilled heavy manual jobs in such plants [17].

The limitations of sociotechnical theories for job redesign have been comprehensively criticised by many authors [18]. The problem with this approach that we wish to emphasise here is that its underlying humanistic prescriptiveness abstracts the achievement of job design at the level of the individual work unit from the wider economic, political, technical and social pressures that lead managements to introduce new forms of work organisation (Knights et al 1985, pp 1-3). There is a danger in much sociotechnical writing of reducing the adoption of its job design principles - however desirable these might be - to the level of a rational management choice. In some forms, such as Hirschhorn (1985), this becomes distorted by overemphasis of the potency of computerised technology into an assumption that job redesign exercises are almost compelled thereby (Jones and Scott 1986, p356; see also Silverman 1970).

vi) Beyond technological determinants

The above discussion demonstrates that theories of a more or less unmediated relationship between changes in technology and skill levels are untenable. Such deterministic perspectives are flawed because of the unwarranted extrapolation to the level of societal trends of the limited evidence presented of changes in skill and control in selected occupations. Additionally, as Blackburn et al (1985) argue, they are beset by an inability to distinguish between different types of mechanisation which suggest contradictory skill outcomes. Because these theories see just one category of "automation" they are only able to postulate one direction of effects upon skill.

Ironically, these theories were formulated within an era of inflexible production technology and stable markets now being rapidly superceded and consequently rendering such views outmoded even on their own terms. Because of microprocessor-based and information technologies, mechanisation is now associated with increased (rather than decreased) production flexibility. Technology may constrain work tasks required, for these are largely technically determined, but does not in itself determine work roles (Clegg 1984, p135).

In common with the findings of previous research (Buchanan 1985; Child 1985, pp 134-136; Jones 1982, p198), a number of factors additional to technology which act as independent influences on skill structures and the division of labour have been identified in the course of the discussion above. These additional variables are managerial intentions, inherent task variability, product market characteristics and labour market characteristics. The last two of these factors can operate at both the general level and specifically at the unit of production. The first two refer exclusively to the unit of production [19]. They can be expected to intervene to a greater or lesser degree between the choice of a given technology and the resultant effect on skills. In this section we intend to demonstrate the relevance of these factors, and to show how interrelationships between technology and these other factors may also impact on skill requirements.

First, however, let us add a note of caution. The introduction of these additional factors does not signal a belief in total contingency. The position adopted here is similar to both "labour process" and sociotechnical analysis in according primacy to managerial intentions as a determinant of labour roles within a given technology. However, this is done for different reasons, and in a more qualified fashion. There is definitely no agreement here with the view that managerial objectives cannot be thwarted! My doubts concern similar areas to those raised above in the criticism of labour process approaches. These objections concern the assumptions about the centrality accorded to labour control; different levels of management having identical objectives; the possibility of effectively insulating the achievement of labour objectives from the wider manufacturing and marketing goals of the organisation; and - as far as the introduction of particular new technologies is concerned - the role of existing institutional frameworks.

Having inserted this caveat, we can now examine the role of the four factors identified above, beginning with the part played by managerial intentions and objectives. The argument concerning the use of technologies by management to achieve objectives of control over labour can be treated at both an abstract and a specific level. At an abstract level any management has influence over the technologies that are developed. At a specific level the choice of technology is constrained by the requirement to perform a particular set of production tasks. Within this limit management then has a degree of choice about the policies it wishes to adopt towards labour roles, and the extent to which these determine the final configuration of the technology employed [20].

The choice for patterns of working policies and labour control within a given technology, which Littler and Salaman (1984) have called "design space", will also be affected by the interplay between different managerial objectives. A useful distinction has been drawn between three types of management objective, which tend to be characteristic of successively lower levels of management. These are respectively strategic objectives, which are external and market-orientated, such as a more rapid rate of product innovation; internal and performance-orientated operational objectives, such as high machine utilisation; and control objectives, which include labour control and improved management information (Buchanan and Boddy 1983, pp 243-244).

All of these objectives (insofar as they are present) will impinge upon work organisation and the degree of latitude in decision-making accorded to operatives. As Buchanan and Boddy rightly argue, the pursuit of control objectives may conflict with and impair the achievement of strategic and operating objectives. A policy of devolution of labour control will tend to favour the retention of skill on the shopfloor, the kind of autonomous workgroups advocated by sociotechnical writers, and the compensation for production variables at source. Tight labour control will reproduce the Taylorite pattern of highly prescribed work roles and the transfer of major production decisions from the shopfloor to professional engineers and managerial personnel. Plant size appears to be an important variable in determining the institutionalisation of the division between categories of labour and the autonomy permitted to production workers in methods decisions (Sorge et al 1983).

The subdivision of tasks and lack of autonomy implied by the pursuit of labour control objectives appears counterproductive in view of the increased interdependence between manufacturing functions engendered by microelectronic technology (Buchanan 1985). As Buchanan argues, the pursuit of control objectives is likely to be disfunctional to overall efficiency to the extent that unexpected variances enter into the production process. It becomes less likely in circumstances where the possession of production expertise is diffused among many separate occupational specialisms that anyone with the ability or authority to correct errors will be available to catch them as they arise at source.

A distinction needs also to be drawn between policies for labour management at plant level and changes proposed to those policies because of the introduction of particular new items of equipment (Jones and Scott 1986). Proposed changes in work patterns as a result of the introduction of new technology are crucially mediated by already existing frameworks for working practices operating within influential institutional contexts. Technological innovations - especially those having implications for several manufacturing activities simultaneously - can provide challenges to these established norms. However, in all bar exceptional circumstances (such as relocation on a "greenfield" site) they must be somehow "fitted in" to existing company organisational systems, cultures and industrial relations frameworks. These latter are unlikely to have been built up in readiness for the new technological systems, but will ultimately have the potentially greater influence over labour deployment. This tends to be ignored in practice, as innovation is normally seen as essentially a technical process to which human and personnel factors are secondary and consequent (Clegg and Kemp 1986; Jones 1984c; Jones and Scott 1986).

Let us now turn to the second factor: task variability. As Perrow (1970) argues, the variability inherent in tasks is determined by their degree of complexity and uncertainty. Perrow refers to variations mainly in the context of the raw material of the product, but we wish to emphasise additionally variability in the process of production itself. Mechanisation may have contradictory effects upon task variability depending upon the interplay of the changing demands of the product and process. As Buchanan (1985, pp 24-25) says, one of the purposes of mechanisation (and particularly flexible microprocessor-based technologies) is to eliminate the need for human discretion in dealing with exceptional circumstances in the manufacture of products.

With relatively standardised products whose requirements are well-known and static this is likely to present little difficulty. However, Buchanan argues that (even with the aid of advanced manufacturing technology) it will not be possible where products are frequently changing, or where the procedures for dealing with exceptions are difficult to analyse directly or poorly understood (as with craft knowledge). In such cases one may still need to compensate for variability at source, although whether this happens or not will depend on managerial intentions (see above). But, as Hirschhorn points out, the price of building control over product-centred variability into systems may be an increased dependence on operators to manage greater instability in process-centred variability. In other words, even if product complexity and uncertainty can be diminished by mechanisation, this may only mean that the sophistication of the new process creates novel types of fault and sources of uncertainty.

Thridly, product markets are generally becoming more differentiated and rapidly changing (as was noted in Chapter One). At the level of the unit of production, firms' response strategies to these developments will impact upon skill requirements in terms of such factors as the breadth of product range, quality required, batch sizes, response times demanded, rate of product innovation, complexity and novelty of components, and so on. The product spectrum will in turn determine the complexity and variability of the tasks required, and reflect back on the possibility and/or desirability of pursuing particular managerial objectives towards labour roles.

Our final factor concerns the role of the labour market. At a general level the labour market affects individual firms in terms of the balance of supply and demand for particular kinds of labour. This in turn affects the general climate of labour relations in encouraging management or labour to act as independent agents in pursuit of their opposing bargaining objectives. These factors, which operate at both national and local levels, are further faced at the stratum of the labour market confronting the individual firm. Of course, different categories of labour will be in more or less demand even at the same time in the same plant. A relative scarcity of workers with particular skills not easily reproduced, for example, is likely to result in such groups accumulating considerable bargaining power, which will be reflected in such factors as high pay, considerable control over the labour process, and autonomy. In such circumstances those workers with scarce skills and/or who are able to maintain a high degree of control over the production process - such as craft workers - are also likely to be in an advantageous position to inflate their status through the social construction of skill that overlays "real" skill levels. Cockburn (1983) suggests that this has been the case with compositors in the printing industry, for instance.

A number of studies argue, against more traditional views, that technologies are often developed and adopted for labour and skill substitution objectives to break this dependence. Wilkinson (1983, pp 9-12) argues that political considerations and goals of production engineers and managers themselves colour the technologies developed and innovated [21]. For Wilkinson, and for Piore (1968a), these goals frequently include labour substitution and a reduction in skill and control on the shopfloor. Senker (1979) also provides some evidence that the adoption of certain automated equipment by firms is a substitute for the lack of availability of skilled craft-trained labour [22].

Cockburn (1983) and Sadler (1970), in their studies of the printing industry, see the introduction into the production process of new technologies having labour- and skill-displacing effects as a prime factor in creating discontinuities in the process of social construction. Such changes will have the effect of both reformulating "real" skill requirements and, where skill or control is removed, placing pressure on the ability of the workers concerned to (at least) maintain their claimed skill level and privileged position.

Some commentators, such as Hill (1981, pp 116-118), argue that technology is used to deskill in turn those occupational groups holding a pivotal position in production. This process has only been obscured and mitigated by the continuing social construction of skills, thus enabling "labelled" skill levels to be artifically inflated above the actual technical content. The opposite to this view of an immanent logic of technical development is that an overall redistribution of skills between different sections of the total workforce is occurring, resulting in a complementary process of deskilling and reskilling of different jobs (Edwards 1978; Jones 1982).

In conclusion, the second view seems more accurate on the basis of the evidence above. The development of control mechanisation makes likely the formalisation of increasingly complex human abilities. The intervening variables are managerial intentions, product and labour market characteristics, and task variability; combined with the development of technology that is increasingly flexible in terms of its end use. These variables allow a considerable range of outcomes for work roles, control of the labour process and the locations of required skills. Straightforward "deskilling" or "upgrading" could be among these outcomes but, should this be so, would be filtered through the above factors. Outcomes for skills and work roles of the introduction of new technology must therefore always be assessed with these institutional factors in mind.

CHAPTER FIVE: The labour process of small-batch machining

i) Introduction

It is clear from the discussion in Chapter Four that the "impacts" of particular technologies on work roles and the distribution of skills are partly contingent upon intervening variables acting at both a general and plant level. To understand the implementation of FMS technology it is first necessary to comprehend the particular characteristics of those industries producing in small batches in terms of the variables identified above, and the "machining labour process". For these have been the traditional bases whereby engineering workers have been able to retain a degree of skill and control over the labour process.

ii) The small-batch engineering industry

As a whole the engineering industry in Britain (which includes vehicles, aerospace, marine and electrical, as well as mechanical, engineering [1]) was responsible for some 10% of gross domestic product and the employment of some 2,100,000 workers in 1985. Total engineering employment has fallen by one-third (from 3,200,000) since 1979 (Financial Times 1986, p15). The domestic economic recession of recent years has affected the less electronically based, maturer, sections of the engineering industry disproportionately hard. These conditions have been exacerbated by the simultaneous increase in penetration of foreign imports in many of the industry's sectors. Thus reductions in employment and output have been most pronounced in sectors such as motor vehicles, and the majority of mechanical engineering industries rather than in sectors like aerospace (Fidgett 1984; Freeman (ed.) 1985; Sciberras and Payne 1985). The total number of employees in mechanical engineering alone has dropped from 919,000 in June 1976 to 659,000 in September 1983 (Freeman (ed.) 1985, p5) and to 630,000 in 1985 (Financial Times 1986, p15).

Britain's Engineering Industry Training Board (EITB) divides engineering industry employees into nine separate categories. These are: managerial staff, scientists and technologists, technicians (including draughtsmen), administrative and professional staff, clerical and office staff, supervisors, craft workers, operators in occupations requiring at least one week's training, and all other employees. One of the most pronounced trends within the overall engineering employment statistics has been the relative decline in the manual categories of operators and (less so) craft workers at the expense of technical and managerial occupations (Burgess 1985; Financial Times 1986, p15). The two manual classes have fallen in number from two million to 1,200,000 in the period 1979-85, although they still remain the largest single groups employed.

A declining proportion, now some 18% (approximately 500,000), of the total number of employees in engineering are craft workers (Aspinall 1981; Machine Tool Trades Association 1985, p21). The proportion of craft workers in each sub-sector of engineering fluctuates considerably, increasing in proportion to the variety and complexity of work, and lower batch sizes. Thus proportionately fewer craft workers are employed in the motor vehicle industry than in aerospace (Fidgett 1984) or the machine tool industry (Sciberras and Payne 1985; Machine Tool Trades Association 1985, p21). Small companies, whose production requirements tend to be more varied, tend to rely more heavily on such workers (EITB 1980c).

It is important to define the categories of operator and craft worker here in anticipation of later discussion on changes in manual work roles. The Engineering Industry Training Board provides an official definition, which distinguishes between these two grades according to the breadth of skills employed, degree of autonomy and discretion exercised, and transferability between firms of expertise:

The operator:

(a) Generally works on short cycle repetitive tasks or task clusters.

(b) Usually works to explicit instructions and close supervision.

(c) His tasks are usually product or process orientated and therefore his skills tend to be particular to the company/employer. (Oxley 1981, p579, my emphases -

PJS).

Whereas the craft worker is:

(a) Characterised by lengthy training - usually an apprenticeship lasting four years.

(b) The engineering craftsman is distinguished by a broad range of skills which he deploys with minimal instruction and/or supervision.

(c) He adapts and applies his skills flexibly and with discernment. He therefore plans and makes decisions.

(d) His skills are highly transferable. (Oxley 1981, p579, my emphases - PJS).

And, as the Manpower Services Commission (1984, p3) adds, craft workers:

> are trusted to work on their own with minimal supervision because they are capable of achieving the necessary results to the standard, and in the time, required.

The usefulness of craft-trained machinists lies in their ability to independently apply abstract engineering principles of machining operations, tooling, materials, and cutting theory gained in their initial year of apprenticeship training. This provides the basis for the subsequent extension by practical application of this theory in a range of situations. Craft workers thus understand work problems in terms of the abstract principles underlying tasks they have learned to perform, and which may therefore be applied to new situations encountered, and to the diagnosis and solution of problems (Berger and Piore 1980, p21).

iii) <u>The labour process of machining</u>

It will be recalled from Chapter Four that a labour process consists of a body of purposeful activities, together with particular technical means and a knowledge base to achieve these. In its widest sense a craft engineering labour process would involve all those activities, from design through machining to assembly, required for the production of an item (Kelley 1984). Yet this craft basis to engineering has been gradually fragmented through the successive separation of the various activities involved so that, for example, design, assembly, manufacturing engineering, and machining now each form distinct labour processes of their own [2].

At this point we shall treat machining as an occupation in its own right, although later sections will discuss the division of labour within the various tasks that make up machining. As a distinct labour process the "craft" of machining presupposes that certain task functions must be carried out [3]. These consist of planning, setting up the job and machine tool, performance and monitoring of the cutting operation, and inspection and finishing. In this section we will examine the nature of the tasks involved throughout the machining labour process and assess the skills and requirements necessary for the performance of these tasks. This will form a basis for later discussion of the division of labour within the machining labour process itself and the effects of mechanisation in small-batch machining operations.

Harrington (1973, pp 281-282) provides an appropriate introduction to this topic in an excellent summary of the skills exercised by the engineering craft worker on conventional machine tools. This bears quotation at length, for it provides a superb "feel" for the context in which craft skill is exercised:

> The old-time machinist knew how to read a blueprint and look at a pallet of castings or forgings. He could plan how he would convert the raw material into the part shown on the drawing....
>
> The machinist knew how to set the part up on the machine table or chuck. If he received a part unlike any he had seen before and the manufacturing engineer had not designed a fixture for it, he would confer with his foreman....

> The machinist knew how fast a 3/4 in. carbide tipped drill could safely be fed into an annealed nickel steel forging. He either found the information in a well-thumbed (and probably obsolete) handbook, or he remembered what he did the last time the occasion arose, or he ran his machine at a speed his "intuition" told him was safe....
>
> When the cuts were made, the machinist could measure the finished part with his micrometers and gauges to decide whether the surfaces were within the tolerance limits....
>
> Cutting tool selection and, in some shops, tool sharpening were normal functions of the machinist. There is nothing more important in metal cutting than the complex relationships of cutting edge, rake, and clearance angles; tool tip shape; depth of cut, feed per cut, and metallurgy of the part, on the one hand, and the surface finish, metallurgy of the tool, tool wear, time required, and power, on the other.

The first task in performing any job is to plan a method from the "job card" and component drawing (see also Table 2 below). It is necessary to decide upon the order, sequence and nature of cutting operations; the tools to be used; how the job will be held in place on the machine; type of coolant; the most suitable speed at which to run the machine, and the relative rate at which tool and workpiece should feed into each other.

Planning is basically a conceptual process involving a series of decisions based on fixed information and variables. This decision process takes place within an implicit framework, both as regards the types of decisions that need making, and the existence of general engineering principles (the "do's" and "don't's" of engineering practice) in order to aid that decision-making [4]. The translation of this generality into specific decisions in the concrete situation of a particular job is based on the accumulated experiential wisdom of the engineering craft worker. Essential features of these principles are their flexibility and ability for modification in the light of new developments. The EITB study of craft skill goes so far as to characterise these principles and their application as "the central feature of skilled behaviour" (EITB 1971, p25).

For any operation on a particular machine the limitations of the machine itself are the first constraining factor. Its capacity, rigidity and range of speeds will determine what work can be put onto it in the first place. The component drawing and/or the job card will give the rest of the basic information from which it is necessary to work: that is, the size and shape of the workpiece; the material form and type; together with the surface finish,

TABLE 2

PROCEDURE OF PLANNING FOR THE CRAFTSMAN [5]

Check drawing, job instructions and materials and decide following:

Operation sequence- - - - -	Location for further operations
	Measurement
	Time factor and safety
Workholding - - - - - - - -	Distortion to workpiece
	Finish and accuracy
	Safety
Cutters - - - - - - - - - -	Mounting
	Size and type
	Finish required
	Speed range of machine
	Safety and swarf clearance
Speeds and feeds - - - - - -	Finish required
	Safety
	Time factor
	Cutter life
Cutting fluids - - - - - - -	Use as coolant
	Use for flushing action
	Use for dampening
Measuring equipment - - - -	Select type required

accuracy, operations, and batch size. Within the constraints of the job required and the limitations of the machine, the method of arriving at the finished goal is normally very much up to the craft worker.

In the case of planning the variable job factors such as methods and sequence of operations, and selection of tools, the machinist's decision must take into account multiple influences, some of which may have synergetic effects. For example, the important final selection of feeds and speeds (which themselves normally possess an inverse relationship) is influenced by material type and form; tooling material, type, shape and cutting angles; size and shape of the workpiece; range of spindle speeds; quantity of workpieces required; and surface finish. To further complicate matters the cutting process usually proceeds in two stages: a series of "roughing" cuts to remove the bulk of the metal followed by a "finishing" cut run at a faster speed to provide the required quality of surface finish.

After the planning process is complete conceptual skills are still required as the job must be laid out ready for machining by etching or dyeing cutting guide lines onto its surface. This requires mathematical ability and accuracy, coupled with visualising the shape of the workpiece at the various stages of transformation. It is also sometimes necessary to remove surplus rough metal from the blank workpiece. Following this, the job must be set up on a specific machine. This requires the workpiece to be fixed onto the machine in correct alignment (normally by means of special fixtures) according to the layout markings. Similarly the appropriate cutting tools must be set in their holders. In some cases it may be necessary for tools and fixtures to be made specially. The machine tool's rotating speed is also set at this point by means of the appropriate dial.

The process of setting-up demands a degree of positional accuracy and care directly related to the tolerances allowable on the finished article; and a related ability to use measuring equipment of a comparable standard. In the case of a requirement to perform a number of operations at one setting the skill needed for setting up will be greater, in order to position workholding equipment such as clamps in places which will not foul the toolpath of a subsequent operation at the same setting. In any case a knowledge of all the operations to be carried out will be required in order that the tool and workpiece can be positioned aright. Achieving sufficient tightness of tools and workholding equipment is very much a matter of exercising perceptual skill, for distortion will result if overtightening occurs. This is more critical on fragile or flimsy workpieces and soft materials such as aluminium.

During the actual machining operation itself the types of skill required tend to shift away from conceptual skill towards the exercise of motor and perceptual skills. The operator has a certain amount of discretion (within time constraints) over the method of achievement of a required standard of accuracy because of the fact that cutting is taken in two stages. The coarseness of the rough cuts requires relatively less attention than the finishing cuts which remove material to the final dimensions and surface texture called for. The finishing cut will normally require more accurate tooling (for example, a drilled hole is normally bored to the finish diameter) and more constant and detailed machine control. For any machining job, therefore, the real operational skill of the machinist is concentrated into the finishing cut towards the end of the operation. The accuracy achievable here is entirely dependent on the manipulative skill of the operator.

The rate of feed of the tool into the workpiece (or vice versa in the case of lathes) is controlled by the operator via handwheels, and therefore calls for the exercise of a continuous combination of subconscious motor / perceptual abilities in the machining process. It is important to realise that much of the skill employed in the cutting process itself consists of recognising and pre-empting the development of error conditions (Engineering Industry Training Board 1971). On conventional machine tools the successful performance of the operation and the avoidance or correction of errors depends upon the exercise of perceptual and motor skills for defect recognition and correction.

The operator is in close proximity to the workpiece and the cutting process is easily observed, the view of the workpiece only being obstructed (if at all) by the flow of coolant or swarf. On conventional machine tools the operator's proximity and need for continuous control permits small but potentially significant dynamic changes in operating variables to be readily perceived and modified. The perceptual skill consists in the ability to detect very slight warning signals in, say, the colour of the swarf or the sound of the tool from the high level of "background noise" present [6]. Control of the machining process in this manner relies heavily on reaction to sensory data, primarily of an aural or visual nature. The experienced machinist can detect early warning signals for a large number of operational errors (which can be specific to either the machine or the part). Many signals are common to a variety of different causes, however, so the skill lies in dissembling the exact cause at any given time. The vibration and ridged surface appearance characteristic of the fault known as chatter may be caused by over a dozen faults, which may not even be mutually exclusive, including incorrect speeds and feeds, worn or loose tooling, insecurely fixed work, etc. The appearance of ragged or discoloured swarf may be traced back to a number of coolant or tooling problems [7]. Therefore the machinist must recognise faults overwhelmingly by means of secondary signals.

Nevertheless a large number of faults of dimensional accuracy permit no easy early warning, and these must be rectified after the machining process is complete. Once again a single effect (i.e. machining out of tolerance) may have a wide variety of causes: in the case of tight tolerances (finer than about IT6 according to British Standard 1916) thermal factors from the outside environment itself come into play as a possible variable - heat can expand both workpiece and machine column causing inaccuracy. Many conventional machine tools suffer from a lack of rigidity in construction, and consequently of accuracy. Thus ability to achieve required tolerances is often only enabled by the "tacit" preventative skills exercised by the machinist to make up for the deficiencies of the machine tool by "tricks of the trade", such as by physically putting his or her own weight onto the machine to affect its deflection and compensate for the flexibility in its structure. In addition the machinist must compensate for the idiosyncracies that develop over time in all machine tools. It is a common observation in machine shops that no two machines are exactly alike, even if they are the same model (and this is equally true of computer-controlled machine tools). Machine accuracy is affected by a host of electrical and mechanical factors, inertia, friction and so on (Donmez et al 1982), while part-specific errors may be caused by deficiencies in the raw material or by incorrect clamping pressure resulting in the deformation of the part.

During operations it will be necessary to measure the part to ensure the machining process is according to plan. The variables to be measured are textural and dimensional accuracy. The inspection of the standard of surface finish produced basically requires perceptual skills. Texture is checked by comparison plates of guaranteed standards of surface finish which are held against the work. The proximity of texture is then checked against that of the workpiece by means of a visual and tactile comparison (EITB. H4, n.d., p81), which clearly allows the machinist the exercise of a limited amount of discretion in passing judgement. The checking of dimensional accuracy, although basically similar, may have a conceptual content depending on the complexity of the measuring equipment required. Some mathematical ability may be called for, as in using a clinometer or vernier height gauges (see for example EITB. H29, n.d., pp 70-71), although this is unlikely to be more complicated than simple division.

Thus machining as a distinct labour process comprises a number of task areas (planning, job layout and set-up, the machining operation itself and final inspection), which demand different types of skill at different points. The conceptual and planning content of the work is concentrated into the tasks preparatory to the machining process itself. During machining predominantly manual skills are required, although we have seen that craft work implies the concurrent exercise of decisions to prevent the emergence of fault conditions.

iv) The sub-division of labour and functional organisation

We have argued above that the machining labour process comprises particular purposeful task functions which require certain skills. It has been assumed that this labour process can constitute the entire occupation of a craft-trained machinist. In reality, matters are more complex because of the role played by the organisational, task-centred, product and labour market factors discussed in Chapter Four. In this section we shall apply these factors to small-batch engineering in order to establish how far a process of skill fragmentation has occurred.

Studies of industrial relations in the labour-intensive batch engineering industry (Goodrich 1975; Hinton 1973; Jefferys 1946 inter alia) argue convincingly that a primary motivation of management has increasingly been to gain control over the labour process from craft workers. The attraction to management of a strategy of wresting skill and control from these traditionally militant workers to reduce unpredictability within the production process and lower labour costs can be readily understood [8].

Following Kelley (1984, p65), a useful distinction can be drawn between a craft tradition as discussed above and a craft task structure. A craft tradition, in the sense of a distinct "artisanal" set of social arrangements surrounding the labour process (such as limited entry to the ranks of the "skilled" by means of a period of apprenticeship), remains a force of some sway in engineering, although now declining in influence. A parallel craft task structure (of the sort reviewed in section iii)) has been gradually whittled away by various forms of interacting horizontal and vertical divisions of labour since the nineteenth century. In small-batch engineering, firms made sporadic attempts (the first of which long predated Taylorism) to achieve the fragmentation of labour by these methods [9].

The horizontal division of labour was achieved firstly as a consequence of the development of particular classes of general purpose metalworking machine tools. By the end of the nineteenth century the four basic types of machine tool that exist today (the lathe, milling machine, grinding machine and drill) had evolved. Between them these tools were able to perform the main processes of metal removal (Williamson 1968b). The basic organisational principles of the small-batch engineering production system (which have remained virtually unchanged since the nineteenth century, despite the vast increase in the scale of production since this time) were organised on so-called functional lines. In this form of organisation each type of machine tool is normally allocated to a particular area of the shopfloor, so that (for example) all drills would be clustered in one section while the various types of milling machine would be grouped in another area (see for example Edwards 1971, pp 20-21). Functional organisation was a response to the very diversity of batch engineering production.

The functional organisation of production based around single-process machine tools has also resulted in a distinct pattern of evolution of the division of labour within small-batch engineering [10]. Machinists on the shopfloor were subject to a horizontal division of labour according to specialisation in particular machining processes. Sub-classes of these machine tools, which were often designed to simplify or eliminate human intervention as far as possible (as in the development of the bar-fed automatic lathe, for example) evolved for more specialised purposes. In these cases the skills required to operate such tools diminished accordingly. Thus, after apprenticeship, the craft increasingly implied specialisation on one type of machine: one was a turner, or a millwright, and so on. A further evolution of increasing task specialisation within the "craft" tradition was the development of the principle of "one man (sic) to one machine". This was supported by the main engineering craft union, which is now known as the Amalgamated Engineering Union (AEU) [11], as a method of maintaining the numbers employed in workshops. Operating functions were further sub-divided by means of the introduction of semi-skilled helpers to deal with ancillary tasks such as workpiece transfer and swarf removal.

The more significant development in the division of labour in machining work, however, has been its concurrent organisational sub-division on a vertical basis, so that management, planning and pre-production (indirectly productive) functions become separated from execution tasks. During the era of the factory system a feature of capitalist production has been the attempt to transfer the former functions from the control of the machinists on the shopfloor to a new class of predominantly office-based indirectly productive workers. In the engineering industry this was expressed in the advent of specialist supervisory, production control, work methods, quality control and other task functions. In production control, for example, decisions on which job should be machined next became the responsibility of the foreman and scheduling personnel; and progress chasers were employed to track down, and expedite the completion of, parts on the shopfloor. Most importantly, the Methods Department took over the craft worker's task of deciding how a part would be made and the machines to be used in doing so, and would try to set a rate and time for the performance of the job.

At least in theory the craft task structure of machining has been threatened by the extension of the division of labour both laterally and vertically. The question remains to be asked, however: how far has this tendency towards increasing sub-division been realised in practice in small-batch engineering? The principles behind the methods described above have diffused widely in small-batch engineering to the point where they represent the standard basic structure according to which all engineering firms are organised. In many cases batch engineering firms have tried to sub-divide labour wherever possible. For example, small turned parts required in large numbers (such as discs or shafts) have been assigned to bar-fed automatic lathes staffed by semi-skilled operators; or complex, non-standard components have been sub-contracted to outside engineering firms.

However, as we have hinted above, such methods have so far proved inappropriate to the majority of the production requirements in the industry, and this has resulted in an uneasy tension in small-batch engineering between the attempt to sub-divide and rationalise wherever possible, and a continued reliance on the tenacious craft skill of the machinist. Small-batch production, mostly carried out in the small firms that form the greater part of the engineering industry, is predomininantly concerned with the manufacture of very wide ranges of specialised capital goods, which are normally required in limited numbers and may rarely be re-ordered in the same design. In many cases the unpredictability and variability of the production requirements for such goods, and the need to maintain maximum productive flexibility to respond to a wide variety of potential orders, have necessitated continued reliance on craft skills in small-batch engineering. These factors have discouraged the rigorous application of Fordist methods through the pursuit of the intensive sub-division and simplification of labour, the detailed pre-planning of production, and standardisation of techniques.

The components produced are themselves often complex to manufacture, possibly requiring the working of difficult materials or machining to tight tolerances. In the latter case, the lack of rigidity, inaccuracy, and poor repeatability of many of the general purpose machine tools necessarily used has also ensured a continued need for machinists' skills to enable the production of components to the standard the customer required. In this environment a combination of the difficulty in analysing craft skill, and the unwillingness of the machinists to share their knowledge, ensured its retention.

The limited success of these strategies to rationalise the machining process can be exemplified by the fate of one early attempt to introduce indirectly productive staff to take over the task of stipulating the operating values of machine tools. As early as the turn of this century, some engineering employers began to introduce "feed and speed men" into turning machine shops, whose function was to work out for each job the depth of cut and cutting speed. These tasks had previously been the prerogative of the machinist. This attempt to wrest skill from the shopfloor by means of a heightened division of labour was too primitive to succeed, though, for the following reasons:

> The feed and speed instructions were very crude: a combination of worker resistance, and their own inaccuracy, effectively put a stop to the introduction of the instructions in their original form, and much more responsibility had to be given back to the workers in order to make the system operate satisfactorily. (More 1980, pp 189-190).

Moreover, the varied nature of batch production itself proved a stumbling block to the diffusion of the "feed and speed man" system. In many machine shops "such methods were not so much unknown as inappropriate because of the diversity of work." (More 1980, p190).

Other writers also show, for example, how attempts at technological deskilling backfired by merely stimulating new customer demands for work of more exacting quality. Jefferys (1946, p16) for example, details the way in which engineering employers foresaw the introduction of new tools such as the planer as reducing skill requirements. Although, in themselves, the machines did just this, the increased accuracies and speeds permitted by the new tools created a demand for entirely new classes and standards of work. These changed requirements enabled by the new machine tools resulted in skilled workers still being necessary to enable the novel demands to be met.

It has already been suggested that the relative strength of craft labour in small-batch machining constituted an important reason for the weight accorded by management to deskilling objectives. In Britain craft "skills", and the period of apprenticeship considered necessary to attain them, have historically been defended by craft unions such as the AEU. Because of their value in bargaining over jobs and pay the real basis of these skills has often been questioned by those preferring a social definition of skill (see Chapter Four). Evidence confirms that the union has used its strength wherever possible to maintain job controls untenable by workers with more job-specific skills (More 1980; Penn 1982, 1984). For instance, the union tried (with limited success) to oppose the "dilution" of skills by means of the employment of less "skilled", non-apprenticed women workers on work normally performed by its members during the First World War (Hinton 1973). Pursuing this theme, Penn's (1982) study of engineers in Rochdale notes the ability of the craft engineering trade union in times of labour shortage to dictate the level of skill of the employee that will operate any machine, quite regardless of the "technical" skill requirement.

These historical attempts to assert workplace-based skill construction have fluctuated in their success rate according to the relative strengths of management and craft workers at any given juncture. It seems clear that the social construction of skill has been rife in small-batch engineering. This certainly does not mean that the real basis to craft skill discussed above is insignificant or non-existent. One would expect the much-vaunted management offensive launched in the wake of the post-1979 recession to have succeeded in pruning such social construction of skill as did exist prior to the time of this study. However, recent studies still report skill shortages at craft level in certain firms and areas, even despite heavy redundancies (Confederation of British Industry 1985; Smith, M 1986; Wilkinson 1983; inter alia). Such shortages were also reported by many of the firms in southern Britain studied in this project.

Recent moves to reduce the control exercised by craft workers (and other directly productive personnel in engineering companies) have included attempts to gain greater flexibility in labour deployment between tasks. This managerial focus results from the belief that, as Kilpatrick and Lawson (1980) pose the issue, poor British economic performance relative to other countries can be partly attributed to the historical rigidity of occupational demarcations, which has been occasioned by the peculiar form of the British industrial relations system and the strength of the labour movement. Thus, it might be said, the preservation of "overmanning" through the artificial maintenance with the aid of union power of technologically obsolete craft divisions has hindered innovation, reduced the mobility of labour and increased its cost relative to other factors of production.

Some writers argue that an attack on the restrictions preserved by trade demarcation lines has become one of the most significant themes in industrial relations bargaining generally in the 1980s; and that economic and technological pressures have led managers to attempt to win greater flexibility among employees (Connock 1985). For so-called "core" groups of employees, such as craft workers, pressures for flexibility mainly take the form of attempts to make workers responsible for a more extensive task repertoire, which Atkinson (1985) calls functional flexibility [12]. Studies of progress towards craft flexibility in British manufacturing industry (which include examples from batch engineering) suggest that the two main enabling factors for employers have been the labour shakeout caused by the economic recession of the post-1979 period coupled with the introduction of new technology (Atkinson and Meager 1986; Dunn 1986; Incomes Data Services 1984a, 1986). It is largely coincident that these two factors should come into play at the same juncture. However, it is possible that their combination in firms badly hit by the recession but nevertheless investing in new technology may well have produced synergetic effects enabling both labour reductions and more flexibility from those workers directly involved with the new systems.

Empirical studies convincingly question just how widespread or effective the drive towards labour flexibility has been. They conclude overall that major headway has been minimal, agreements have often been subject to formal and informal workforce or union pressure for reversion to previous arrangements (Incomes Data Services 1984a, 1986), existing demarcation lines have proved tenacious, and that little extra training has been provided by employers (Atkinson and Meager 1986; Labour Research Department 1986). Major changes in labour flexibility are usually related to production on greenfield sites and/or the introduction of new technology [13]. Work role modifications on greenfield sites include fewer tiers of management and supervision, minimisation of status differences, avoidance of existing trade demarcations and the "restrictive" practices of other plants, thus enabling attainment of maximum functional labour flexibility. The institution of forms of vertical or horizontal labour flexibility intended to encourage joint responsibility, individual motivation, discretion and autonomy, and to reduce indirect costs is often part of this process (Incomes Data Services 1984b).

It can be seen overall that the high degree of production flexibility required in small-batch engineering has preserved a considerable role for the craft skills of the machinist. By its nature this skill is hard to analyse. With this skill, therefore, has come control over the labour process, a degree of which has remained, despite encroachments by some technological and organisational developments, and management intent.

v) Conclusion

This chapter has investigated the nature of craft skill within the small-batch engineering industry. It has shown that, notwithstanding atrophy over the long term, features inherent in this sector as the producer of specialised capital goods have been responsible for a continuing requirement for such skill. Despite considerable social construction of craft skill at periods of labour strength, such skill must have an underlying real basis, otherwise the concept of craft control could not be operationalised. The real basis lies in the tacit conceptual and executive skills which form the grounding for so much craft job knowledge.

Managerial intentions have succeeded to some degree in reducing the skill and control exercised by craft workers. These intentions spring from a Fordist dream of production rationalisation. This vision entails both decreasing labour costs through skill substitution (as labour has been believed to form a high proportion of total costs in batch engineering); and increasing the predictability in operations through the transfer of as much control over the production process as reasonably practical.

Considerable emphasis has been placed by managers on reducing labour's control over the production process at the expense of tackling the basic organisational problems of batch engineering. These include low rates of machine utilisation stemming from the frequent need for skilled and lengthy resetting of machines; a lack of control over the production process, due both to the autonomy of labour, and to the complexity of production and inventory control under functional organisation for wide varieties of parts; long component lead and throughput times, which were hampered by and high material costs tied up in scrapped components, work in progress (WIP), and in finished stocks because of the need to machine components in an economic batch quantity (EBQ) [14]. Overall these problems have resulted in the inability to respond rapidly and flexibily to changing production demands (Skinner 1971; Williamson 1968b, 1972).

Indeed, the focus on sub-dividing labour, when pursued, has actually exacerbated organisational problems. Labour fragmentation has created both formal and informal job demarcations, and consequently greater difficulty in overall coordination and control of operations between different groups in the production process. This latter point was demonstrated in the example of the rise and fall of "feed and speed men".

Technological developments, which might be another vehicle for the removal of skill, have been sparse because of the difficulty (until recently) of developing cost-effective special purpose machinery to operate at low scales of production. Secondary and tertiary mechanisation have thus only affected the periphery of small-batch engineering. Sometimes, moreover, their effect has been to create new skills which have given birth to new roles for the craft worker.

The managerial problem to be confronted in small-batch engineering can therefore be summed up as follows. There is a need for production flexibility, which in turn presupposes a need for versatile technology. Hitherto the use of such technology in the form of general-purpose machine tools has involved the devolution of considerable control over the labour process to skilled craft workers. The power conferred by this control has prevented managers from obtaining labour flexibility; and the development of horizontal and vertical demarcations has impaired the ability to achieve a rapid response to market changes through a wider organisational flexibility. We can now turn to the technical and organisational solutions that have been proposed to these problems.

CHAPTER SIX: Technical and organisational change in small-batch machining

i) Innovation in small-batch machining

Several technical and organisational innovations have been introduced into small-batch machining in recent decades, of which FMS is but one of the most recent. The basis for the development of FMS rests on two preceding innovations which were separately introduced into batch engineering, particularly from the 'sixties onwards. These are an organisational arrangement called group technology, and a set of technical changes generically known as numerical control [1]. Group technology is an alternative form of production organisation to the functional type; while numerical control transfers the technical control of a machine tool's cutting process from human to programmed form. The program can be expressed in either "hard-wired" punched paper tape (NC) or, latterly, "soft-wired" digital forms (computer numerical control, or CNC). Direct numerical control (DNC) - a further refinement, and a prerequisite for FMS - enables the transmission of programs to individual machine tools from a central computer.

GT and NC should be understood in terms of their usefulness as analytical tools to comprehend the basic technological and organisational principles on which FMS is grounded rather than as production systems in themselves [2], for diffusion of both GT and NC in Britain has been minimal to date [3]. The relevance of discussing these precursive innovations here stems from contemporary debate upon the intended and actual changes in the machinist's labour process as a result of their introduction. Our investigation provides the background to the argument in subsequent chapters on how labour roles evolve further with FMS.

Firstly, as we saw in Chapter One, the subject of whether such innovations have been basically intended to extend to low-volume manufacture traditional, quantifiable, "Fordist" production benefits has been much debated. Such benefits include calculable gains like reduction in inventory and work in progress levels, faster throughput times, higher levels of utilisation of capital equipment, and reduced unit labour content (particularly that of direct labour). Moreover, it is alleged that the increased control over production available through innovations like GT and NC largely equates with a desire for tighter specification of labour roles and a reduction in workers' discretion. Thus technical flexibility is viewed in terms of an operational ability to increase management control, eliminate human intervention and machine downtime, and thus boost productivity.

In contrast to this narrow approach, it has been argued that the increasing fragmentation of product markets renders these traditional cost and labour control aims increasingly insufficient to resolve wider business and marketing problems. Recent evidence suggests that these difficulties are particularly relevant to British manufacturing industry [4]. Instead, it is suggested, the pursuit of intangible, qualitative, "strategic" benefits available through increased flexibility and wider manufacturing control are more important reasons for innovation [5]. Such benefits include improved product quality and consistency, reduced need for fitting and assembly work, ability to respond more rapidly to market changes in terms of product mix, volume, or type of product produced, and rationalisations of product designs. Qualitative benefits are difficult to define or measure because of the additional (and often poorly understood) dimensions of the manufacturing flexibility available, and may consequently be more difficult to exploit [6], but may have an indirect, "knock-on", effect in improved long-term manufacturing profitability, as non-price factors become more important in overall competitiveness (Goldhar and Jelinek 1983; Jones 1985c).

Controversy has also centred on the extent to which traditional "Fordist" productivity and labour control objectives are realisable through innovations like GT and numerical control in small-batch machining while preserving necessary adaptability. Chapters Four and Five showed the difficulty of attaining these goals while simultaneously retaining the production flexibility associated with functional organisation and conventional machine tools operated by skilled labour. And, as Fenwick (1984, p27) says, automation in any form introduces an element of dedication into the manufacturing process and reduces productive flexibility. It will therefore be difficult to harmonise the competing claims of productivity and adaptability. For example, high levels of machine utilisation will be more difficult to achieve if a firm also desires frequent switches between products to capture new markets.

Several questions interest us here. Firstly, to what extent does the introduction of GT and the various generations of numerical control demonstrate the application of traditional labour control and deskilling objectives? Where attempted, it is possible that such aims could be thwarted by a number of factors. These might include a technical requirement for machinists to acquire additional skills or to exercise greater judgement than hitherto, or resistance to deskilling through industrial bargaining power. Secondly, how far has the pursuit of labour control aims through GT and NC proved compatible with the achievement of productivity and - even more so - production flexibility benefits under conditions of more complex and integrated technology, and of increasing market fluidity and fragmentation? To what extent, therefore, have these innovations enabled the satisfaction of more or less varied market requirements while incorporating the technical control of activities that would otherwise be the prerogative of labour? Through investigating these questions we hope to better understand the manner in which FMS's proposed solutions to productivity, control, and adaptability in small-batch manufacture flow from the shortcomings of these less integrated systems.

ii) <u>Group technology</u>

Group technology, which was much discussed in the 'sixties and 'seventies, was intended to redress shortcomings of functional organisation such as low machine utilisation and long resetting times, poor production control, and high material and labour costs. GT developed in three phases: group technology, cell layout, and group working (Bornat 1978). GT's first stage promised firstly the reduction of the time and skill involved in machine set-up. The essential feature of GT is that it reverses the emphasis found under functional organisation on differences between components, and concentrates instead on their similarities. "Families" of components are formed according to their alike size and shape [7]. Specialist, semi-dedicated, tooling and set-ups could be designed for machining of such part families on given machine tools, allowing a reduction of necessary changeover times between different batches within a given part family (Mitrofanov 1966).

The second stage of GT, cellular manufacture, proposed a group - rather than functional - layout [8] to bring simplified, faster material flow and, with it, improved production control. Cellular manufacture extended the basis of classification to a requirement for similar sequences of different machining operations. Such part families could then be routed for production on set machine tools, which (by logical extension) could be grouped into specific working areas, or "cells", on the shopfloor (Hyer and Wemmerlov 1984, p142). This created a simplified, although largely fixed, path of material flow within component groups.

Group working, GT's final stage, applies "human relations" approaches to changes in the organisation of work and deployment of labour to GT cells. Higher productivity and improved worker motivation are claimed to be possible through increased flexibility of labour between machines. For the machinist cellular manufacture introduced a number of the disadvantages characteristic of flow-line production to smaller batch work due to the increased standardisation of components and techniques (Wild 1973). Lower utilisation levels of individual machine tools in the typical GT cell encouraged managers to counteract this problem by trying to achieve greater flexibility of labour between machine tools than usually found under functional organisation [9]. It was proposed that a flexible workgroup smaller in number than the machine tools dedicated to a cell should become responsible jointly for all production tasks within the cell [10].

Overall, then, it was believed that GT would lead to such benefits as faster resetting of machines between batches of parts (through the use of specialised tooling set-ups), simplification of materials flow, materials handling and production control (as all components within a family are produced in one area), reduction of throughput times and work in progress; and thus lower demand for indirectly productive workers such as storekeepers and progress chasers (Burbidge 1975, pp 236-237; 1979).

To what extent is achievement of the presumed increase in productivity, manufacturing control, and flexibility in GT dependent upon the modifications to labour roles proposed by the advocates of group working? And do the changes planned for work organisation entail increased or decreased levels of skill and control exercisable by machinists? Three conflicting explanations have been proferred on the basis of analysis of some well publicised examples of GT "successes" (Bornat 1978) [11]. These accounts originate respectively from "technicist", sociotechnical, and neo-Marxist perspectives.

The first approach suggests that the economic and technical aspects of group technology are the main reasons for its success, with changes in labour flexibility being largely irrelevant. Any social benefits that may accrue in terms of increased job satisfaction are seen as incidental secondary, if useful, consequences of the technical changes (see Gallagher and Knight 1973; Hyer and Wemmerlov 1984).

A second school of thought is influenced by the ideas of the sociotechnical theorists. Edwards (1971, 1974b), Fazakerley (1974), and Burbidge (see especially 1976) argue that the advantages of group technology cell layout in terms of higher productivity cannot be separated from greater worker motivation attributable to benefits from work reorganisation. These writers' stress falls on the importance of predominantly horizontal forms of task flexibility such as job enlargement and task rotation within self-contained work groups. It is believed that improved worker motivation will result from an increased breadth of responsibility for the process of manufacture, encompassing several different machines, perhaps of dissimilar types, thus creating a new involvement with the machining of a component from start to finish; possibly more varied work because of the likelihood of lower batch sizes; increased autonomy while still being part of a distinct team; and higher pay as a result (which can be financed through the higher productivity) (Burbidge 1979, p245). Burbidge (1978, p89) claims that skill requirements are often increased in GT cells.

The third school of thought is primarily influenced by Marxist writings. It is concerned with relating changes in labour organisation within a specifically capitalist labour process to the development of a real subordination of labour in the Marxist sense (that is, the control of human labour power by machinery) [12]. Reversing the sociotechnical school's interpretation, Bornat (1978) and Green (1978) argue that the economic benefits of group technology occur at the expense of workers' skills and control over the production process.

It is argued firstly that group technology offers management the opportunity to reduce skill levels by limiting the variety of parts processed in any one cell (through their classification into families of like components); use of more specialised machine tools, and rationalisation of the variety of tooling and set-ups. Through these techniques the level of overall skills required within the cell is reduced accordingly. As Bornat (1978, pp 77-78) argues, for example, the reorganisation of product information and machining along the lines suggested by group technology then provides a basis for further automation by means of the simplification of workflow and machining processes.

Secondly, it is argued that management control over production is increased. GT is thought to extend to small-batch engineering mass production's depersonalised technical control over workers' execution of tasks. Quality and production control are built into the system. This technical discipline functions through the interdependence of workers (each team member has a vested interest in ensuring he or she receives work of adequate quality from team mates), the fact that overall accountability rests with one person (the cell's foreman) rather than many, and the removal from workers of discretion in scheduling.

For these reasons the above critics argue that the sociotechnical proposals for the creation of autonomous work groups are not incompatible with what they see as increased management control and deskilling, for such "autonomy" disguises the reality that most of the major methods decisions on work planning and scheduling have been removed from the shopfloor into the Planning Office. Thus, it is argued, production engineers and managers can afford to grant what superficially resembles greater autonomy, although the worker's performance is in fact now more closely specified and technically supervised than was possible under functional layout.

The neo-Marxist argument that GT has the consequence of enhancing and centralising overall management control of the production process at the expense of workers' discretion appears convincing. But, while GT may have reduced workers' control, it is less certain that they were also "deskilled". Some evidence (Leonard and Rathmill 1977a, 1977b) confirms our view that GT's outcomes for skill levels and working practices are more indeterminate than the neo-Marxists suggest. Leonard and Rathmill insist that the implications of job flexibility for skill levels have proved highly ambiguous. As they ask, does labour flexibility refer to:

> a skilled operator producing parts on another specialist machine? A semi-skilled operator using a skilled operator's machine? Or a skilled operator making simple parts? (Leonard and Rathmill 1977b, p43)

Leonard and Rathmill (1977a), who argue for the need to generally reduce operator skill requirements in engineering, conclude that GT systems could only have viably achieved both this objective and improvements in machine utilisation if used on flowline principles for machining simple parts with a high similarity of design (such as valves) [13]. GT was, therefore, technically ill-suited to more than a small proportion of the wide variety of products machined in small-batch engineering, and this partly accounts for its minimal diffusion. Considerable preparatory classification and coding of very wide varieties of components into families would have been necessary. Even with the aid of a computer this presupposed a significant amount of indirect work, which even many firms that did consider GT thought unjustifiable (Gill 1985, p69) [14].

GT also failed in the 'seventies for industrial relations and organisational reasons [15], many of which are still relevant. Management were unwilling to tackle existing demarcation lines and labour practices for fear of shopfloor resistance, or to invest in necessary extra training [16]. Where attempts were made to attack demarcations in the process of introducing GT, Leonard and Rathmill (1977a) note that there were difficulties in obtaining the desired degree of labour mobility. Further, as the above quote indicates, the first two of Leonard and Rathmill's three possibilities imply a need for training to be provided for additional skills, thus increasing workers' bargaining power at the expense of management and confounding deskilling motives. Under GT many firms underestimated the amount of retraining of already skilled workers that would have been necessary to adequately instill the skills of operating different types of machine tool, and were reluctant to pay the price for achieving labour flexibility by providing extra training (Leonard and Rathmill 1977a; Swords-Isherwood and Senker 1978). The organisational complications were also prohibitive. Because of the wide variety of parts processed in small-batch engineering, in many cases GT cells resulted (ironically) in increased complexity of overall production control. It was less versatile than functional organisation in terms of the ability to produce a given part on different machines (which we shall call routing flexibility) and to respond to sudden fluctuations in production volumes (volume flexibility). Moreover, much expensive upheaval would have been involved in the change from functional layout and organisation to GT.

Evidence indicates that GT's promise of increased productivity, manufacturing control, and flexibility of resetting was only attainable in certain restricted applications. In particular no necessary correspondence can be found between GT and "deskilling", although machinists' discretion appears to have declined. The skill in machine operation was still firmly located within the operator. It seems highly likely that many firms realised that labour flexibility, if it required additional skills, might actually compound the problems of labour cost and control they hoped to solve and, for this reason among others, did not pursue GT.

iii) <u>Numerical control: separating conception from execution?</u>

Many of the benefits of productivity, control over production and labour, and flexibility claimed for GT were also believed to be achievable through the technical means of the numerical control of machine tools. With numerical control these benefits were intended to occur through increasing mechanisation of machine tools requiring reduced labour inputs, management-determined production methods and cycle times, improved manufacturing information, and the ease of reprogrammability. After the effective demise of GT in the 'seventies the diffusion of NC in small-batch plants began to increase therefore, although the technology had been first developed as early as the late 'forties for complex applications in the aerospace industry [17].

The term "numerical control" conceals a number of stages of technical development. It is necessary first to appreciate these different phases in order to see why - as we shall argue below - possibilities for machinists to expand their skills and control have been extended by successive technical refinements. Under numerical control the control of a machine's cutting motion, and the sequence of necessary operations, are directed by programmed means rather than the conscious activity of a machinist. In its original form, NC, the "pattern" of coordinates for the tool to follow (the toolpath) and other necessary sequential commands (such as instructions to turn coolant on and off, to change tools and so on) was generated digitally on a mainframe computer, the information transferred to punched paper tape, and this program fed in sequence through a control unit connected to a machine tool (Noble 1985).

Manufacturing control objectives were enhanced by direct numerical control, which linked groups of stand-alone NC machine tools to a central computer with a larger memory and "downloaded" the required programs from this to the relevant machine tool. DNC was even more complex and expensive than NC (and was only adopted in a few large aerospace plants), but overcame the incompatibility of the control systems on different (particularly early generation) NC machine tools, and their lack of computing power and program storage ability. Improved management information on machine status could then be obtained through the transmission of data in the opposite direction to a central level.

The level of flexibility and manufacturing control available from numerically controlled technology was really revolutionised by the development of microprocessor-based CNC in the 'seventies. CNC provides a cheaper, more powerful, compact, and reliable means of machine control than its predecessors (Ferguson 1978). Computer numerical control allows part programs to be amended more quickly and simply than could the older punched paper tapes (a form of adaptability I shall call modification flexibility). Greater computing power means that it is possible to store and run increasingly complex part programs and to incorporate additional facilities into machine tool control systems, making available more management information (such as machine status), diagnostic maintenance routines (such as displaying fault codes in the case of malfunction) and other information of value to the machinist. This permits improved management control over the production process by allowing statistical data on performance efficiency (such as information on machine utilisation and downtime) to be collated. In the more powerful recent versions of CNC programs can even be created through manual data input (MDI) of information into the machine-level control unit [18]. CNC enables all these facilities to be obtained at the level of the individual machine tool. DNC, now redeveloped on the basis of microprocessors, replicates these advantages of CNC, but centralises the locus of machine control. With DNC, machine-level CNC controls are little more than a transmission belt for the downloading of part programs from a central computer and the uploading of management information (Harrington 1973; Kochhar and Burns 1983).

The mechanical capabilities of numerically controlled machine tools themselves have increased concurrently with the innovations in control systems. The development of the machining centre demonstrates this particularly [19]. Such machine tools are multi-functional, integrating hitherto separate machining processes such as milling, drilling, boring and tapping; and increasingly universal, being able to perform a number of operations at one setting. They can also assume a number of hitherto manual monitoring and ancillary functions, such as changing tools and compensating for unexpected machining conditions. A further embellishment is the partial mechanisation of the material transfer process by the provision of a number of pallets on which workpieces may be set up away from the machine tool, and then presented to the machine according to a predetermined schedule. Remote set-up and automatic toolchanging finally permit the considerable increases in machine utilisation that were unattainable with early numerically controlled tools. Much improved cutting speeds and standards of accuracy compared to older machine tools are also possible with the more recent models of machining centre.

Radical authors such as Braverman (1974) and Noble (1979), following claims made by some managerial writers (see for example Harrington 1973), have been influential in propagating the view that the main purpose of numerical control is to destroy craft control of machining. These writers argue that cycle times, tool life data, the consistency and repeatability of machining performance, machining methods and other operating phenomena can be precisely specified under NC, thus removing the variability caused by the operator's direct control over the machining labour process.

Enhanced managerial control finds expression largely in the manner in which the machining labour process is fragmented under NC. The machinist's most skilful tasks concerned with methods decisions on job planning, set-up, fixturing, feeds and speeds, and tooling are taken over by process planners and manufacturing engineers - although, in some cases, certain of these responsibilities had already been transferred under conventional methods - and by a new office-based occupational specialism responsible for part programming. The part programmer's main task is to construct a computer program to replace the operator's direct control over the planning and performance of the machining operation. The machinist is neither required to conceptualise and plan how the part is to be made nor to directly control the machine's motion, as these tasks are incorporated into the part program. On this view, the machinist is reduced to loading and unloading the job and minor monitoring, finishing and inspection tasks. For Braverman and Noble NC as a <u>system</u> of manufacture completes the deskilling of engineering work begun by Taylorist methods of organisation by enabling the rationalisation of variables in the production process and extending the division of labour in small-batch machining.

Predictions of an overall deskilling of operators have not been borne out, however (Taylor 1978, p95). Radical authors made three mistakes. Firstly, they failed to appreciate the technical reasons for the division of labour under NC. They also underestimated the continued requirement for machining skills with numerical control in small-batch production and the methods whereby machinists were able to retain control over the labour process (see also Chapter Four). Finally, they neglected to take account of the manner in which the technical flexibility of CNC has disproved the assertion that numerical control has rigid organisational ramifications.

To take the first point, technical difficulties in the original development of NC made it unamenable to decentralised control. These were exacerbated by the production requirements and well established organisational demarcations in most of the plants that could afford NC. NC was originally used within the aerospace industry to ease the ability with which the contouring of complicated parts could be reproduced without the inaccuracies inherent in templates or manual control (Ferguson 1978). Thus NC was developed for the production of relatively low batches of complex components with high quality standards and cycle times that would otherwise have required a very high direct labour content. Such components would have been technically very difficult - perhaps impossible - to fashion by manual means (Noble 1979). Programming control tapes for such NC jobs was therefore a time-consuming, repetitive and intricate process on the relatively primitive computers then available. As utilisation rates of stand-alone NC machine tools tended to be low in practice anyway [20], managers would not have wished to diminish them further by permitting the operator to construct the program. Technical support facilities such as programming were readily supplied in the large establishments where NC was first used. Once established, however, this division of labour was reproduced when NC then found wider application in smaller engineering firms, and for turning and other less complex small-batch work requiring lower precision.

Secondly, the technical limitations of NC and CNC machine tools; and organisational, product-related, and industrial relations factors specific to the small-batch environment, combined to ensure that such machines still often benefitted from a skilled labour input, and that machinists were able to maintain a measure of control. These variables include the design of the machine tool itself (for example, whether it could change tools automatically) and of its control system; the ability of the part programmers, how well support facilities were coordinated, the prevalence of a horizontal division of labour between machine operation and setting as distinct job categories; complexity and value of components, batch sizes machined and the frequency with which new jobs are introduced, thus necessitating prove-outs; and workforce bargaining power (Hazlehurst et al 1969; Jones 1982; Senker and Huggett 1973 inter alia).

Compared to current numerically controlled machines early NC and CNC models were technically backward, and required considerable manual attention. Continued attendance at the machine of an operator was still needed to perform remaining unmechanised functions, deal with any unpredictable contingencies that might arise, and (importantly) to use tacit skills to detect the development of potentially dangerous situations. As Jaikumar (1984, p35) says, a comparable level of skill to manual machines was still required from the operator in these circumstances, for the lesser skilled person was incapable of recognising systematic errors in the machine, and the early control systems could not notice or recover from faults.

Existing literature [21], confirmed by fieldwork evidence from this project, demonstrates that the usefulness of experienced machinists lies in their ability to employ their knowledge to improve machine performance, and thus achieving the maximum productive potential and versatility from NC and CNC tools. For example, a manager at Plant T succinctly described the traditional skills thought to be necessary on the company's CNC lathes as follows:

> of conventional skills you lose nothing: you still need to know the basics of how a lathe works; what it can do, what it can't do, how you set up the tool, when a surface finish has deteriorated, and that still comes down to something as old-fashioned as if you suddenly hear the noise it's making has changed. You still have to be able to put the tool in properly in the toolholder...

Ironically, perhaps, evidence from Plants T-Z suggests that the very complexity and technical refinement of recent CNC machine tools creates skill requirements where additional, more generalised, machining knowledge is needed while control skills become less transferable and more process-specific. Because machining centres can perform several different types of machining operation at one setting, they therefore require the recombination within the operator of the specific basic skills and knowledge relating to these hitherto separate machining processes. The improved technical performance of CNC machine tools in terms of the increased speed at which it is possible to cut (which increases the potential for damage in case of error), and the geometry and quality of work achievable compared to conventional machines, also brings about a need for an improved understanding of the theoretical aspects of cutting and how these relate to the capabilities of particular CNC machines. CNC machinists interviewed in the project fieldwork emphasised the importance of familiarity with a particular machine control system for optimum performance [22]. CNC control systems can vary widely, and sometimes use the same codes for different purposes. Therefore, as Sorge et al (1983, pp 1-2) argue, the main changes in skill requirements for machinists operating CNC machine tools consist of "mastering a more demanding cutting process by means of electronic controls which become increasingly easy to use."

Organisational factors allowing the retention of machinists' skill and control include the difficulties of coordinating information between different grades of personnel when management chose to subdivide machining labour, and the frequently haphazard availability of support facilities. The fragmentation of necessary tasks between programmers, machine setters, and operators created difficulties in coordinating vital machining information. Off-shopfloor programming, although often intended to bypass machinists' expertise, was normally unable in practice to optimise the metal cutting process without their assistance, and access to their tacit knowledge. This proved especially true when those employed as part programmers had not previously been machinists themselves [23]. In an important sense the hiatus in knowledge between programmers, setters and operators:

> derive(s) from the problems of communicating technical information between occupations that have been organisationally segregated. (Jones 1983, p99).

Thus Hearn (1978) even argues that effective and unambiguous communication between these different grades of personnel is the key to successful exploitation of numerical control. Furthermore, as Jones (1982) observes of NC, deskilling and overall control of labour were lessened because support activities necessary to reaping the benefits of fixed cycle times (such as provision of the right tooling and fixtures at the right place and time) often appeared to be as uncoordinated as before. Managers frequently relied on machinists' initiative in such circumstances to enable the continuity of production.

The high value and degree of complexity of many of the jobs allocated to numerically controlled machines made it advisable to employ skilled operators in order to optimise the running of the machines and avoid accidents. Indeed, Hazlehurst et al (1969) find that the skill levels for particular NC jobs often have more in common with those for the conventional jobs they replace than with other NC jobs. This is because of a continued requirement for skills relating to knowledge of the product and its machining difficulties. When new jobs were introduced machinists' accumulated skills were still necessary to "prove out" the first run of a part program. This involved ironing out wasteful machining methods as well as technical programming mistakes in order to optimise the program for production use. High skill requirements were more constant when new jobs were continually being introduced, as required skill levels often tended to decline after amendments to the initial run and establishment of a "production version" of a program (Senker and Huggett 1973). Hearn (1978, p2) notes, however, that optimum methods to minimise non-cutting time and improve process efficiency are difficult to visualise at the programming stage and may indeed vary when the next batch of the same components reappear. Regular skilled interventions will be helpful in correcting these deficiencies.

Traditional staffing patterns remained little disturbed as a result of stand-alone NC/CNC machine tools, despite evidence of a managerial desire for greater control over machinists that can be related partly to peculiarities of British industrial relations traditions (Senker 1984; Sorge et al 1983) [24] and to plant level internal politics (Burnes 1984; Wilkinson 1983). Craft engineering union activity often played an influential role both in inhibiting horizontal and vertical labour flexibility and, in many cases, preserving skilled status for NC operators in cases where management had attempted to reduce skill levels (Swords-Isherwood and Senker 1980, p22). Machinists' control over the labour process, although diminished by the removal of planning tasks in the first instance, was not exorcised entirely, as machinists found various tactics to reclaim some of the control that they were deemed to have lost. As Wilkinson (1983) demonstrates, machinists developed arguments in favour of shopfloor editing and programming to maintain or improve their sphere of control [25] which they were often able to deploy against the competing claims of part programmers [26] (who, to further emphasise divisions, are organised by different unions).

Machinists' roles sometimes formally or informally expanded into editing programs or reprogramming jobs themselves. Even when operators were officially forbidden to tamper with the programs, it appears that pride in the job sometimes led them to learn programming and to express their tacit skills in the conceptual terms of its abstract codes and symbols rather than techniques of physical coordination. The operator was also still able to exercise ultimate control of the feed and speed rates employed through access to an "override" facility officially intended for use in the event of unexpectedly difficult machining conditions being encountered. Operators used these facilities to regain some of their control over cutting conditions in a way management considered unnecessary, such as slowing down the feed rate to make what they thought was a better job.

NC was costly and diffused into few firms, in which the conditions of production were such that machinists could often retain skill despite the sub-division of labour. The fears of the radical critics that NC would usher in systematic deskilling of machining in the small-batch environment proved largely unfounded, although such a tendency cannot be denied when NC was applied to large-batch turning work. Skill preservation occurred partly because of the continued usefulness of traditional machining skills and "know-how", and partly due to the sometimes serruptitious knowledge gained by machinists of machine control procedures, which enabled the partial clawback of skills.

With CNC, the remaining <u>technical</u> obstacles to the control of editing and programming being located with the machinist are increasingly being eliminated. So a number of different options for the division of labour in the programming and control of CNC are now realistically possible [27]. The most radical possibility is to reverse the centralisation of support functions and allow operators to perform all programming themselves at machine level from component drawings using MDI. This technical capability reduces the significance of part programming as a separate occupational specialism, allowing the machinist to absorb this task as an <u>additional</u> responsibility [28]. The option of decentralised programming returns to the operator many of the planning tasks and decisions on work methods removed under NC. Alternatively, one could choose to program CNC machine tools centrally, away from the shopfloor, employing specialist programmers, as was typical with NC (with operators perhaps being permitted a role in editing programs to various degrees). Taking centralisation a step further, one could diminish the autonomy, and degree of intervention required, of machinists through the use of remote office-based direct numerical control (which can also be interfaced with other information technologies, such as computer aided design and manufacture (CAD/CAM) databases).

How these planning and decision-making tasks are in fact allocated are the expression of <u>managerial</u> choices. This choice has become clearer as CNC has diffused into a wider range of small-batch engineering applications, and the technology has become more versatile and affordable to a greater number of companies [29]. Many of these firms - especially the smaller companies - have been unencumbered by the restrictive division of machining labour characteristic of NC, having never previously purchased programmable equipment.

Much contemporary debate on future adoption of these alternative divisions of labour in batch engineering turns on the degree to which machinists' discretionary inputs are still believed necessary and/or desirable for productive efficiency and flexibility in increasingly competitive markets. Sorge et al (1983) argue that the continuing fragmentation of most product markets and the increasing complexity of parts manufactured will help to check the drift of direct labour skills into occupationally separate planning functions (which they associate with the idea of the "automatic factory") because of the desirability of managing increasing production variances at source. As they see it:

> The present phase of technical advance is less characterised by stable, specialised mass markets, but by more differentiated and shifting market patterns which always bring about the need for human direct intervention because standard solutions are too costly, complex and liable to fail in view of unanticipated variety. (Sorge et al 1983, p163).

Devolution of management of the machining process to craft workers will permit a greater flexibility of response to production variables and ease problems of accountability and labour coordination. This view is reinforced by proponents of the adoption of "flexible specialisation" (Piore and Sabel 1984), who set great store by the improved production flexibility believed to be enabled by such devolved labour control. The fear for management is that operator programming could also require expensive training, and lead to sub-optimal use of expensive capital equipment and reproduction of the worst excesses of craft control.

Centralised responses should enhance managerial control over direct labour and permit the precise specification of machining methods. The cost will be a lack of flexibility in amending programs, slow response to faults, reduced accountability for errors, and increased power for part programmers. The labour process approach suggests that increasingly centralised technologies and lower labour discretion will be chosen, even at the expense of optimum productive efficiency and high flexibility. DNC, as a technology developed for control objectives, is viewed as attractive to management because of its value as a vehicle for increasing management subjugation of the labour force (Gough and Stiller 1983; Winch 1983a, p9).

NC and CNC, despite - perhaps even partly because of - their increasing technical sophistication, have been largely unable to dispense with at least some role for the skill of the machinist, thereby allowing the retention of a degree of craft control. This latter has also been effective in restricting the degree of labour flexibility between machines realisable as a result of such technology. The manufacturing flexibility (in terms of rapid response to production problems and changing demand) increasingly required has continued to depend upon the autonomy and discretion of machinists. This versatility appears to have been most readily achieved in CNC systems allowing MDI, although there is no reason in principle why even DNC systems should not be managed and programmed by machinists. Such was the case at Plant V, for example, whose DNC system was under the explicit control of retrained machine setters. The question is now, however: does the higher level of technical control and integration enabled by FMS allow the simultaneous achievement of the productivity and flexibility denied under the technologies discussed above?

iv) FMS: flexibility for what purpose?

A wide range of productivity, control and versatility benefits are claimed to be attainable from the introduction of flexible manufacturing systems. Influential analysts (see for example Hartley 1984; Ingersoll Engineers 1982) suggest that considerable quantifiable benefits are achieveable [30]. These include reduced product throughput times, lower labour requirements, faster changeover times, less inventory and work in progress, and reduced economic batch sizes. The possibility of higher levels of machine utilisation, particularly by exploiting the opportunity to run FMS unstaffed in new shifts, is strongly stressed. Such benefits are believed particularly pertinent to the justification of FMS in Western countries (Ingersoll Engineers 1982), and Britain in particular (National Engineering Laboratory 1978) [31]. A number of less quantifiable and predictable benefits such as greater overall manufacturing control, rationalisation of product design, improved management information, higher quality, shorter product lead times [32], better response to customer requirements and enhanced manufacturing flexibility are claimed to be both possible and largely mutually compatible with the former group of advantages.

Evidence from both this project (see also Jones and Scott 1985) and other analysts (Primrose and Leonard 1986; Smith, P 1986, p70) does suggest a concentration on the more quantifiable of the above benefits, albeit to the exclusion of the more intangible advantages. Senior management pressures for immediate production and high levels of machine utilisation were observed at most plants, and were a particular source of complaint at Plants G, K, M, N and R. The grievance of plant engineers and operational staff was that they were thus denied adequate time to develop the control and flexibility capabilities of the FMSs concerned to accept broader product spectrums.

This calls into question the exact meaning of the "flexibility" attributed to FMS. I believe that the term is ambiguous and requires clarification. Several authors [33] have already demonstrated that numerous different types of flexibility can be identified within FMS which, depending upon the particular production benefits desired, will condition the type(s) of technical flexibility needed (Ewaldz 1986; Hannam 1985). On the evidence of this project, seven senses were identified in which the term "flexibility" was used [34]. These I call machine, mix, routing, volume, size, modification and product flexibility. Of these, mix, routing and size flexibility are concepts applicable only to multi-machine systems. Flexibility in FMS can therefore be interpreted in more ways than we have done so far, because of the increased integration of flexible manufacturing systems. For the purposes of clarity, and to prepare the ground for later discussion of how exactly different forms of adaptability may affect skills and control policies in FMS, it will be helpful to define flexibility.

Machine flexibility consists of the ease of resetting the FMS to produce a different part or set of part types that have already been programmed to run on the system by means of the provision of a new set of tools, fixtures, part programs, and so on. In itself, however, the pursuit of machine flexibility does not discount the possibility that the batch sizes processed may still be relatively high, although the economic batch quantity will be reduced. Machine flexibility can also be related to the ability to achieve high rates of machine utilisation, primarily through minimising the need for human intervention in resetting FMS. Machine flexibility entails the incorporation of sufficient features on the work stations within the system to enable switching between the production of different components with mimimal time delay for resetting. For example, machine flexibility may be increased by reducing the need for tool changing between different jobs by the provision of extensive tool magazines, or by minimising the variety of tools the system is required to carry (by means of tooling or part design rationalisation).

Our second category, mix flexibility, refers to the ability of the

FMS as a system to simultaneously process in varied ways different part types already programmed. Most specifically, the presence of this type of flexibility would mean that components for possibly several different products could be produced in sets rather than batches at the same time. As Gerwin (1985) and Jones (1986a) claim, this would be a very rigorous concept of flexibility, allowing the considerable reduction of batch sizes and the ability to diversify products.

Routing flexibility consists of the ability to provide alternative routings for given components in the system so that a choice exists as to the work stations at which they can be machined [35]. Routing flexibility may be employed only in cases of machine tool breakdown, thus enabling production to be maintained by means of provision within the system of a level of machine redundancy; or under normal production conditions too. This form of adaptability is predominantly related to traditional operational management objectives of maintaining production.

The next two types of flexibility are closely related. The first, volume flexibility, refers to the ability to manufacture parts in varying volumes according to short-term fluctuations in production requirements. This type of flexibility would allow a reduction in the lead times necessary for response to changes in product demand. The second, size flexibility (to which other writers do not seem to have referred), can be employed partly in connection with more long-term demand changes. This is concerned with the ease of altering the existing FMS configuration. This could mean adding equipment to the FMS to respond to a need for increased capacity, or a wish for greater technical refinement by the integration of additional equipment. Equally it might have to mean removing work stations from the system and turning them to other uses. This latter type of flexibility also depends for its realisation on available floor space and the ability to integrate direct numerical control with further facilities.

The last two forms, modification and product flexibility, are also related, and refer to the ability to modify and expand the part types produced. The former of these types is believed by some authors supporting the "neo-Fordist" position, notably Shaiken et al (1986) to be the dominant form of product versatility in FMS; while those arguing for the existence of flexible specialisation tend to stress the latter. Modification flexibility is the ability to incorporate design changes to the parts already produced on the system, or to introduce within an existing family of components additional parts requiring only minimal alterations to data for current components (small changes to dimensions of drilled holes, for example). This refers only to making changes within part programs, therefore, implying incremental innovation and representing a relatively low addition to the learning curve.

Product flexibility refers to the ability to introduce entirely new families of parts onto the system in response to fluctuating and developing market requirements. Product flexibility is taken to imply major innovation requiring a considerably greater learning curve than modification flexibility. It refers not only to writing new programs but also provision of new fixtures, tooling and so on compatible with the existing system hardware elements.

In practice flexibility is finite. Certain of these forms of technical adaptability are mutually incompatible; or at least they are prohibitively expensive to harmonise simultaneously, as flexibility is further conditioned by the scale of the costs and time incurred to make a given set of changes. The more "flexible" system will be the one that can adapt more quickly and cheaply (Slack 1984, p107). Authorities on FMS caution that such systems are not naturally adaptable, as most of their features (such as tools, fixtures, programs, handling equipment and pallets) potentially introduce an element of dedication and militate against flexibility (Ingersoll Engineers 1982, p31). As Small (1983, p137) encapsulates the problem: "Flexibility is selective and exists where it is specifically forced into the system by its planners."

To take one instance of selectivity, a system comprising a number of identical machining centres will enable the satisfaction of operational criteria such as the provision of alternative routings for parts within the system and response to sudden surges in demand (routing and volume flexibility respectively). If employed, however, this will reduce the ability of the system to fulfill more strategic objectives by accepting many different types of part simultaneously (mix flexibility) because of the need in the former cases to keep the same sorts of tooling at each machine.

Firms must therefore tailor the respects in which they require flexibility to the benefits desired from an FMS. In the example above the pursuit of routing and volume flexibility may well result in low levels of machine utilisation because of the need to incorporate into the system a possibly substantial degree of surplus capacity (or redundancy), which could be exploited in the case of breakdown or short-term additional demand.

However, FMSs may also display elements of more than one type of flexibility. For instance, a high level of machine flexibility would be a precondition for the random assignment of parts to machine tools proposed by a rigorous form of mix flexibility. A difference also exists between the explicit and implicit possession of a given type of flexibility. We mean by this that an FMS may only accidentally or belatedly be found to be capable of exhibiting a mode of flexibility for which it was not specifically purchased [36]. For example, both Plants K and P in this study were employed to machine products other than those for which the systems were originally specified. Thus they possessed an implicit product flexibility which was not originally intended to be exercised (or of which maybe even the system engineers and managers were unaware) but was nevertheless present. To clarify the relationship between these types of flexibility and the purposes of FMS introduction in the case study plants Appendix Three details the main aims for which the FMSs studied were introduced and the degree to which plants exhibited these seven types of flexibility in practice.

v) Conclusion

GT and numerical control could each form only a partial solution to the manufacturing problems of small-batch engineering. In particular major advances for management in productivity, while also reducing machinists' skills and control, have only been possible at the expense of reduced flexibility in terms of the variety and material variability of components processable (although recent developments in CNC machining centres have allieviated this situation somewhat). Where GT and NC were applied with labour control and deskilling motives primarily in mind the result was often inflexible response to production variations, which was reflected in the rigid compartmentalisation of labour categories. In the 'sixties and 'seventies this was exacerbated by the technical shortcomings of the innovations, poor coordination of support services, and by union strength illustrated in the ability to maintain demarcation lines.

Current innovation is diffusing in a climate in which standardised technological solutions and traditional forms of labour utilisation are declining in effectiveness as product markets become more competitive and unstable. Increasingly the diversity of production appears to require local decision-making as to the best method of performance, devolution of detailed labour control and provision of additional training to instill the necessary skills required for optimum operation. Successful implementation of GT and increasingly powerful numerical control technologies beyond the mere periphery of small-batch applications might well require organisational and labour fixities to be challenged in a manner which would devolve direct control over labour in order to optimise production as a whole.

FMS publicity claims now hold out the promise of allowing simultaneous achievement of greater levels of productivity, manufacturing control, and versatility than have proved possible when GT and numerical control are applied separately. In practice the types of flexibility - and, with it, of benefits - available from FMS are indeed more extensive than were available with earlier innovation. But they are neither infinite nor wholly mutually exclusive. A choice must still be exercised in small-batch engineering as to the benefits and adaptability sought.

Several questions worthy of discussion in relation to the fieldwork evidence are raised by these findings. Firstly, to what extent have firms adopting the even more integrated and complex technology of FMS learnt from the experience of GT and numerical control that organisational readjustments, a greater devolution of labour control, and new skills and training needs are often required for optimum operation? Or, alternatively (and as some publicists suggest), does FMS enable these human resource needs to be effectively bypassed? And how far are these new needs dependent upon the kind of benefits and versatility sought from FMS?

CHAPTER SEVEN: Changes in tasks, skills, and work roles in FMS

i) Introduction

Flexible manufacturing systems combine the technical principles of direct numerical control with group technology in order to facilitate the production of small batches of components in a manner akin to a continuous process. Because of the fact that FMS as a production process bears a resemblance to certain facets of continuous flow or transfer line production, some discussions of skill requirements in FMS use these comparators to reach a bewildering variety of conclusions, and to selectively emphasise one type of skill profile at the expense of the others. Thus, for example, Ingersoll Engineers (1982) foresee the operational skills in FMS becoming akin to those of operators in continuous flow processes.

On the other hand, analysts such as Shaiken (1985) and Blumberg and Gerwin (1984) see a continuation of the trend toward the transfer line form of labour process, implying less skill and responsibility for FMS operators. These critics argue that tasks in FMS tend to be highly prescribed and proceduralised, so that the technical skills in FMS consist mainly of mastering a more complex set of routinised, computer-based, procedures than those applying on conventional or stand-alone CNC machine tools. Procedures can be more easily formalised and variables taken into account, it is suggested, because the range of products manufactured on FMSs will usually be considerably less varied than in the machine shop as a whole [1]. Blumberg and Gerwin therefore argue that the skills in FMS are those of a trained operator rather than a craft worker.

The diversity of opinion in the above literature on the nature of FMS skills often results in part from too literal an attempt to reduce them to those abilities characteristic of the manufacturing method with which the authors concerned wish to demonstrate an affinity; and, also, inadequate attention to Clegg's (1984) distinction between tasks and work roles. If these accounts are true, moreover, it becomes difficult to explain why, as an earlier paper (Scott 1985) also points out, the vast majority of the direct workers employed in the FMSs studied should be the products of a craft-trained background?

We wish to do two things in this scene-setting chapter to the later substantive discussion on the reasons for, and efficacy of, the forms of labour deployment found within British FMSs. Firstly, by looking at the task functions required within FMS we wish to deduce the consequent skill requirements and, in particular, the role that might still persist for the craft skills discussed above. We can then progress beyond these technically generated requirements to the latter part of Clegg's distinction by looking at the various possibilities of how these tasks, and inherent skills, may be combined into work roles, and comparing these possibilities to the arrangements found in the FMSs studied. We are particularly interested in evidence of the development of more flexible labour combinations which undermine traditional occupational demarcations.

ii) Task functions in FMS

To explain the task requirements of FMS it will be helpful to describe how a typical system works [2]. As with numerical control, it is first necessary to undertake considerable programming and preparatory work in order to introduce new components to be machined on an FMS (see Figure 2 overleaf). Tools and fixtures must be provided, machining programs written and parameters set. The programs for the part concerned must then be "proved out" to ensure that they will run satisfactorily. Fieldwork evidence indicates that introducing and "proving out" new parts is a time-consuming activity, which can take up to several weeks (depending on how complex the parts are, and how much time is made available for such development work).

To process an already "proved" mix of parts an FMS typically requires a number of preparatory actions (see Figure 3 below). Operators are notified by the host computer of the type of blank components next requiring machining operations and the priority rating of each job. These components are located, and are normally set up manually on prescribed fixtures at a central loading station [3]. The host computer is notifed by the operator that parts are ready for machining. It is then necessary for the host computer to check that the prescribed machining and any other required programs, and work stations, are available for use. The host

FIGURE 2

STAGES OF TASKS IN INTRODUCING NEW PARTS ONTO FMS

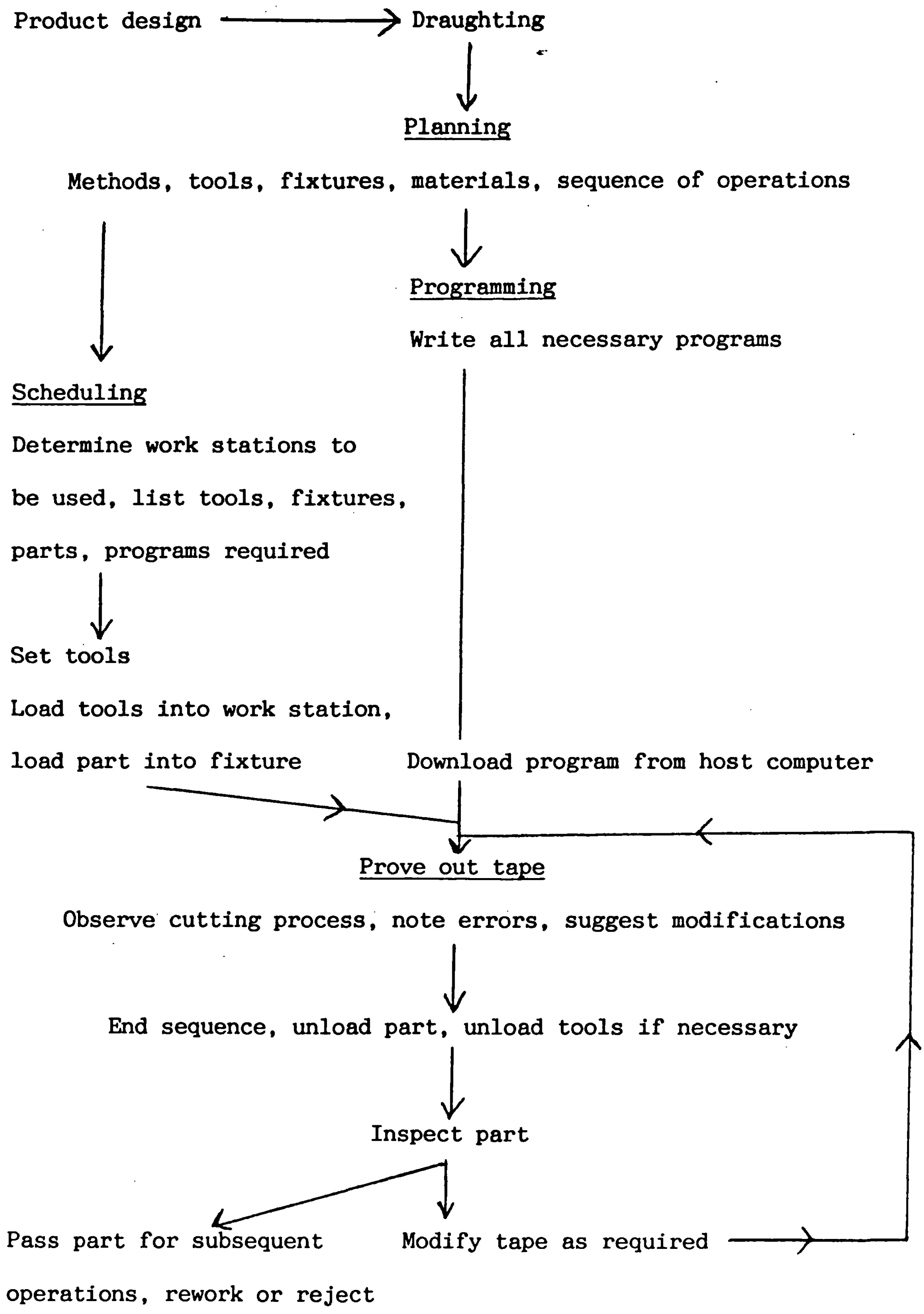
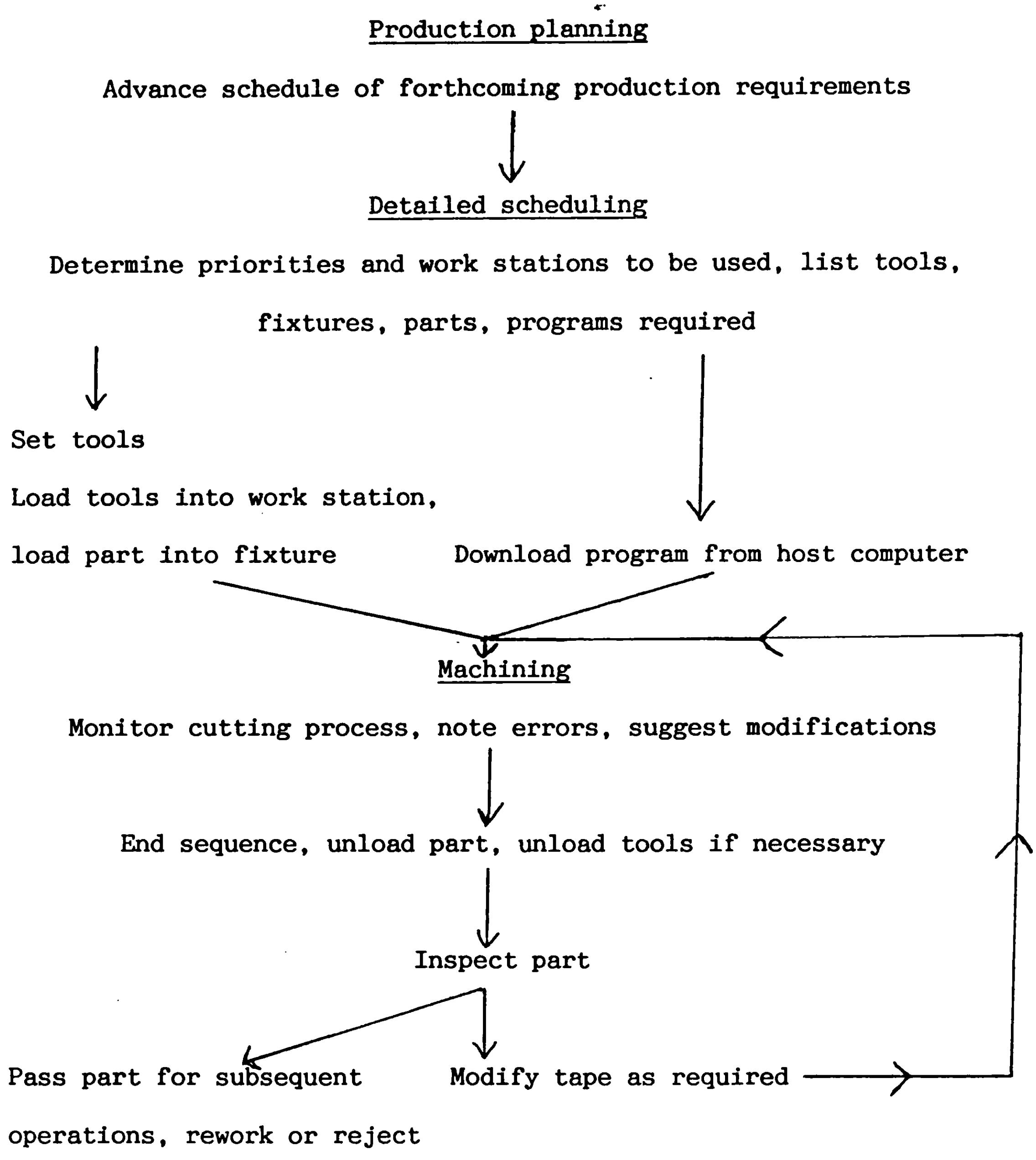


FIGURE 3

STAGES OF TASKS IN PRODUCING PARTS ON FMS



computer also checks that the required tools have been loaded into the correct tool magazines, the details of which will have already been the subject of a previous set of instructions from the host computer to the system personnel.

Tool condition management becomes one of the most critical problems with FMS if the promised minimal staffing levels are to be achieved. Several mechanised methods can be employed to pre-empt, detect, or sometimes to compensate for, tool wear, and to recover from tool breakage. These include pre-programmed probing features on the machine tools to measure tool lengths, any deviation from the specified length being relayed back to the host computer and the dimensions updated in the relevant part program accordingly. A more advanced method is adaptive control (introduced in Chapter Four) which, on the basis of pre-programmed safety values, records any unacceptable torque levels drawn by tools during the cutting process. Alternatively, a simpler and more common method known as historic life monitoring involves the nomination of a cutting "lifetime" for each tool in the system, which is usually decided according to past experience. Progress toward expiry of this life is monitored by the central computer, which alerts operators to change tools when a given percentage of this point is reached. In most FMSs studied a number of these methods were used in conjunction to minimise the likelihood of part damage through tool wear or breakage.

Assuming the required tools have sufficient life left to complete machining of the component it can be released into the system for operations at the various work stations according to a predetermined schedule of routes. (This schedule need not be automatically generated, though it normally is.) To aid the progress of operations with minimal human intervention the individual machine tools in FMS are normally designed to reduce the requirement for direct human attention during the machining process. This is achieved by the addition of a greater number of mechanised measurement, feedback and control facilities than are usually found on stand-alone CNC machine tools. Both the literature (Felstead 1983; Lord 1984, p186), and fieldwork evidence from Plants F, J, R, U and X, indicate that machine tool designers specifically intend these features to replace the sensory control functions by which the machinist monitors and guides the machining process when present rather than to confer any addition production flexibility [4]. Features such as touch trigger probes, pre-programmed to detect the presence or measurement of parts and tools at given locations, oversee the satisfactory progress of the machining operations and transfer between machines. After machining the part is returned to an unloading station for removal from the system or resetting for another batch of operations.

Should the host computer detect an error or malfunction in the system (say, if a tool breaks or a guided vehicle misreads an instruction) it will normally shut down the part of the system concerned and notify the system personnel that attention is needed. If the breakdown is at a machine tool an operator will typically be summoned by a flashing beacon at the machine concerned. On arrival at the machine a diagnostic maintenance code displayed on that machine's visual display will often be available to help locate the fault. Similar systems of coded multi-coloured light beacons at load/unload stations are also often used to indicate to the operators the status of each pallet, and which pallets or machine tools need attention. If remedial attention is needed the operator will be required to confirm to the host computer when the necessary tasks have been performed.

Thus a particular set of task functions are required with FMS which, compared with stand-alone CNC machine tools, have further modified machine operating tasks. Certain hitherto manual tasks are now effectively superceded. Most importantly, it is no longer necessary for workers to set up workpieces on, or to actuate, individual machine tools, or to manually transfer components between work stations. Table 3 indicates those task functions which are always mechanised (except in very exceptional circumstances) in FMS.

TABLE 3

MECHANISED TASK FUNCTIONS IN FMS

Actuation and performance of machining cycle

Loading of tools from magazine to spindle

Transportation of parts

Transmission of programs from host computer

Collection of management information

The primary unmechanised human interventions now required with FMS, which are summarised in Table 4 overleaf, are of two types. These

TABLE 4

EXCLUSIVELY MANUAL TASK FUNCTIONS IN FMS

A) MANAGEMENT AND CONTROL

Programming of machine tools, computer routines, system parameters, and transfer mechanisms

Overall management of system and personnel functions

B) SERVICING AND ANCILLARY

System start-up and shutdown procedure

Initial loading and final unloading

Loading tools to either central tool library or tool magazines

Use of manual over-ride facilities on machine tools (in rare cases)

Recovery from unprogrammed malfunction

Manual action on computer-generated messages and print-out

Toolsetting

Reworking / fitting

Miscellaneous "housekeeping"

Most maintenance

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concern overall management, coordination and control of the technical and human resources in the FMS; and a number of unmechanised servicing and ancillary functions. Firstly, supervision, management and day-to-day coordination and control of personnel and production activities is still required. The extent of these functions is also likely to increase because of the greater number, integration and complexity of activities subsumed within an FMS. One of the most important component parts of this group of activities is the pre-production, preparatory decision-making on working methods. This includes the writing of machining programs, as with stand-alone CNC, but encompasses additionally a number of new tasks created because of the additional programming requirement to generate parameters for the transport system, extra monitoring equipment, production scheduling, and so on. Secondly, a number of residual servicing and ancillary productive functions are necessary to keep the system running. Some of these functions must be performed at particular points in the production cycle (such as changing tools, loading parts, and breakdown maintenance), while others are not so time-dependent (such as toolsetting, swarf clearance and regular maintenance).

The tasks outlined in Table 4 are technically difficult to automate, either because they are believed to require greater dexterity than mechanised means are able to achieve; or because they contain too much variability, a large number of exceptions, and/or are based on the exercise of inscrutable human judgements, to be formalised in computer software.

These technical limitations to mechanisation have been overcome in a third and expanding group of FMS task functions (outlined in Table 5 overleaf). These include both the coordinating activity of production scheduling and a further number of servicing and ancillary functions. The procedural rules necessary to execute such tasks can indeed be formalised. Doubt remains in each individual case, however, whether the degree of variety and complexity in the application concerned makes mechanisation a justifiable

TABLE 5

FMS TASK FUNCTIONS CAPABLE OF MECHANISATION

A) MANAGEMENT AND CONTROL

Production scheduling

B) SERVICING AND ANCILLARY

Inspection and quality control

Transmission of tool offset data into machining program

Tool wear monitoring

Deburring

Swarf removal

---

proposition. In such cases fieldwork evidence indicates that economic considerations dictate which of these functions are to be performed by human operatives and which mechanised. Here the decision on whether or not to automate a particular task is determined by managers' subjective preferences for technical as against human solutions to production problems. The significance of these preferences will be discussed further in subsequent chapters, but at this point we should note simply that many different allocations of tasks between human and machine are possible.

iii) Skill and discretion in FMS tasks

Table 3 above shows that the skills unquestionably removed from human jurisdiction in FMS are, firstly, many of those concerned with the manipulation of objects, such as machine operation and materials transfer, and, secondly, mathematical calculations. The skills found in the remaining human tasks, which were described in Tables 4 and 5, will be analysed in this section. In summary four types of skill are required in FMS. The first of these are conceptual skills concerned with the control of workflow and pre-planning of working methods. Some of these skills involve a high discretionary and decision-making content. Then there is an altogether more diffuse and, as yet, poorly understood set of partly tacit conceptual and perceptual, so-called "control", skills enabling the day-to-day operational control of FMS. Thirdly, and considered in some depth here, we discuss the continued role of theoretically grounded, yet difficult to articulate, "craft"-type problem-solving skills with a high discretionary content. Finally, there are low-level manipulative and dexterous skills, which tend to be highly proceduralised and allow little discretion.

The first group of skills concern the conceptual planning skills required to decide on working methods. These planning skills concerned with methods and work scheduling are essentially the high-level conceptual abilities traditionally employed by craft workers and already described in Chapter Five. As we showed above, many of the tasks requiring such skills have been excised over the years to become managerial prerogatives because of the considerable decision-making content such skills possess, although there is no reason in principle why craft workers should not continue to control planning tasks. To some extent, however, the discretionary element of even these skills within FMS has been reduced with the development of advanced computerised programming techniques (as discussed in Chapter Six), which have in many cases enabled the formalisation of programming methods. Scheduling of production, being based largely on mathematical skills, has tended to become even more formalised. In the FMSs studied, scope for human intervention in scheduling varied between the two extremes of being entirely computer-determined (such as Plants B and C) and, much more rarely, being subject to the decision of an operative to choose options based on a computerised display of the consequences of various possible options (such as Plants F and R).

Three varying types of operational skills can be identified in FMS, which resemble respectively the skills believed to be characteristic of continuous flow, small batch and transfer line production processes. Here it is argued that tasks variously requiring the exercise of operational skills of all these types are demanded in FMS. Therefore, although we are particularly concerned to identify the persisting role of traditional engineering craft expertise, operational skills must be understood as being hybrid in nature, bridging aspects of the three skill types to be discussed below.

The skills needed by operators of continuous-flow processes in order to monitor, manage and control the actual production process have been found to comprise a number of aspects [5]. Such skills involve the correct perception of the status of the process, anticipation of process behaviour, a knowledge of the dynamics of system variables, and the ability to choose what action is necessary to modify system behaviour in order to achieve a desired output of a given quality. Such skills are also characterised by considerable discretion to perform chosen actions, and to manually override the process if necessary. As Crossman (1960, p15) states, decision-making on required action to modify continuous processes can take place within prescribed (or "rule of thumb"), logical / rational, or tacit / intuitive modes. Significantly, in view of the argument in this thesis, Crossman (1960, p16) and Bainbridge (1978) find that the last of these appears to be the most effective, and seems to allow the greatest flexibility in learning.

This learning aspect of process control skill is amplified by Hirschhorn (1984). Hirschhorn wishes to question how process skills are modified by the greater technical sophistication, enabling the improved production flexibility demanded by more volatile markets, of current generations of process technology (in which he includes FMS). He argues that the acquisition of effective control skills under conditions of high technical and production flexibility requires an open-ended and dynamic process of tacit learning. This will enable operators to comprehend the evolving abilities of the system as it develops, and is progressively upgraded and modified over time in order that they may satisfactorily deal with novel and increasingly elaborate possible failure modes. In such complex integrated systems, it is also argued, operational skills become more closely intertwined with maintenance skills, which themselves require both mechanical and electrical expertise.

Evidence from FMS operators interviewed confirms to some extent the use of skills of this type. Most specifically, now that operators no longer perform machining tasks (and indeed may work at some distance from the machine tools) they must visualise what is occurring by construction of a mental model of the system's action. This allows operators to "read ahead" the times at which further direct intervention will be called for, and to plan their tasks accordingly. This model also enables them to intuit when malfunctions are developing at an early stage. Interaction with FMS controls normally occurs remotely from the machine tools and is based on the understanding of how various controls will affect the machine tools' cutting action.

My evidence suggests, however, that there is considerably more skill input to the successful control of FMS than the story so far indicates. In important respects the skills appropriate to the remote control and adjustment of continuous processes sit uneasily with the expertise necessary for FMS. For, as with preceding machining technologies (but unlike process production), FMS involves the manufacture of discrete items in batches by an unchanged method of material transformation. The skills necessary to understand system variables and their interaction, to detect error, and to attain output volume and quality, still consist to a large extent of "craft" knowledge therefore. This comprises those residual fault-finding and problem-solving competencies based on the autonomous application of engineering principles and machining know-how with which we are particularly concerned in this thesis.

An earlier paper, based on this research project, by the author (Scott 1985) argues that a continuing requirement exists for craft expertise in setting-up and monitoring functions, and intervention in programmed sequences. Certain functions, notably tool- and machine-setting and any residual machining tasks for example, do indeed benefit from the application of craft skills. Yet in retrospect this paper erroneously suggests that (possibly temporary) economic or technical limitations in mechanisation are the primary reasons for the employment of skilled craft-trained labour in FMS, and does not necessarily overcome objections that further mechanisation might eventually obviate such a skill requirement [6].

In fact craft skill really comes to the fore in the avoidance, detection, diagnosis and correction of metal-cutting errors. This resource is often capable of being subsequently incorporated into part programs (although this does not invariably happen). The Charles Stark Draper Laboratory (1984, p367) distinguishes between two types of error source occurring in FMS: static (such as a sag in one axis of a machine tool's bed), which occurs constantly at equal magnitude each time the manufacturing task concerned is performed; and dynamic, which occurs randomly and unpredictably. Of the two sorts, static errors are normally the more readily corrected or resolved because of their predictability through programming compensating values into the FMS software.

Craft skill is most valued in the ability to deal independently with dynamic errors, because these are not easily programmed out. The scope for dynamic errors in FMS is considerably greater than on single machines. For two of FMS's main selling points, minimal staffing and the possibility of processing different parts on several machines simultaneously, are also its greatest drawbacks if precision machining is to be achieved (Hannam 1986). Because of these features FMS brings an alarming increase in the tardiness and difficulty of tracing back the source of errors that might occur. Detection of the origin of tolerance errors could result from tool wear or interface misalignments between spindle, tool, part, fixture, pallet or machine. This already extensive list of potential culprits is further complicated in systems incorporating duplicate tooling, as it becomes necessary to identify precisely which equipment was used on any given job (Charles Stark Draper Laboratory 1984, pp 146-147; Hannam 1986).

The FMS at Plant H provides an example of such problems. Here the difficulties caused by dynamic errors resulted in management operating policy decisions to confine each job within the system to running on only two machines if possible, and to restrict the number of pallets in the FMS at any one time to eight (of a possible maximum of twelve), to minimise the difficulty in tracing back the correct source of such errors.

The role of craft skill in tackling the variances of dynamic error is well illustrated by the FMS at Plant P. At this plant production normally centred on a small spectrum of high-value components, which were nevertheless complex, fashioned from difficult metals to work, and included tight tolerances. One machinist (in this case trained initially as a turner) described the importance of craft apprenticeship as follows:

> how are you going to recognise tool wear, or how are you going to recognise if a tool's not cutting properly, if you've never actually had the experience of standing right next to it when it's cutting? It's all very well to press the button and shut the job in and to run a program and at the end of it it comes out wrong; but you've got to be able to recognise <u>why</u> it's wrong, and what you're going to do about it. You're never going to be able to do that unless you understand about the cutting process and so on...

Moreover (and referring more specifically to the nature of this FMS) he added:

> You could certainly have a semi-skilled or even an unskilled person loading the bits providing he knows what he's doing... but what's going to happen when something goes wrong, which it does regularly? With nuts and bolts, fair enough, not much can go wrong, but (with) the complicated bits we make here and the limits we work to, which are very tight,

> things drift on a daily basis. Obviously your tools wear, even the outside temperature can have an effect on it, even how long the machine's been running can have an effect, things like this.... that's where your skill comes in, that's what you have to find out, you know, recognise and sort it out.

Thus, as the following quote from an engineer at Plant F acknowledges, the knowledge base of craft skill in FMS is seen as conferring sufficient responsibility to enable its possessor to be entrusted to independently intervene in the system:

> (The operator) needs the basis so that he recognises there could be problems within the system, that he might by ear know that there was a problem coming up before the system saw it. He could interfere with the system then. He's got to be of a skill such that he's allowed to interrupt the system.

Returning to Plant P, a second machinist (apprenticed as a jig borer) expanded on the use of a craft training background to diagnose dynamic faults:

> Quite often you put in a back-up tool, and you've got a problem, and you put another tool up, you've

> still got the same problem. You've got a choice between the machine, the program and the tooling, so you can break it down a bit. (Fixtures are dedicated to pallets, and so the problem rarely lies here.) And you start eliminating one or two of them.... well, program, you can normally eliminate that, so you've finally got the machine itself, or the tooling. You can probably bet on the tooling really.... You've got to have a little bit of basics to know what you're talking about.

The importance of the theoretical background lies in the ability to look beyond what appears to be the immediate reason for a fault to a possible deeper cause, however:

> it's knowing what does what, a little bit about the program and quite a bit about the machine itself, because you could get a fault that you think happened, you think it's something to do with the tooling, it could turn out to be the machine itself.

Further evidence from machinists indicates that attempts to formalise decisions in computer software can sometimes be misleading, and thus still require the knowledge to carry out further investigation. For instance, diagnostic codes intended as an aid to maintenance, which are displayed on the machine tools'

VDU screens when a fault occurs, often refer to only a subsidiary error (such as a tool conveyor out of position), which has been created in turn by a more basic underlying problem remaining undiagnosed by the software (such as a power failure). Manual investigation will be required to deduce this deeper error.

To sum up our argument on craft skill, such an input into FMS is valued for both the combination of theoretical reasoning and practical "hands-on" experience of machining it brings. Craft skills are still of value as a repository of largely tacit knowledge, which can be independently applied to the production process, of the separate and synergetic properties and behaviour of tools, materials and machines.

The fourth type of skill input to flexible manufacturing systems is characteristic of low-level manipulative or highly proceduralised tasks needing little discretion, although such tasks may carry a high burden of responsibility for the achievement of optimum FMS operation. Skills at this level tend to consist of one of two components. They can concern firstly low-level physical competencies, often substituting for activities that are too difficult or expensive to mechanise. Alternatively they may involve the ability to understand, and respond to, system-generated commands by means of the simple selection of displayed options or the input of the required coded information. Examples of tasks at this skill level include the loading of tools, transmission of tool offset data into machining programs, the actuation of mechanised functions (such as the system start-up procedure), deburring and swarf removal, and response to system-generated instructions. Inspection and the initial setting-up of components normally come into this category also, although evidence from many of the FMSs studied, and especially Plants G and P, indicates that - depending upon the degree of mechanisation employed - craft skills can still be important in loading tasks in certain circumstances [7]. In some FMSs, loading clearly involves little of the traditional discretion regarding decisions on clamping positions and pressures. For example, at Plant H loaders are instructed by the central computer of the precise torque levels at which to clamp components.

Thus we see that the hybrid nature of FMS as a production process, bearing features of each of the three forms of manufacture discussed above, creates a quite unique combination of skill requirements. As with previous advances in machining technologies, FMS places further emphasis on the pre-planning of working methods and residual servicing functions (many of which undeniably require little skill) rather than machining. Planning tasks increase in extent compared to numerical control, but the skills required are essentially similar in nature to craft planning skills. At an operational level, the skills required to control FMS begin to resemble certain aspects of those encountered in continuous flow process technology. However, at least in the cases studied, they still retain an important engineering craft content because of the little-changed nature of the machining process. A role will be retainable for craft skills inasmuch as unpredictable machining errors occur in the production process. Indeed, the greater integration of FMS compared to previous machining systems makes it more likely that, when faults affecting part or machine do occur, they will be more complex, and thus require considerable diagnosis.

iv) <u>Recombining task functions</u>

So far in this chapter we have catalogued the human task functions required as a result of FMS technology, and shown that these call for four differing types of skill. It now remains to assess how the various tasks described can be combined into work roles. In Chapters Four and Five we reviewed the historically pervasive "scientific management" job design principles, which have partially succeeded in stripping functions away from craft work roles, and contrasted these with recent forms of horizontal and vertical task flexibility which could allow the recombination of tasks. In this section we shall compare the possibilities for the recombination of tasks into more flexible work roles with the practice in the FMSs studied.

Existing studies of labour roles in FMSs [8] find examples of job designs based both on broadly "scientific management" principles and on the idea of the "autonomous workgroup". It is clear from this literature that the first type is the more common of the two. Previous studies do however contain a significant weakness. For virtually none of these investigations relate to British systems, although several authors agree that (*contra* CNC) distinct national patterns of work role allocation seem to be observable with FMS (Jaikumar 1984; Jones 1986a; Kelley 1985). In the US, for example, the continuation of "scientific management" approaches and labour inflexibility within FMSs is encouraged by peculiarities of the American system of industrial relations, notably tightly specified and legally enforceable employment contracts. How homogenous, therefore, are workgroup structures in British FMSs?

The influence of scientific management principles was diluted in the FMSs studied, being clearest in the almost ubiquitous tendency to separate planning and management from operational tasks. In some instances the latter tasks were also subdivided. Plants A, and, above all, B and H were the closest approximations to the scientific management approach. At these plants work roles were broadly bounded vertically within three skill classifications, although operational tasks were interchangeable within grades. The lowest grade of job consisted of the loaders and/or labourers, who were normally classified as semi-skilled. Above this, a skilled operator category was responsible for changing tools; (sometimes) toolsetting; general checks, monitoring and perhaps adjustment of operations; and responsibility for contacting specialist help (in the form of maintenance engineers and part programmers, etc). Finally, a supervisory grade of employee undertook overall management and control functions within the FMS. Ancillary functions necessary, such as part programming, determination of work methods and maintenance for the FMS, were normally added to the workload of the organisationally separate departments already performing these tasks for the rest of the machine shop. The aid of these supernumerary personnel was enlisted as necessary.

Horizontal labour flexibility in flexible manufacturing systems was found to take the forms of either job enlargement or, more rarely, job rotation. Job enlargement, consisting of FMS workers expanding their sphere of competence beyond their conventional machining skills (in cases where more than one worker was employed on a given grade) was found at most plants. Typical of this were the skilled FMS operators at Plant A, who were assuming tool grinding and toolsetting tasks as well as machine monitoring functions.

More extensive horizontal flexibility at craft level in the form of multi-skilling of apprenticed machinists, particularly as regards the expansion of task roles into maintenance duties to create what has been called "polyvalent" craft workers (Cross 1985), was very rare [9]. The only examples encountered were at the greenfield sites of Plant P and R, where machinists were expected to perform certain maintenance tasks, and (at Plant P only) to undertake post-machining processes such as heat treatment and cadmium plating of components. In other plants expansion of work roles into maintenance duties only progressed as far as the performance of routine maintenance checks (such as at Plants C and J).

It was noted in Chapter Four that job rotation does not of itself signify a departure from Tayloristic principles of job design. Job rotation schemes for FMS operators were encountered most prominently at the large automotive plants D and L. Such forms of shopfloor flexibility were nevertheless relatively unusual in the plants concerned. At Plant L the four direct workers in the FMS themselves determine who should perform the necessary task functions of tool setter, roving operator and two loaders as they think fit, but subject to the important underlying condition that each worker is required to be capable of undertaking all of these jobs in order to cover for absence. Plant D, on the other hand, adopted a more formal job rotation scheme whereby the team of four workers per shift interchange the jobs of tool setter, operator for a shaving machine, and a loader/unloader for each of two FMS cells, on a weekly basis.

Vertical flexibility of workers to assume tasks of different grades - and particularly higher grades - is more corrosive of Taylorist principles of division of labour. This form of mobility, it was suggested in previous chapters, is eased by new control technologies, which allow direct workers to assume certain supervisory and post-production tasks. Instances of vertical flexibility were common to most of the FMSs studied. Only at Plants G, K, M and R did these extend to the crucial programming and planning tasks, and (in normal circumstances) at Plants F, G and R to scheduling tasks. Elsewhere such tasks remained the prerogative of production engineers and production controllers respectively, both of which groups were external to the FMS work crew as such.

Most frequently "vertical flexibility" in fact tended to mean one or both of two things. Firstly, craft-trained FMS operators at nearly all FMSs except B and H additionally assumed lower grade tasks, such as loading tools or parts. Secondly, and part of a phenomenon becoming more widespread in British manufacturing, direct workers at plants such as C, H and K became responsible for certain residual indirect tasks (such as quality control) which can be performed at any point during the production cycle.

The greatest challenge to neo-Taylorist forms of job design lies in the formation of autonomous workgroups. Such groups would display both horizontal and vertical flexibility between the full range of tasks within an FMS, including programming and management duties. Unsurprisingly, in view of the prevalence of the rather more limited patterns of labour flexibility described above, few examples could be found of truly flexible workgroups in the cases studied. Plant R, which will be discussed more fully in subsequent chapters, provided the only genuine example of this alternative approach involving flexible workgroups, especially under its original management team; although two of the one-person-operated FMSs, Plants F and M, also allowed the assumption of many management functions.

Workgroup structures in the FMSs studied varied sufficiently for it to be difficult to identify a distinct indigenous "pattern" of job design. There is certainly a tendency, albeit uneven and incomplete, for the collapsing of both horizontal and vertical demarcations at an operational level. At this level, near complete, or total, task interchangeability is the more common arrangement (Plants C-F, J and L-R), although more restrictive formal vertical demarcations apply in as many as one third of the systems investigated (Plants A, B, G, H and K). Despite these often quite significant changes, instances of extensive multi-skilling, or the expansion of direct workers' (nearly all of whom are craft-trained) jobs into programming and management functions, are still very rare.

v) Conclusion

The evidence presented in this chapter shows that FMS, despite attenuating machine operating tasks at the expense of overall planning, servicing and control functions, has not dispensed with a role for traditional engineering craft skills. At a technical level FMS has created a need for a hybrid range of skills requiring a wide range of planning, control, and diagnostic abilities and tacit learning of system capabilities (the extent of which may not yet be fully understood).

The existence of the different types and levels of skill described above can exert pressure for the formation of work roles according to these distinct bands of ability and responsibility. But this is offset by counter-pressure towards the reduction of direct and indirect labour and, with it, greater job flexibility. The hope that this latter tendency might permit the consequent devolution of many of the necessary planning and decision-making functions to operators has been largely disappointed. There certainly appears to be general evidence of the adoption of more flexible forms of work organisation than found on either conventional machinery or stand-alone numerical control. However, in most cases this mobility seems to have stopped some way short of the multi-skilling necessary for autonomous workgroups of the kind promoted by sociotechnical authors. Let us therefore turn to finding out why this has proved so.

CHAPTER EIGHT: The problem of labour control

i) Introduction

Increased labour flexibility is apparent in the FMSs studied, but there is only limited and partial evidence that the staffing policies applied have thereby succeeded in escaping from the tendency to delimit labour's control over the production process. The manner in which work roles are formulated within a given technological innovation, as we argued earlier, is affected by managers' labour control preferences. These are conditioned in turn by pre-existing organisational and industrial relations contexts, and previous working practices. With FMS, staffing arrangements with existing GT cells or numerically controlled machine tools (as discussed in Chapter Six) are particularly influential.

But, if our thesis is correct, some choice exists regarding whether to duplicate these arrangements, or to modify them in the direction of tighter or looser direct management control over the labour process. Given the high capital cost of FMS, the firms into which it has been introduced tend to be large, characterised by well-established demarcations and industrial relations procedures; we might reasonably expect such plants to attach considerable importance to undermining the system of craft control of work and its legacy of labour inflexibility which, although now weakened, remains important in British batch engineering.

This chapter investigates how labour control is achieved by both technical and hierarchical means, the importance management accord to it, and its relation to demands for task flexibility in FMS. One of the most striking findings to be illustrated is the largely ad hoc nature of much of the managerial decision making on labour control. Because most (but not all) of the plants studied exhibit Fox's (1974) pattern of "low trust" relations, as stated above, it is unsurprising that FMS job design reflects aspects of this pattern too. However, there is also a management countertendency to permit work group autonomy simply to get the necessary work done. The rarity of the <u>explicit</u> adoption of autonomous work groups, often recommended in the literature, is explained by reference to a relevant case study (Plant R). This study assess the extent to which explicit management policies for job redesign in FMS are realisable within the wider context of plant-wide labour policies.

ii) Technical control

As we saw earlier, writers such as Brighton Labour Process Group (1977), Edwards (1979) and Palloix (1976) allege that direction and supervision of the performance of workers' tasks in computerised systems is now enabled by "technical control" (rather than the "hierarchical control" of supervisors). FMS, because of its degree of computerised integration, provides an ideal opportunity to assess the extent to which management tasks have really been superceded by technical control.

The technical system management functions in FMS are subject to a varied, but generally fairly high, level of technical control. This applies particularly to a number of functions that would have been human tasks prior to the advent of DNC and FMS. These tasks include the scheduling of parts through the system, transmission of instructions to machine tools and loading stations, and the collation of data on system status and utilisation. Managers interviewed tended to consider a high degree of technical sophistication in such uses conducive to the achievement of improved inventory control and machine utilisation through better management information.

A further advantage for management is the ability to enhance the level of technical control over the discretion exercisable by operators by restricting access to the higher levels of software control. This can be achieved by the use of password protection to access of certain facilities and the assignment of "levels of responsibility" to different classes of employee, thus limiting the functions each is able to access from the FMSs computer terminals. Such mechanisms were employed in the software at the majority of the FMSs studied (although not at Plant's C or M), usually at the request of the user firms. Occassionally, as at Plant G, the system suppliers had stipulated such restrictions, which therefore limited the degree of interchange between the personnel in the system it would be possible to achieve [1].

A particular advantage of the electronic collation and processing of data available with DNC, especially compared with stand-alone machine tools, lies in minimising the need for increased paperwork, and supervision and labour control costs (and therefore numbers of indirect workers required) that would be otherwise incurred by hiring additional workers. This was explicitly stated as a reason for adopting FMS at Plant C; and at the two expanding companies, Plants G and K, for whom FMS was intended to diminish their need to hire additional machinists and associated supervisors.

Many aspects of the traditional role of the supervisor or foreman, notably in the allocation and routing of work, are largely superceded by the technical sophistication in FMS. As the discussion in Chapter Seven indicates, the host computer control normally incorporates work scheduling, and instructs operators on which tools and parts to load. In theory, therefore, a very high level of technical control could be achieved. At our most extreme case in this respect, the shoe machinery maker Plant C, manufacturing managers had deferred consideration of the need for a supervisory job within the FMS until running experience indicated whether such an appointment was actually necessary. The shop foreman remained solely responsible for personnel management of the FMS operators, having been stripped of his work allocation functions elsewhere in the machine shop because of managers' wish to exert more direct control over the work going through the FMS.

By and large, however, the degree of technical control achieved over supervisory and management functions is in practice incomplete. The rather ambiguous situation at Plant C was not encountered elsewhere. Other plants normally employed a system supervisor or manager to oversee personnel, deal with sundry administrative matters and coordinate with other departments (such as Production Engineering and Inspection). This grade of personnel also decides on broad system priorities (such as overriding computer-generated schedules in the case of an urgent job) which are too complex or variable to be incorporated in system software.

There are also important technological, economic and social limitations to total mechanisation in FMS which deny the realistic possibility of complete technical control. Technological limitations derive from the restrictions of particular items of equipment design. For example, in two cases, Plants F and R, the technical specification of the scheduling software still necessitated the manual selection of component routes; and at Plant A the use of adaptive control was incompatible with the original machine-level control systems used. This technological limitation became an example of economic limits to mechanisation, however, as adaptive control became available when new machine control units were purchased. In this instance, the additional cost of adaptive control was not deemed cost-effective compared with the alternative of manual monitoring of machining operations.

By "social" limits to mechanisation I refer to the deliberate non-use by personnel of even such mechanised facilities as are available because traditional methods using existing know-how are seen as adequate or as more reliable. Numerous examples of this were discovered. Instances include the frequent overriding of system-generated component scheduling priorities by the loader at Plant G to minimise the necessity to retool the FMS for machining different materials; and the personnels' preference at plants such as F and H to record details of system problems and malfunctions longhand in a loose-leaf book. One operator at Plant P's observation of the fate of system management information on tool life status printed out *via* the host computer: "Most of the time it just ends up in the bin," was perhaps the most instructive of all.

Overall, therefore, technical control is not ubiquitous in FMS, although system operations themselves are subject to a generally high level of mechanisation. Personnel management functions are still necessary, despite the reduced numbers of employees in FMS compared with stand-alone systems. Furthermore, complete control by technical means is not yet possible. Even were it so, however, most managers still see a role for human intervention because of both the frequent expense and inefficiency of mechanisation compared to the retention of some labour intervention. The issues of the degree to which employees can attain control over FMS operations, and the extent to which local conditions in plants may help or hinder this, remain contentious, however. These questions will be tackled below.

iii) Programming: the frontier of control

The main site of debates over the locus of control of new machining technologies in small-batch engineering remains the question of who is responsible for the determination of the machining methods and sequence of operations to be employed, which must still be decided by human conceptual labour. That is: who writes, and who is responsible for "proving out", the programs for the probing devices, transfer mechanisms, and the all-important machining of components? We must ask why it is that methods decisions are still normally treated as the prerogative of separate occupational groups in the FMSs studied. Do such arrangements reflect a further sub-division of labour, a reduction in direct control, or essentially similar arrangements to those applying elsewhere in the plants concerned with NC and CNC machine tools? In particular, what circumstances have enabled the examples of more devolved control in our case studies?

The locus of decisions on working methods, and the construction and amendment of programs to machine parts, has traditionally been a contentious issue. Such tasks have normally been split between different occupational groups. This division had already been established with numerical control at all bar two (Plants G and K) of the firms studied. A management desire for even closer control over the determination of programming and editing procedures through the transfer of responsibility for these tasks to part programmers and manufacturing engineers was evident in most of the cases studied. Thus there is strong evidence that FMS tends to be used to achieve a further separation of conception and execution. This pattern was part of a process of diminishing craft control over methods decisions. In most plants, long histories of what manufacturing and supervisory levels of management considered to be the abuse of craft control over the labour process had imbued them with strong labour control objectives in the introduction of FMS. It was argued that management control over the machining process would have to be enhanced to monopoly levels in order to debar the direct worker from introducing unanticipated and uncodified variables into machining operations. This was stated explicitly by the FMS project manager at Plant J, who considered that it was no longer acceptable to permit the degree of operator freedom that existed on the firm's older NC machining centres:

> (With FMS it is) vital that the operator should not interfere with the programs.... If the operator does, and doesn't tell the Programming Department, he is throwing a spanner in the works because he is creating an uncertainty that was not there before in the production process. Now a job has to be exactly as it's programmed - for better or worse.

Such arrangements were often stricter than, and ran counter to, the procedures established elsewhere on the shopfloor for editing stand-alone CNC machine tools, where the balance of authority was weighted more in favour of operators as opposed to programmers. The difference in approach arises because of the closer direct control of production engineers over the work allocated to the FMSs concerned. At Plant C, for example, the FMS operators have been forbidden to write or edit part programs (although prove-outs are conducted by the programmer who wrote the program and the operator together). Even during the latter stages of a prove-out, when the operator will usually officiate on his own, he is still debarred from making any amendments himself. Instead he must note them down and tell the programmer, who has the responsibility for the actual editing. In contrast to this procedure, operators of the plant's stand-alone CNC machine tools are allowed to edit the programs themselves. At certain other plants slightly fewer restrictions on operator editing of tape "prove-outs" applied. For example, at Plants A and (even) J operators were allowed to make minor modifications on the proviso that they were required to tell the programmers what changes had been made, but amendments were otherwise definitely discouraged.

In one extreme instance (Plant H) senior management objectives of gaining increased control over working methods as a result of past disputes led them to use FMS against the power exercised by the firm's part programmers as well as its craft workers. Here a manufacturing engineer has been added to the FMS work crew. This person is responsible for tooling, programming, determination of manufacturing methods, the introduction of new components to the FMS and any necessary modifications and "fine-tuning" of existing components, and possesses the major responsibility for proving-out and subsequent amendment of programs [2].

Management felt that in the past, with stand-alone NC, the

Production Engineering department had created internal demarcations, which had produced industrial relations problems, by managing to gain an unjustified monopoly of expertise on part programming. In one manager's phrase, by virtue of their monopoly the programmers had suceeded in giving part programming the image of a "black art". The FMS has been deliberately used to spread programming knowledge beyond the existing part programmers in order to prove that it is not that difficult a task to learn. Management also consider it important that the manufacturing engineer (rather than the setter/inspector within the FMS work crew) retains control over programming for reasons of accountability to overall company manufacturing objectives. The manufacturing engineer is charged with the task of programming according to the criterion of achieving "the most economical workable method" for the job. Managers interviewed thought that setter/inspectors would be unlikely to accord this objective their highest priority if they were allowed the major say in programming. Instead it was believed that they would probably be "too concerned with perfecting the job."

Where methods decisions had long been under the control of well-established engineering departments, and operator editing not permitted, the advent of FMS as part of the process of increasing overall manufacturing control made no difference to established policy on programming. This status quo was found in the two aerospace plants, B and P, and in Plant D, the large manufacturer of earthmoving equipment. Here it was considered that exacting quality specifications required the abrogation by operators of discretion for amending standards.

The removal of operator control of methods decisions need not be an inevitable goal of FMS introduction, however, for the role of managerial control preferences remains crucial. In certain circumstances the existing industrial relations context and level of technical knowledge may favour the devolution of planning decisions to the direct workteam itself. Beneficial conditions were encountered in a few plants where the continuation of craft autonomy in controlling FMS was considered by managers to have an important role. Here we focus on two: Plants G and K, both small but expanding companies, where the introduction of FMS was seen by management partly as a means of absorbing increased production while changing the nature of the companies' *modus operandi* as little as possible. (Situations with certain parallels at Plants M and R will be discussed in section v)).

At Plant K, the automotive subcontractor specialising in relatively high volume and low variety work, a high degree of devolution of production decisions on the FMS is attributable to the previous history of CNC within the plant. The company had some prior experience of CNC lathes of the type used in the FMS, the programming for which has always been done by craft-trained setters at machine tool level by manual data input (MDI). Thus there has never been a separate NC tape preparation department. Managers, who were concerned to minimise the extent of the additional infrastructural support required, saw no reason to change this state of affairs simply because of the introduction of the FMS. From the outset, therefore, manual data input by setters was very much part of the firm's philosophy for FMS programming.

At Plant G, on the other hand, the development of a high degree of workforce autonomy on the FMS resulted mainly from the lack of any experience of CNC (or any other forms of computerisation) whatsoever prior to the introduction of the FMS. Because of this, the fragmentation of functions between part programmer and operator, entrenched at many of the other plants visited had never become established.

Moreover, the company had no real internal resources or knowledge to support the development of FMS because of its small size and lack of previous CNC experience. Thus, uniquely, the only "tradition" of labour practices within the company on which the FMS project could draw was of a small, tightly-knit, but highly skilled workforce, to which management granted very considerable autonomy. Because of this lack of expertise, the two senior of the three FMS personnel concerned with implementing the project had to be externally recruited. One of these, the project manager was given a free hand by senior management on staffing decisions, and thus had no entrenched opposition from the plant's existing staff on appropriate working practices to contend with.

Overall, then, in the majority of plants in the study (mainly

Plants A-D, H, J, L and N) improvement of overall manufacturing control appeared to be a major aim of the introduction of AMT generally. Within the overall control of the production process, though, labour was seen one of the least predictable (albeit in fact one of the least expensive) elements. FMS was therefore visualised in important respects as enabling the reduction of labour variability through residual control over manufacturing methods which had not always successfully been removed by previous innovations. The contingency of this objective is however demonstrated by the evidence above from other plants, which shows that managerial attitudes to craft autonomy are crucial in determining the degree of control managers wish to gain.

iv) Servicing and ancillary functions

The greater prevalence of labour flexibility between servicing and and ancillary functions in FMS (as opposed to programming and management functions) reflects the fact that the former kind of labour flexibility impinges upon craft control of the machining labour process. As such, it represents an aspect of more general occupational trends towards eliminating demarcations between trades (and particularly production and maintenance), achieving the multiple operation of machine tools, and amalgamating directly and sundry indirectly productive functions. The latter two of these tendencies were found to be the more common in the systems studied.

A considerable lack of uniformity was observed as to which particular unmechanised servicing functions (most notably, tool setting, maintenance and inspection) were performed within the FMS workgroup. These differences reflect dissimilar organisational attitudes to certain categories of indirect worker depending on whether managers desire to maintain the existing division of productive functions or to make the FMS concerned as self-contained a facility as possible.

On the shop floors of most of the plants studied (A-D, H-N), levels of labour mobility between tasks remained low outside of the FMS. Examples of multi-machine staffing were very uncommon, even with CNC machine tools, let alone expansion into additional task functions. But, normally under the banner of technical necessity, managers tended to use the adoption of FMS as one method of attacking pre-existing labour demarcations in order to begin the process of promoting labour flexibility more generally within the plants concerned. To be sure, however, evidence at the time of interviewing suggested that the recombination and integration of necessary activities was still specific to the FMSs concerned.

Most particularly, there is a pronounced tendency to end the separation of tool- and machine-setting, and manual inspection, tasks, from "operating" and machine-tending functions. The assumption of quality control tasks by FMS workers, and the engineering of many supervisory functions into the computer software, were intended to begin the process of reducing the separation of direct from indirect functions in order to increase labour productivity. At Plant C, where this process was perhaps most explicitly articulated, two justifications were given by management for allowing FMS inspection by operators. The first reason is to instill a sense of responsibility in the operators for the quality of the work coming off the FMS. As one manager put it:

> the company are trying to eliminate the idea that the operator's job ends with making the parts, and that then it is an inspector's job to decide whether or not the operator made them correctly.

The second reason is a deliberate decision to give the operators something to do while the machine tools are running automatically, and to supply some involvement in the production process now that they are not actually cutting the parts themselves.

At this plant the assumption of many unmechanised indirect tasks by the direct FMS workteam was intimately connected to an overall management strategy of reducing certain categories of indirect labour cost (mainly inspection, progress chasing, stores, and some supervisory occupations), numbers of which had remained stubbornly static over the period 1981-84, while still limiting the overall management control relinquished.

At the time of final interview the procedure for inspection was that every part was inspected by separate inspection staff. But by moving to operator quality control, as well as instituting a system of random rather than 100% inspection on the FMS, the company will be able to further its aim of reducing indirect labour by cutting the number of inspectors. At this time the only indirect labour in the FMS area itself already consisted of the occasional inspector and a foreman [3].

Moves toward labour flexibility are geared to the breaking down of craft control, but have only interfered marginally with inter-craft divisions. Thus flexibility does not seem to have extended to the thorny issue of breaking down the division between production and maintenance craft skills, as the barriers between these remained firmly intact (with the partial exception of the greenfield sites, P and R, which had no on-site maintenance back-up). Certainly there was no evidence of the conscious development of the multi-skilled, or polyvalent, craft worker.

Intra-craft control, and particularly the issue of craft workers' ability to dictate the skill level and numbers of machinists who will operate a given type and number of machine tools, is under general attack in FMS. Plant H provides an illustration, which holds good for most plants studied. Here the FMS is seen as being an important means of introducing more multi-disciplinary work and breaking down demarcations, particularly those between machine setters and inspectors, throughout the factory. Here the final occupational structure in the FMS consisted of a system manager, two setter/inspectors and a loader per shift.

One of the reasons given by senior management for the introduction of FMS was to attack what were perceived as existing overstaffing and bad working practices which were felt to have developed when three stand-alone CNC machining centres had been introduced onto the shopfloor some years previously. At the close of negotiations on staffing levels the unions had succeeded in obtaining the staffing of each machine by a skilled operator. The production engineer currently in charge of valve production thought this level of skill had proved excessive, preferring a semi-skilled operative at each machining centre coupled with the introduction of one roving skilled machinist. It was felt by the management that FMS represented a sufficiently radical technological break with stand-alone CNC equipment to force the issue of job flexibility and relevant skill levels to be confronted head-on, rather than simply treated as an evolutionary extension of CNC.

Flexibility between servicing and ancillary functions can prove a contentious issue between workers and management, however, and is often subject to formal and informal pressure for reversion to more fixed arrangements. The FMS at Plant P is an excellent example to choose of this tendency because (to a greater extent than anywhere else except Plant R) such labour flexibility objectives were an integral, initial part of the rationale behind the use of a greenfield site. At Plant P management objectives of improved labour mobility compared to that applying at the headquarters plant (at which the principle of one skilled machinist to each CNC machine tool still prevails) were intended even before the product to be manufactured was finalised. Shopfloor workers for Plant P were internally recruited from the headquarters plant largely on the basis of their willingness to adopt more flexible working practices than those applying at the latter plant.

When Plant P first began production a number of impressive claims were made by the company's management, technical journals, and at least one academic study regarding the degree of labour flexibility prevailing. Fieldwork reveals these claims to have been very much exaggerated. Such reports have omitted to mention the fact that the company management has been wary of trying to press for greater flexibility than that to which the AEU would agree. Likewise the AEU are unwilling to concede significant additional degrees of flexibility than pertain at the headquarters plant in view of the potential "knock-on" effects. Nevertheless, a higher degree of flexibility between separate production processes undoubtedly pertained at this plant than any of the others visited [4].

In practice flexibility is limited by a *de facto* specialisation of work tasks among the machinists. Only three workers on each of the three shifts take prime responsibility for the plant's machine tools and, of these, one is responsible for the machine tools in the FMS (although the loading of pallets is performed by all these personnel). Vertical flexibility extends only to minor maintenance (the nearest permanent maintenance team being based ten miles away at the headquarters plant), first-line inspection and occasional minor reprogramming (for example, if a tool becomes unavailable and a new one of different dimensions has to be substituted to perform operations). In other respects - typically for the aerospace industry on the grounds of high quality requirements - indirect functions remain firmly under the higher-level operating control of the headquarters plant (to which Plant P is linked on-line and which provides part programmers for the plant) rather than being delegated to the FMS work crew. Final inspection after the testing of assemblies is also performed by two inspectors based on-site and toolsetting for the whole plant including the FMS is performed by one worker in Plant P's toolroom.

Such problems are even more acute in those FMSs installed within existing sites. As a result of management's inability to insulate working arrangements on these FMSs from wider considerations of extended shopfloor labour flexibility and craft control relatively restricted moves toward flexibility have had to prevail. Management pressure to achieve flexibility has resulted in workforce resistance to aspects of the changes, some of which are likely to be of long-term consequence if labour's bargaining position improves. The flexibility of job descriptions, or (more commonly) demands for regrading and higher pay in return for flexibility, have been the most common causes of disputes. At Plant H the issue of the flexibility of job descriptions caused a dispute with the shopfloor unions, which is now resolved largely in the company's favour. In several cases (such as Plants E and L) management have headed off such disputes by upgrading FMS workers to take account of the additional levels of responsibility, and even (at Plant B) by putting all craft workers on "staff" pay scales and working conditions, a long-term demand of the main shopfloor union. In other cases, such as Plant K, increased management bargaining power had been used to keep FMS workers' pay rates in line with the rest of the shopfloor, despite admittedly increased responsibility. To illustrate this, at Plant A the ten skilled operatives on the FMS are paid on the same level as all the time-served employees on the shopfloor throughout the rest of the factory. But, because management are looking for a novel degree of task flexibility on the FMS, the skilled workers have put in a claim for higher grading which the company was unwilling to concede. The system supervisor did not think that this claim would be successful, because the management believe that there are other groups of workers on the shopfloor in the factory who have claims for regrading of equal merit to that of the FMS crew, and acceptance of the FMS workers' claim could open the floodgates to many more.

Overall, then, FMS's enhanced ability to break the dependence of the machining cycle on the direct presence of an operator has facilitated widespread labour flexibility between servicing and ancillary functions. In most plants this process has formed a new stage in the attempt to break down craft control over the machining process. Importantly, though, no less significant a development in some plants has been an attack on the exercise of certain <u>indirectly</u> productive functions as activities separate from the work of the FMS operator. These moves have normally been somewhat tentative, largely specific to the FMSs at the time of interview (rather than yet having wider application on the shopfloor), and occasionally subject to contention in the forms of informal restrictions on working practices and pressure to limit the extension of mobility between ancillary functions.

v) Plant politics *versus* the "autonomous workgroup"

The persistence of "low trust" employment relations, which underpinned the *ad hoc* approach to FMS job design, in most plants studied, has largely stifled the explicit adoption of labour policies allowing a high degree of devolution of control over operations and methods. In two cases, Plants M and R, such policies had been adopted. Yet labour deployment preferences of this ilk appear to be distinctly vulnerable to the former, more established, principles of job design. In this section evidence from one of these FMSs in particular, the machine tool makers Plant R, demonstrates the frequent inability of companies to come to terms with reorganising their pre-existing personnel policies [5].

At Plants M and R, the devolution of control to operators was part of an explicit personnel strategy decided at a relatively high management level. In both cases the organisation of industrial relations within the parent plants suggests that labour control policies more akin to the majority of the plants discussed above were likely. Both FMSs were originally set up on new sites, however, which facilitated more liberal arrangements. Plant M's FMS was however eventually dismantled and transferred to the company's large headquarters plant, where more rigid labour demarcations prevailed: Plant R's FMS was given over to an entirely different management team during the period of fieldwork.

This section gives detailed consideration to Plant R. The fate of the flexible workgroup consequent to the changeover of management is instructive as it emphasises the role of existing management policies and organisational industrial relations structures, and their tendency to stifle the devolution of control and self-contained workgroups. The changes at Plant M, where one worker was responsible for most system management as well as operating duties, will simply be noted here, as its transfer to the headquarters plant properly occurred after the project fieldwork ended.

Plant R, which began as an example of an FMS development in a dedicated building, is not on a "greenfield site" in the strict sense. However, the FMS did originate as an essentially technical research and demonstration exercise in high technology on a dedicated site for the parent group that owned it. This means that Plant R nevertheless bears the essential features of such a project, which have affected the subsequent development of its labour policies. The FMS project was originally set up as a new and entirely separate company by Plant R's parent firm and installed in a spare building on the production site of Plant R. For some time the FMS was used for experimental and demonstration purposes and was not integrated into the business activities of the sister company on the same site. Most of the FMS managerial, technical and operating personnel were however recruited from this sister company (referred to henceforth as the "main" company on the site). Since the beginning of 1985 the FMS itself has been handed over to the main company on the site and gradually absorbed (in managerial and manufacturing senses) into this company's own production facilities. The former management no longer bears any responsibility for the FMS.

At the time of final interview there were five personnel employed within the FMS. These consisted of a supervisor (or system manager) and four operating personnel, comprising two direct workers and two programmers, of whom only one is permanently with the system [6]. The permanent programmer, recruited from the main company, has been with the project since the start of its construction in the early 'eighties when the FMS was first assembled. The system supervisor was employed in a technical capacity by this same firm before it was shut down, but was only brought into the FMS project in mid-1984 mainly for the twin purposes of helping change the system into a production project and breaking down labour demarcations among the lower-grade employees. His job is itself very fluid and overlaps with some of the functions performed by the operators themselves. Prior to his appointment no intermediate level of supervisory line management existed between the three FMS workers and the directors of the plant-based company (as it then was) (see Figures 4 and 5 below). The two direct workers had been employed on the shopfloor at the main company before being hired to work in the FMS at an early stage of its installation.

The original management team for the FMS, who had been transferred from the main company on the site, had undertaken a world tour of existing FMSs during the time that the specification for the project was being conceived in order to assess the contemporary technical state-of-the-art and labour profiles. The managers decided, on the basis of their observations of the division of labour in the (mainly Japanese) systems viewed, that the philosophy of FMS required broad-based jobs rather than the conventional specialisms of Taylorism which had diffused to batch companies. To this end they hand-picked a number of operating personnel without CNC or computer experience but whom they thought would be sufficiently adaptable. These personnel were granted "staff" status on the relevant payment scales applying in the sister company as it was considered that the piecework-based payment system according to which "works" personnel were paid was rendered obsolete with the predetermined cycle times of NC.

The managers' approval of these international observations were reinforced by their own past domestic experiences. They had concluded that the multiple tiers of skill levels and hierarchy in traditional machine shops like that of the main company (of which they had had lengthy experience) and the consequent lack of accountability for management, were the main labour problems to be tackled in the FMS. Moreover the managers' previous experience with NC had led them to conclude that utilisation rates were too low. It was felt that the established division of labour, especially the provision of indirect programming and maintenance functions, resulted in an excessive number of personnel demarcations between different aspects of the productive process. The major disadvantage perceived in this was that accountability for faults and delays in production could never be attributed to any one person.

The installation of the FMS on its own site, from which the main company's unions and even its own managerial personnel were originally excluded, enabled these problems to be more easily addressed. By introducing multiply-skilled workers into the FMS the management felt both that it would gain the elusive accountability and the workers' job satisfaction would be improved. Therefore this policy was adopted at an early stage. The three workers were encouraged to learn everything about the system including programming, inspection, scheduling, operation and maintenance of the machines (see Figure 4 overleaf), and thus they gained an unusually broad and deep level of understanding of the system. The workers appear to have dictated the level of mechanisation adopted within the system, with production scheduling, inspection, and tool life monitoring being retained largely on a manual basis, while software was written at the operators' request to facilitate the incorporation of tool offset data into part programs.

To motivate personnel, and to accelerate the learning process, operators were originally encouraged to gravitate towards the tasks they most preferred. However, in retrospect members of the original management team soon came to see this policy as mistaken, as it reintroduced (however informally) the demarcations it had been

FIGURE 4

ORIGINAL FMS WORKGROUP STRUCTURE AT PLANT R (1981-84)

2 Company directors - 1 responsible for hardware development

1 responsible for software development

↓

System supervisor (May 1984 onwards only)

↓

3 operating staff - all responsible jointly for programming parts &

machines

tooling

setting

loading

inspection

scheduling

maintenance

all other tasks

---

intended to break down. Individual workers tended to guard particular areas of expertise gained and became unwilling to share them with their fellows. The original management team had considered it important to break down this reluctance once it had begun to develop, this being one of the reasons for the introduction of a supervisor, but had found it difficult to do so.

However, at this time the resistance was limited and tacit. By and large all operators involved themselves in the many tasks needed to keep the system running. The managers freely admitted that by sealing the FMS off from the main plant in this way they were "ducking out" of labour problems they knew would arise when they had learned sufficient and had to relinquish control over the system. The original management team surmised that labour classification within the cell would be the gravest assimilation problem when the management of the FMS was transferred to the main company on the site. Further interviews after the changeover, when the FMS had ceased to be a "special case", tend to confirm this; although other technical and organisational problems have also been encountered (Jones and Scott 1985, pp 15-33).

At Christmas 1984 the FMS operatives were given the choice by the personnel management side of the new employers of choosing between classification as "works" or "shopfloor" employees (weekly paid manual) or as "staff" employees (monthly paid). In Plant R's case workers on shopfloor scales actually tended to earn approximately £100 per week more because of a works bonus scheme exclusive to the production workers, although the staff scale is usually considered as possessing greater prestige and career structure. Moreover, from the commencement of their employment on the FMS until this time the operatives had been classified and paid according to staff rates.

Neither the former managers of the FMS nor Plant R's new production engineering management had wanted this "choice" to occur as it implied a more formal reversion to the traditional job demarcations between direct and indirect labour largely jettisoned on the original FMS. The FMS operators themselves and the production engineer in charge of adapting the system had wanted the company to adopt a new skill classification of "cell technician" entailing total flexibility between jobs in the cell. However the personnel management of the company adopted a more traditional approach. Personnel management was already in conflict with the shopfloor unions because it was attempting to change the basis on which the works bonus system was calculated. It did not want the additional problem of creating a new skill level.

To compound matters "works" and "staff" personnel are (as in many other British engineering plants) represented by different unions, each of which also preferred to keep the classification of the FMS workers along traditional lines in order to be able to recruit the personnel. In the event a compromise solution was reached whereby the management washed its hands of the issue and allowed the FMS operatives a choice of payment scales while job titles remained unchanged. Of the three main FMS workers one stayed on staff rates. The other two transferred to "works" status in order to receive the financial benefits of the bonus payment scheme.

With the adoption of different types of job classification for the FMS operatives (based upon their preference for "shopfloor" or "staff" payment scales) a more distinct division of labour has become entrenched (see Figure 5 overleaf). The two employees who chose to be transferred to payment on "shopfloor" scales together

FIGURE 5

NEW FMS WORKGROUP STRUCTURE AT PLANT R (1985-)

Senior plant management (production and personnel sections)

↓

System supervisor - supervision and productionising system.
Also takes some *de facto* responsibility for
electrical maintenance and loading the FMS.

↓

1/2 "staff" personnel - responsible for programming

1 "works" operative - mainly responsible for robots
loading
inspection
scheduling
minor maintenance

1 "works" operative - mainly responsible for tooling
setting
loading
inspection
minor maintenance

Major maintenance by Plant R's Maintenance Dept.

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deal with the tasks more usually associated with work on such scales. One now assumes responsibility mainly for the robots and the scheduling for the system. According to managers interviewed, the latter task may well become one of the responsibilities of the system supervisor in due course. The second operative attends largely to the machine tool hardware and tooling. The remaining one of the principal three workers who chose to stay on "staff" scales now takes exclusive responsibility for the system programming.

It can be seen that the initial intentions of the original senior managers, who wished explicitly to allow operators effective total control over the system, were thwarted by the partial replication of the divisions troubling the rest of the main site. The point of this example is therefore to demonstrate the practical difficulties in adopting more enlighted control policies specifically as a result of the adoption of FMS. It was only possible at Plant R to shield the system from destabilising personnel policy influences in the rest of the site as long as the FMS remained organisationally separate. If the FMS was to be integrated into Plant R's wider manufacturing facilities, the option of segregating labour classifications proved no longer viable. In principle the difficulties that occurred latterly could have been sidestepped by the adoption of the new "cell technician" grading. Yet this was not possible while power remained (not atypically) in the hands of relatively unsophisticated managers unwilling to countenance the extensive devolution of control originally adopted.

vi) Conclusion

A combination of the technological components of FMS and the opportunities presented to management by the poor bargaining position of labour due to recession has provided an ideal opportunity for increased management control of machinists' labour in FMS. Has this chance been taken up? This chapter demonstrates the existence of two tendencies - as opposed to irrevocable laws - in labour control as a result of the adoption of flexible manufacturing systems (although, as much of the evidence was provided by managers, precise working arrangements may differ slightly). These tendencies are stimulated by the existence of "low trust" employment relations in many of the plants that have adopted FMS rather than inherent in the technology itself. Firstly, there is increased technical control over labour through the extension of mechanisation to cover more areas of the transfer and control process in particular. Secondly, enhanced task flexibility, and managerial control over manufacturing methods for the relatively restricted range of FMS components, at the expense of craft control appear to be important in most plants. These latter aims are achieved particularly by the removal, or reduction, of a role for operators in programming, editing, and overall system control, and the substitution instead of additional ancillary tasks.

The most typical forms of labour flexibility - functional flexibility between machines and often assumption of a number of indirect functions - can be conceded by management relatively easily while only marginally increasing the overall discretion or control exercisable by workers. Nevertheless such limited opposition as seems to have occurred to management demands for labour flexibility have concentrated on these attacks on demarcations. This may well be because of the fact that programming tasks had already been largely removed from machinists in most of the plants studied.

The evidence in this chapter suggests, however, that labour control objectives have been a subsidiary motive for the adoption of FMS, and are far from ubiquitous. As a general rule the extent of technical control established and labour control policies are determined on a largely *ad hoc* basis, taking the pre-existing status quo as a starting point. Thus aims of minimising the amount and level of labour input appear to be pursued by only the largest case study plants, like B and D, where such policies were at an advanced stage irrespective of FMS. Conversely, in cases such as the small plants G and K, the reluctance to introduce new institutionalised divisions between conceptual and executive tasks explicitly facilitated the continued unity of conception and execution tasks within the FMS work group (although see also Chapter Nine for some qualifications to this statement).

Overall, managers appear generally uninterested in closely defining labour roles in FMSs, partly because of this *ad hoc* approach, and further due to a difficulty in being sure of the level of competences required from workers. These factors have often enabled some *de facto* measure of devolution of labour control, as operators are left to define their own jobs within certain boundaries.

This relatively uncoordinated approach is considerably more common than the explicit specification of conscious policies for expansion of job boundaries, which was best demonstrated at Plant R. Indeed the former approach may well be more successful as it skirts the issue of confronting the frequent mismatch between companies' pre-existing personnel policies and the desirability for technical and operational reasons of broadened work roles. As the example of Plant R 's transfer to new management shows, wider institutional constraints tend to diminish the extent to which managers are prepared to overtly relax labour controls in FMS.

CHAPTER NINE: Productivity, flexibility and labour control

i) Introduction

The preceding argument reveals tendencies towards both an increase in control over labour through both technical and hierarchical means as one effect of the introduction of FMS; and, running counter to this, the beginnings of a trend towards the relaxation of control and greater worker autonomy. The question that arises from this finding, however, is: does increased management control over labour in FMS actually matter in terms of being able to respond successfully to traditional manufacturing requirements of productivity and - even more so - of new demands for various types of flexibility?

We raise this doubt because of the belief that new manufacturing technologies such as FMS need to achieve both quantifiable manufacturing goals and the so-called strategic production objectives in order to improve overall competitive positions. Yet analysts are divided on the subject of whether the continuation in FMS of "low trust" employment relationships, orientated predominantly towards the control of workers, is capable of achieving these aims. Writers such as Shaiken et al (1986) have argued that no necessary incompatibility is involved. Alternatively, Piore and Sabel's thesis of "flexible specialisation", upon which the debate, and my line of argument, is predicated, proposes that manufacturing versatility requires what one might call "autonomous flexibility" from labour. The latter view is given some support in some recent empirical trans-national evidence on FMS (to be reviewed below).

Such an incompatibility is no doubt involved. However, these type of arguments underestimate the difficulties plants may face in relinquishing traditional objectives of increasing control over labour in order to pursue eventual manufacturing goals. These problems are exemplified in many of the plants studied. Nevertheless, FMS operators are able to regain - sometimes officially, sometimes not - a considerable degree of control within the production process as they use their expertise to optimise the running of such systems. Where such openings are created by the simultaneous conjunction of a number of factors then theories of increased management control are at least partially contradicted. These factors include the willingness of managers to surrender a high *de facto* degree of autonomy in order to meet more pressing and overriding manufacturing goals; the extensive learning curve in FMS technology necessitated by its very complexity, novelty and customisation; and the lack of - indeed, the inadequacy of much - formal training for FMS operation.

ii) Labour and production goals: the literature

Some of the scant literature on labour flexibility and other managerial manufacturing objectives in FMS, while acknowledging the pursuit of different sorts of technical and of labour flexibility, mistakenly fails to consider how these categories might impinge on each other. Lim (1986), for example, does not consider in his study of three British FMSs a possible interrelationship between technical and labour flexibility, or apparently believe that the interaction between the two may impact on overall production versatility.

Significant contributions to the literature by Jaikumar (1984, 1986) and Kelley (1985) [1] have however drawn attention to the importance of the relationship between managerial policies for labour deployment and the ability to achieve particular externally-oriented manufacturing goals. Jaikumar (1984) finds a great difference in technical flexibility and manufacturing philosophy between flexible manufacturing systems operating in Japan, the USA and West Germany, despite a high degree of similarity between the market conditions faced and FMS technology employed in these countries. He argues that a major reason for the disparity is the different average skill levels of the labour inputs, and managerial attitude to worker autonomy, characteristic of each country's approach.

In US systems Jaikumar (1984, 1986) finds a low degree of product flexibility, coupled with an emphasis on traditional quantitative benefits such as high machine utilisation and productivity at the expense of qualitative gains. These aims are underpinned by the use of semi-skilled direct labour and a continuation of the techniques of scientific management [2].

In Japanese FMSs, and even more so in West German systems (Jaikumar 1984), much evidence suggests an alternative emphasis on the use of FMS for qualitative gains (while still achieving high quantitative benefits), continuous development of system capabilities and expansion of part capacity. Achievement of these benefits is based on the use of relatively autonomous teams of skilled workers.

Particularly in Japanese systems there is believed to be greater integration between the designers of the system and the operating personnel, and consequently a higher degree of customisation, than in American systems, and more emphasis on incorporating workers' skills into system software in order to achieve the benefits of unstaffed running (Jaikumar 1984, 1986; see also Jones 1986a). These claims are tempered, however, by Driscoll's (1984) study of some of the most highly mechanised Japanese systems, which finds that the ability to minimise the need for operator intervention in FMSs, particularly on the much-publicised "unstaffed" nightshifts, is enabled as much by cautious operating policy decisions as incorporating skills into software. The technical "fixes" employed include such methods as deliberately reducing cutting speeds below the optimum to minimise tool wear and breakage, and running only the simpler, longer cycle components during unstaffed nightshifts.

Jaikumar's emphasis on national cultural factors does not see them as rigidly delimiting the possibilities for the emulation of (in practice) Japanese success elsewhere. Indeed he believes that a conscious managerial strategy of importing Japanese production philosophies and labour practices is readily feasible, given only the will to do it.

Kelley (1985), on the other hand, analyses the predominance of managerial preferences in determining labour roles within national industrial relations frameworks. She finds that eventual labour roles are strongly influenced by the production goals desired of the system and its technological capabilities and complexities compared to more orthodox equipment used. Thus the preference for traditional modes of labour control in American FMSs described above is tempered by the extent of implementation problems encountered, and management's long-term production aims for the system. On the basis of US evidence she distinguishes between three management approaches to work organisation, which she terms scientific management, technocentric participative, and worker-centred participative. "Participation" in Kelley's scheme can be equated to the accordance of autonomy to workers in problem-solving and in experimentation to achieve process improvement.

Kelley suggests that FMSs managed according to the criteria of Tayloristic scientific management tend to possess the following characteristics. Demarcations between direct and indirect labour are very marked, and the necessary skills to develop and operate an FMS tend to become the preserve of the latter rather than the former group. There is an emphasis on the elimination of human skills and judgement wherever technically or economically possible. Production workers' jobs are subject to overt deskilling, by which is meant a reduction in the degree of discretion and control they are able to exercise over the production process. Solutions to technical or economic limitations to system mechanisation are visualised in terms of both further investment (and possibly research and development expenditure) to obviate the need for continued human inputs. Moreover, projects managed according to these perspectives are seen as having a distinct "beginning and end" in terms of being dedicated to the production of only a narrow part family of static design.

FMSs with such characteristics tend to be inflexible in terms of the variety of parts produced on the system and are managed with overwhelmingly traditional Fordist quantitative benefits in mind (notably volume production and high machine utilisation). Thus, it is visualised that relatively high labour requirements during the start-up period (although still low in absolute terms) will reduce to lower "steady-state" needs as knowledge becomes incorporated into the control software.

The technocentric participative approach occurs when the expense and complexity of FMS obstructs management's ability to obtain such all-embracing production control without relinquishing some elementary control over labour (see also Shaiken 1985). Thus it is a compromise between utilisation of the available skills of the workforce and the costly pursuit of continual technical refinements to the "automatic" capabilities of the system (such as adaptive control). The hierarchical, "low trust", pattern of labour relations characteristic of scientific management is not breached. However, technocentric participation informally relinquishes some detailed managerial authority over labour, demands workers to be motivated to tackle problems, and permits (or, at worst, condones) a degree of fluidity between formal job boundaries [3]. Technocentric participation acknowledges that it is impossible (particularly in the small-batch environment) to anticipate every variable in the production process - a difficulty augmented by manufacturing technologies as complex as FMS. This approach grants FMS operatives some discretion to use their job knowledge independently in responding to contingencies and unanticipated production problems. It is intended that this should facilitate improved response to system requirements and production performance overall, while minimising the modifications necessary to pre-existing labour organisation.

In a worker centred participative approach nearly all the FMS tasks (including secondary programming) are devolved to a work team, who operate as a largely autonomous flexible multi-skilled craft workgroup, and are jointly responsible for the performance of tasks. Jones (1984a) has termed authentic examples of this fluid pattern of labour roles within FMS "organic" to emphasise the internal unity and cohesion of such workgroups and the presence of "high trust" labour relations dynamics. Here the division of labour within FMS personnel is minimal, traditional job demarcation lines are more extensively breached and task boundaries fluid, and the average skill level is higher than in the approaches outlined above. This approach, which is akin to that observed in Jaikumar's Japanese and German FMSs (although largely hypothetical elsewhere), is believed to facilitate increased technical flexibility in terms of both high utilisation and product innovation through the use of human, as much as technical, resources.

From the above literature it appears that there is no reason in principle why a strategy of reducing labour intervention and skills in FMS should not be possible. However, success is contingent on certain conditions being met. Firstly, the learning curve necessary for the absorption of FMS technology should be short; and the portfolio of components to be machined should preferably be static and of well-understood variations. Secondly, manufacturing objectives should be fairly traditional, preferably calling for production of relatively high volumes, and not requiring continual or extensive adaptability between different products. If these conditions are met then it may well be that traditional Fordist labour control methods are the most appropriate (although perhaps still morally objectionable).

The fulfillment of either of the above conditions seems somewhat unlikely in the current UK circumstances (see earlier chapters). Relative technological backwardness, low production volumes and fragmenting markets require more rapid organisational responses. The rest of this chapter examines the extent to which British conditions have favoured a return of autonomy and discretion to FMS workers and, if so, whether this has in fact transpired.

iii) Labour autonomy, informal learning and system development

Both the literature reviewed in section ii) and other authors (see especially Jones (1984c), following Piore (1968b)) suggest that workers' skill and expertise is essential to make process technology satisfactorily operational. This section investigates the significance of a role for operators' intervention in the cases studied. This question is given particular pertinence by the relative recency of FMS in Britain. The crucial point to demonstrate about such autonomous expertise is the manner in which the potential to develop and utilise tacit process skills allows operators to exercise control.

The take-up of FMS in Britain is still at a potentially youthful stage. This being so, there is an understandable paucity of readily transferable expertise in FMS projects. Part of the reason for this is the fact that few who claim to be FMS suppliers either produce, or have all-round experience in, the range of technologies that combine to form FMS. The projects studied therefore tended to involve several suppliers (with one taking on the role of coordinator) developing, assembling and debugging an idiosyncratic assortment of equipment. Inevitably, unique difficulties are encountered. This was found particularly in early projects such as Plants A, G and L, although the majority of plants alluded to such problems.

Plant G (where even CNC experience only existed as a result of external recruitment) was a prime example of problems with suppliers. Here the FMS project was supposed to have been developed and controlled by the major machine tool supplier, for whom the project was very much experimental. Yet, according to Plant G's system manager, the project ultimately - albeit reluctantly - had to be user-led, with the plant's engineers (and himself in particular) having to undertake large portions of the software-related aspects of the project. Interviewees felt that in the end the company had taught the suppliers more about the system than *vice versa*, to the extent that the system supplier actually decided against sending a commissioning engineer to the plant on the grounds that the FMS workteam probably knew more about the machines than any of their engineers.

The difficulties of supplier inexperience are exacerbated because of the specifity of each project to a given application. Although the hardware components (like machine tools and transfer equipment) are fairly standardised, the particular configuration of equipment and accessory features required is tailored to the project concerned. System software is highly customised to the particular production requirements of a given system. Overall, then, no true "off-the-shelf" system can yet be supplied, although a number of standardised modules do now exist. This lack of experience, we argue below, tends to limit the possibility of being able to absorb FMS in a ready and untroubled manner without the additional need for considerable informal in-house knowledge.

FMS suppliers are poorly versed with the vital in-house production expertise accumulated through years of manufacturing a particular group of components to be machined on an FMS. Their own efforts to incorporate this knowledge in the programs and methods they provide in "turn-key" projects are often sadly inadequate. Evidence of this surfaced, for example, at Plants D and M, where plant engineers more or less scrapped and rewrote the programs originally supplied; and Plant A, which was forced to change nearly all of the part fixtures supplied. The value of in-house production expertise is demonstrated by the relative success of the plants studied, such as B, H, and M, that elected to perform the majority of the FMS development work themselves.

One may ask how the knowledge necessary for FMS control and operation is transferred to its eventual workers, given the difficulties discussed above of the limited technical experience of many FMS suppliers, and the plant- and product-specific nature of much of the developmental work necessary to make systems operational. At the extremes two distinct methods are of course possible: a formal period of training, or informal on-the-job learning. The former method of structured, formal learning appears more prevalent for higher-level management and engineering personnel concerned with FMS, although much of the specific methods and engineering knowledge is gained in the plant on the job itself.

One finding of the fieldwork which stands out prominently was just how little of the training provided to FMS operators consists of formal teaching or courses. As far as we are able to ascertain, direct operatives received the benefit of short formal courses on the machine tool suppliers' premises in a mere four cases (Plants C, L, N, and the setter/inspector grade only at Plant H). In two further cases (Plants F and J) the user organisation was itself the supplier of the equipment used, and so such formal training as took place still occurred within the plant. In only one case was an external training organisation officially employed. This was at Plant D, where the FMS operators attended a nearby government skills centre course to learn the basics of computer numerical control, of which they had no previous experience. All operator training was carried out in-house at the remainder of plants studied.

The formal courses on suppliers' premises tend to be of relatively short duration - two weeks (as at Plant N) being fairly typical - and the syllabus restricted to gaining familiarity with the specific makes of machine tool control, and so on. It seems that such courses are mostly quite adequate for such factual instruction, although occasional complaints of insufficient length were encountered. In such a short space of time it is nevertheless only possible to transfer a limited degree of the expertise necessary to successfully operate systems as complex as FMS, for only a narrow spectrum of the conditions and eventualities likely to be faced can be raised [4]. These difficulties are eased somewhat when the supplying companies' engineers are present for some weeks on-site as the component parts of the system are gradually installed. These personnel are then available to help in debugging problems and aiding the informal transfer of expertise at the critical introduction phase. This occurred at Plant N, and also at Plants such as E and K where operators were not provided with formal external courses.

The lack of formal training and retraining for FMS operatives is perhaps unsurprising in view of the more general absence of such a policy in British small-batch engineering firms. The subject of limited indigenous training opportunities has been discussed in earlier chapters and is of course frequently regarded as a reprehensible phenomenon. The plants studied were no different to the general trend in that few possessed any formal on-site training facilities to speak of. My argument, specifically as regards FMS, is that the virtual absence of formal training does indeed have some disadvantages, the most particular of which are the difficulties caused by its non-availability within the firm for those technical subjects for which it is appropriate, and the limits it places on the rapidity with which new skills designed to enhance operator flexibility can be learnt. On balance, however, the expertise necessary for FMS operation tends to be so system-specific - once the initial machining skill base has been laid - that the prevalence accorded to on-the-job training is probably an inevitability.

Let us briefly dispose of the disadvantages first. Instances were found where the possibility of workers upgrading their skills and prospects had become dependent upon the voluntary use of external training facilities. For example, one of the workers involved with the FMS at Plant P, whose apprenticeship had been on conventional machine tools, had voluntarily taken an evening class on NC programming in his own time in order to be able to better understand the workings of the FMS. Secondly, the learning of additional task functions, designed to enhance the versatility of workers grounded in a single trade, can only be gained haphazardly and at varying speeds without formal training, depending upon the urgency of production exigencies. At plants such as A and P, for example, management goals of labour flexibility were being retarded by the fact that not all the skilled workers had yet been trained to do every job at the time of interview. For example, only five of the ten skilled men had been trained to operate the system's tool grinding machine. Thus the much-vaunted additional flexibility is conditional on the time and cooperation being available for the informal transmission of expertise between operators.

Despite these undoubted limitations, on-the-job training assumes its importance because the time and resources available for formal teaching are unequal in practical terms to the successful transfer of the amount of knowledge needed, and also because much of the type of knowledge required for successful FMS operation is simply not amenable to transfer by means of formal instruction. To take the first reason, the attainment of well-rounded knowledge requires more time and resources than could be reasonably incorporated in formal instruction by suppliers, who have thus far been unable (or unwilling) to coordinate and construct integrated programmes of instruction for technological systems that are so user-specific. A typical estimate given by the machine tool supplier Plant J of the time required to train an FMS operator to a standard where he or she is capable of assisting with tape prove-out was from two to three months, having previous NC experience, or one to two years without such a background (see also below) [5]. A manager at Plant H suggested that craft-trained CNC machinists would require three to six months further learning to successfully fulfill the intended role of a setter/inspector. An additional problem is that formal operator training for FMS, where given, is only supplied to a limited number of a system's initial workers. Formal operator instruction is restricted by the fact that managers tend only to see it as a one-off event [6]. Training for new shifts of workers, replacement employees entering the FMS, or back-up capability in case of absence, must therefore be provided by the existing job incumbents.

But, more important than the above, formal teaching is inherently incapable of facilitating the accumulation of the experiential expertise in system control characteristics that is acknowledged (by workers and many managers interviewed) to be necessary for successful FMS operation. Gradual, in-house, on-the-job learning is the most effective means of transferring such knowledge. At least one plant studied found this out the hard way. The following, rather jaundiced, view from the project manager at Plant L of the effectiveness of a supplier's formal FMS operator training programme encapsulates the difficulties that can occur in the transfer of expertise:

> I don't think they've got their act together - maybe because they don't understand what they're trying to teach.... Quite frankly, at the end of it all we wonder why we didn't do it ourselves.... we tend to spend so much time explaining to the teachers what we want them to teach us that... you wonder whether you spend more time trying to explain to them what you want; and whether it might have been better to do it yourself in the first place. So we're tending to do more and more in-house, on-the-job training...

With technology as complex as FMS the discovery of system parameters, shortcomings and idiosyncracies, and the evolution of working methods to evade or absorb these limitations, can only unfold gradually as running experience accumulates. For example, operators must become aware of the product- and process-related causes of quality fluctuation, such as the role of thermal factors and the initial inaccuracy of machine tools after restarting, and how to compensate for these. Idiosyncracies that can only be learnt through experience also play a part. For instance, although the machining centres in Plant P's FMS are of an identical model, in practice personnel have to get used to the particular cutting accuracies of each, and route components onto the machining centre they believe will best be able to machine the job.

In practice the necessity to allow for a lengthy learning curve had been acknowledged at most of the plants visited (although subject to senior management pressures for more rapid progress, as Chapter Six showed). This is reflected firstly in the prevalence in most FMSs (especially the more recent systems) of an incremental approach to installation, introducing and gaining experience in one system component at a time before adding further hardware [7]. Additionally, at least one worker was usually assigned to the system before it was "up and running" (often as soon the machine tools were delivered on-site). In this way a gradual build-up of expertise was facilitated, and this could subsequently be passed on informally to new workers.

The vital role of on-the-job learning is underscored if we look at the recruitment and personnel selection criteria for FMS operatives utilised by managers. The overriding impression is that selection criteria are geared towards minimising formal training needs. This results in a management dilemma. The high technical content of the job, coupled with the profusion of control systems, might suggest the employment of technician grade personnel. This possibility was considered at Plant M. It was however rejected on the grounds that such personnel would be difficult to retain once the system was operational, and thus expertise would be lost.

Thus, almost without exception, FMS workers consisted of craft-trained machinists with a number of years experience on stand-alone CNC machine tools. There was some dispute as to the precise value of CNC as against conventional machining experience hitherto, with one manager at Plant C arguing for the latter because of the more direct "feel" it engendered for the cutting process. Against this, the dominant view was that the advantage of prior CNC experience consisted of the general familiarity gained with machine controls. At Plant M, for example, managers had picked one FMS operator without CNC experience, who they argued had been considerably slower in familiarising himself with the system as a result of this lack of experience.

It is apparent, however, that most of the managers interviewed ranked motivational factors, and a willingness to tackle production problems independently, as perhaps more important than their technical skill *per se*. This quality in craft workers was particularly noticeably used as a means of incorporating the expertise of skilled workers in order to minimise the delay in operationalising FMS projects. This evidence parallels Piore's (1968b) findings. At the last named plant, for example, managers sought to use the problem-solving expertise of skilled machinists to minimise delays in installation and shorten the necessary learning period, so as to achieve the aim of rapidly doubling machine utilisation, partly through the potential for unstaffed running as the control of potential variables was gradually incorporated into the system software.

How can we be sure, however, that the employment of craft-trained workers with expertise in making the product results from genuine need rather than "social construction" of skill? To seal the argument in this section let us relate the evidence of the following dispute at the valve-making FMS at Plant H. Because of a dispute with the AEU in the valve production area over pay levels in the FMS the company suffered several months' delay in recruiting and training workers for the system as a result of union "blacking". It had originally been hoped to recruit craft-trained machinists with previous experience in both valve production and on stand-alone CNC machining centres of the same make as, and using similar control panels to, those employed in the FMS. As a result of the dispute, two of the first group of workers selected were skilled workers from the firm's development shop. However, they had no real experience of production work, valve manufacture, or even of CNC machine tools. The same disadvantages applied to an essentially unskilled ex-boilerman also recruited, who wished to change trades and has become the loader on the first shift. The final person recruited was a machine operator who resigned from the union in order to work in the FMS area.

These unpropitious circumstances, coupled with the fact that the firm were on the bottom of the learning curve with the FMS anyway, were cited by managers as the main factors resulting in low initial utilisation levels of between 40-50%, rework rates of 20% and scrap rates of 10%. These problems have declined as experience with the system has grown. At the time of final interview scrap and rework rates had been reduced to some 5% while utilisation levels had increased considerably. Inability to recruit in the valve area continued at the time of final interview because of the dispute and, for example, two of the workers recruited for the second shift had to be transferred from other companies within the parent group (despite the original intention to recruit internally). It is significant however that, despite the recent improvements in scrap and rework rates obtained with even these workers, company policy still remains negotiation with the union to resolve the dispute with a view to recruitment of the valve shop CNC machinists originally desired.

Overall, the importance of the almost ubiquitous internal recruitment of skilled, craft-trained workers to FMS, coupled with the heavy reliance upon in-house, informal learning, is the element of control this <u>may</u> give to FMS operatives through the unique knowledge they are able to develop of system capabilities. In important senses they become the <u>only</u> personnel with the necessary detailed knowledge of FMS operation. As Piore (1968b) also found, this trend of the monopolisation of expertise is intensified as second generation workers are recruited to the system. The initial operators then informally teach them the required tacit skills.

I stress the conditional nature of the monopolisation of expertise by workers. The degree of control they are able to exert can be reduced - although not altogether eliminated - if (as Kelley and Jaikumar suggest in section ii) above) workers' expertise in managing product and process variability can be incorporated into system software during the introduction period. This is most likely if an FMS is managed as a "steady-state" unit for the volume production of a static range of parts. In their pure form such circumstances were relatively uncommon in the cases studied, although elements of this approach were noted particularly at the aerospace plant B, automotive manufacturing plants D and K, and the diesel engine making plant N.

Nevertheless, as Blumberg and Gerwin (1984) argue, the price of trying to minimise human intervention is often to uncover new sources of variability requiring additional skills. At Plant H, for example, the company had to learn a lot about making parts under FMS conditions that it had neither encountered before nor anticipated confronting, despite its considerable previous CNC experience. One example quoted concerned the cutting tool geometry requirements for the setting of drills for machining in an unstaffed mode. On the other machine tools in the machine shop a drill would normally be used to cut only a relatively small number of parts before being returned to the toolroom for regrinding. With the FMS, however, it is intended to minimise necessary toolchanging by keeping tools in the machining centres' tool magazines for as long as possible before having to remove them.

Once the company instituted this policy, however, it discovered that if the lip height of a drill varies by more than two thousandths of an inch it becomes too inaccurate to use for repeated threading operations without resetting. On the former manual system this had never been encountered as a problem because of the frequency with which machinists took tools out to regrind them. It had been necessary in this instance to retrain the personnel responsible for tool regrinding to take the new discovery into account.

If FMSs become more "steady-state" then the danger is that employee motivation will diminish as production variables are increasingly incorporated into software-based control. Evidence on this point is presently sketchy because of the relatively limited time that FMSs have been operational in Britain. However, all operators at Plants P and R (two of the country's earliest FMSs) clearly considered their jobs to have been more interesting during the period that the projects were being set up and debugged. Motivation had tailed off, particularly at Plant P, as production settled into an established and regular pattern of components and production schedules.

The important point here is that "steady state" FMSs are unlikely to be able to retain the motivation of skilled workers, who have been proven so useful during the commissioning process, after the development phase ceases. The danger is however that less skilled workers introduced will not be as adept in recognising or dealing with new problems that occur, and will also have to relearn the set of tacit skills needed to run the system. Preserving the motivation so important for efficient operation and quality output appears to be dependent on the continual development of system capabilities.

iv) Productivity, flexibility *or* labour control

The main question remaining unanswered from the argument above is: to what degree are such factors as the level of equipment utilisation, system flexibility, and (perhaps less frequently discussed) product quality responsive to the amount of skill and control devolved to craft-trained workers in FMS in everyday production? Here I concur with the "flexible specialisation" thesis that devolution of control - or "autonomous flexibility" - appears to be important. Opportunities for operator intervention in programming are the most significant instance of such an assumption of control. Yet "autonomous flexibility" is frequently resisted by managers because of their continued reluctance to relinquish control over labour, even if this could enhance control over manufacturing operations as a whole.

In several systems productivity constraints, reflected in goals of high machine utilisation, favoured workers autonomously monitoring the quality of work in-process. Few plants (except the large aerospace plant B and earthmoving equipment plant D) judged the expense and time of programming in mechanised checks of tool or part condition and position justifiable in terms of the relatively low labour cost saving. For example, at Plant C managers refused to program in many automatic probing routines to verify part or tool condition on the grounds that such programming would result in precisely the increased indirect labour input the FMS had been designed to avoid in the first place. Most FMS managers tended to restrict mechanised monitoring to a form of risk analysis based on historic data (where available) of the life and wear patterns of individual tools, incorporating automatic probing checks of parts only prior to, or after, the use of critical tools (such as drills or taps) to determine the condition of tool and/or part. A common objection to more extensive probing, based on a desire for maximum machine utilisation (and specifically stated at Plants H and J), was that in-process checks, once programmed in, would add to total cycles times and thus increase the machine tool's non-productive time. The machine shop manager at Plant J spoke for many by saying that it would simply "have to be hoped that an operator was around and had his ears open" in the case of tool breakage in an unprogrammed circumstance. By choice such functions were relinquished to the direct operatives.

Traditional characteristics of limited flexibility of workers, adversarial industrial relations, and low trust between managers and employees often remain difficult to reconcile with the pressures generated by FMS to allow operatives greater autonomy in system control. This was most visible in the FMSs at Plants A and L, both of which were large plants characterised by a well-defined demarcation between direct and indirect labour, and in which operators have traditionally been dissuaded from adjusting the methods control established by the manufacturing and production engineers. Management at Plant L believed that the desired degree of labour flexibility and teamwork could only be maintained if operators had a wide knowledge of system capabilities, methods and functions. Managers also wished to minimise possible resistance to the FMS from the workforce and system operators (who were recruited from the most highly skilled CNC machinists). To this end a policy was adopted that the direct workteam should not be barred from access to any level of the system. Operators have therefore been trained in understanding the method of host computer control and part programming to the standard of being able to identify faults in tapes. However, having granted operators this knowledge, management have then discouraged them from making any use of this information to amend the system functions and part programs. Managers' argument for this was that the production methods for the limited range of components on the FMS should be solely determined by the plant's manufacturing engineers.

Similarly, at Plant A managers allowed operators access to the host computer and control room and have shown workers how to operate the password-protected higher levels of computer control unaccessible from their own terminals. Managers did so to avoid operators becoming suspicious that parts of the system are being kept secret from them. Likewise, management recognise that operators cannot be physically prevented from editing programs at the machine tool level or amending feeds and speeds because of the presence of machine level editing and override facilities. However, management intend that programming for the limited number of components in the system should remain the responsibility of the production engineers, who alone are supposed to establish the programs rather than allow any subsequent development. Therefore supervisors have made it clear that operators are discouraged from changing the programs and must relay any changes back to host computer level.

Evidence from this project suggests that "low trust" relations, are encouraged by the context of many of the plants into which FMS has been introduced. These conditions in turn make the achievement of production flexibility and productivity gains more difficult. Let us return to the machine tool manufacturer, Plant R, at which the management team running the FMS was changed, as proof of the particular role of managerial policies [8]. One effect of the alterations in labour classification described in Chapter Eight was the re-emergence of labour demarcations between programming and "operating" functions. This allowed communication barriers to form between the FMS workers, and caused their reluctance to take part in aspects of FMS tasks which were no longer seen as their "own". For example, employees other than the operative remaining on staff scales are now unwilling to optimise part programs for components by editing them, as any of the three would have done previously. As one of the operators, now paid on "shopfloor" rates, explained:

> Now if I walk past the machine and I think it's been programmed to run too slow I'll do one of two things: I'll either tell the programmer and he'll make the changes; or I'll just think, "Oh, he's made a mess of that one!", and let it go rather than tell him for the sake of saving thirty seconds on the job. There's no incentive to now, really.

Neither production engineers nor the FMS operators themselves thought this rigidity was really for the best in terms of the efficient operation of the FMS and they blamed the traditionalist attitude of the personnel management for this state of affairs. The development of such a situation was ascribed directly to the personnel policies of the FMS's new owner.

Further, the more rigid labour structure now adopted is designed to facilitate a new emphasis on quantitative operational production objectives at the expense of the former, more "strategic", outlook geared to the achievement of a wide degree of product and process flexibility through allowing all operatives to learn the full capabilities of the system. These new goals were reflected in senior management attempts to increase batch sizes processed on the FMS (a batch size of six hundred in comparison to a typical batch size of fifty was specifically mentioned by one operator) and to raise the level of machine utilisation by concentrating on production of already proven components. However, in the operators' view, these new short-term goals precluded the availability of the machines and considerable development time to prove out programs for new products.

At the time of final interview these new management policies were about to receive what Plant R's production managers considered would be a more significant test. A second shift on the FMS was shortly to be introduced, for which new operating personnel recruited from Plant R's shopfloor were to be trained. Managers and workers expressed a number of fears. Firstly, the recent changes in labour classification would hinder the breaking down of labour demarcations as the new personnels' experience from Plant R's shopfloor was limited to a magnified form of the divisions of work roles emerging on the FMS. Secondly, the existing operating personnel alluded to the necessity of gaining a comprehensive depth and breadth of knowledge of the FMS as a prerequisite to being able to work and control it successfully. Emerging demarcations would be unlikely easily to facilitate the attainment of such a breadth of expertise, thus confirming the pessimistic expectations of the original project managers. Operators and managers interviewed were certain that the recent divisions, leading to less labour flexibility and inability to experience system-level requirements directly, could only prolong the training process. Introduction of new products, the work group's responsiveness to breakdowns, and recognition of programming and processing errors would be adversely affected as a consequence.

Thus, if workers are to be able to exercise the wider knowledge of programming and system capabilities necessary to respond rapidly and flexibly to production requirements, a relatively high degree of workgroup flexibility, autonomy and discretion is necessary in practice. Whether this is conceded is a matter of managerial choice and local constraints. Evidence from at least one of the systems studied (Plant G) indicates that this is sometimes recognised by managers. At this plant the relaxation of the rather hierarchical workgroup structure originally intended was found to be advisable if the aim of achieving a high level of product flexibility was to be met. In the initial planning stages at Plant G the project manager was uncertain about the level of skills that could be expected from each of the system's workers. This doubt led to a rather restrictive hierarchical designation of job titles (system manager, cell technician, and cell loader) and plans for similarly limited responsibilities. A limited degree of overlapping was envisaged, but merely to provide back-up capability in case of temporary absence. However, the high amount of part programming work required, coupled with the low absolute numbers employed, limited the possible degree of job rigidity. As a result the division of labour within the system became considerably more fluid than was originally intended to be the case. The high degree of craft autonomy permitted at the plant, coupled with the lack of institutionalised restrictions on responsibility for determining working methods, ensured that there was no in-built resistance by managers outside the FMS to these developments.

By the time of final interview (when the system had been running for three months) job responsibilities were being enlarged on a more permanent basis. Managers now intend to gradually increase the overall capabilities of the three workers above in running the system, although the main interchange will still be limited to that between the two senior jobs (cell technician and system manager), either of whom now engage in part programming and overall system control. Any of the FMS's three workers now perform the occasionally necessary manually controlled operations at the CNC machine tools, and load the system if necessary. But perhaps more significantly, the less skilled "loader" is now being trained in toolsetting and part programming, for which the other two workers are already responsible.

In sum, it appears that the propounded productivity, manufacturing flexibility and control benefits claimed for FMS cannot be obtained without some changes to more conventional work organisation. Moreover, these gains are still to some extent alternatives, being difficult to harmonise simultaneously. The most important point is that, if FMS is to be used as anything other than a slightly modified transfer line, all of the above benefits are facilitated more readily by relinquishing tight labour control policies, and allowing space for FMS workers to utilise their particular expertise. This is acknowledged by managers to some extent in the recognition of the role of tacit skill and informal learning, the almost universal preference for craft-trained workers, and the fact that actual job boundaries are often less rigid than their official titles (as Plant G shows). It can be seen, however, that the continuing - and in some cases - increased reluctance to concede operator intervention in the determination of working methods can undermine the achievement of greater overall production control, productivity and system adaptability.

CONCLUSION: The craft worker in flexible manufacturing systems

This thesis has tried to assess some of the human implications of the gradual progress towards the so-called "automatic factory" in Britain through a study of flexible manufacturing systems. The objective was to discover whether, and how far, conventional craft workers' skills were eliminated by FMS-type technology. FMS, by linking machine tools under overall computer direction, is one of the furthest steps yet achieved in practice to so-called computer-integrated manufacturing, whereby all stages of the production process are connected by mechanised transport and computerised control.

It is often believed that FMS will allow significant steps towards the resolution of some of the more deep-seated structural problems of batch engineering. The claims of management and technical commentators suggest that flexible manufacturing systems can facilitate greatly increased productivity through higher machine utilisation and constant production. Greater control over the manufacturing process will ensue, it is said, because of the ability to better calculate total manufacturing times of components in the system and improved control over the tracking and progress of parts. These benefits are now thought to be possible without sacrificing the production flexibility so crucial in small-batch manufacturing. Hitherto these three gains have been unavailable simultaneously with previous technical changes (notably numerically controlled technologies) or, more rarely, organisational changes like group technology.

Our focus has been on the consequences for labour, and in particular for the craft-trained machinist, of the innovation of FMS. For the traditional centrality of craft labour as an element in the production process in small-batch engineering has not been lost on those analysing the take-up of flexible manufacturing systems. According to some, a major purpose of FMS is to reduce management dependence upon the control exercised by such workers by virtue of their ability to dictate working practices and to monopolise particular skills. Freedom from this burden will be possible through the eclipse of the need for each machine tool to be dependent on an individual operator, the ability to cater for product and machining variations with minimal human attention, more precise management definition of procedures, and closer prescription of many remaining human tasks. Thus the realisation of manufacturing productivity, control and flexibility gains is conceived of largely in terms of enhancing control over labour. This aim is not seen as being inconsistent with greater labour flexibility between hitherto separate operational and ancillary tasks necessary to service semi-automatic production systems. This view has been taken by certain managerial and technical analysts, such as Dempsey (1983) and the National Economic Development Office's Advanced Manufacturing Systems Group (1984). Less sophisticated adherents of the "regulationist" school, such as Shaiken et al (1986), concur with such sentiments.

Other commentators argue the reverse case that such sophisticated technologies may require a higher level of skills on the shopfloor and demand greater devolution of control over operations to direct workers in order to accomodate more complex products and production processes. This is the position of more sophisticated "regulationist" analyses, notably that of Blackburn et al (1985). Sociotechnical analysts, such as Hirschhorn (1985) and Sorge et al (1983), those I called "technicists" in Chapter Four (for example, Hatvany et al (1983)), and proponents of "flexible specialisation" (Piore and Sabel 1984) take the same position more emphatically.

My evidence, gained by study of a cross-section of fifteen British FMSs, shows that much of the literature and supposition on the labour implications of FMS is flawed in important respects. One of our main observations is the very diversity of FMS application in terms of profile of the user plants, the production problems they face, and therefore the main benefits sought from this technology. If it were true that work roles in FMS are largely technically determined, or that (as Shaiken et al (1986) suggest) the achievement of different marketing objectives is uncorrelated to the form of work organisation employed, we would except this to be reflected in essentially similar working arrangements. However, this only appears to be the case to a limited extent. How are we to explain this anomaly?

To untangle the contradictions of the literature we have adopted a distinction between tasks and work roles. Tasks are technically generated and call for certain skills. Work roles, on the other hand, are subject to a number of external influences and dictate at which level of personnel these skills are to be exercised (thus bringing in the question of labour control). The tasks necessary with FMS are less concerned with direct operation (as was required on conventional machine tools) or the management of the machining process at a single tool (as was still the case with numerical control) so much as overseeing an interconnected system of computer-controlled work stations. Two types of tasks thus remain, although their extent is subject to the somewhat variable degree of technical sophistication it is decided to employ. Firstly, managerial functions of overall system coordination and control, and of the determination of methods for parts on the FMS, are required. Secondly, a number of servicing and ancillary functions, such as maintenance, inspection and the loading and unloading of tools and parts, are called for to keep the system running smoothly.

These task functions, although now exercised through the medium of computerised (rather than physical) control, are still essentially the same as those comprising what we described in Chapter Five as the machining labour process: that is, conception, setting-up, monitoring, regulation and quality control (although not the actual control of cutting). The necessary tasks are more extensive in some respects as the worker is now responsible for a group of machines. Many of the craft skills appropriate to earlier forms of machining technology are still of value because of the fact that the process of material transformation remains unchanged. FMS is simply a more sophisticated machining technology. With the proviso that additional training would be required in the more advanced methods of computer control, there is no reason in principle why the entirety of the labour process in FMS could not be under the management of the craft-trained worker [1].

The relatively limited evidence of such developments in the cases studied brings in the question of the determinants of work roles, and confirms our hypothesis that the reasons for the non-trial of skill-maximising forms of division of labour are institutional and political as opposed to technical. We have identified managerial preferences for labour deployment as being the main variable affecting the division of labour on the basis of the findings of this project. This approach thus places a heavy emphasis on the distinct role of company manufacturing, marketing and industrial relations policies, and the extent to which these are coordinated, in assessing the outcomes for work roles of the introduction of particular technical and organisational changes. The importance of this factor derives from the fact that new technologies are not introduced in a vacuum. Rather, the existing organisational context into which technologies are introduced colour the dimensions of work role changes sought and realisable.

Supplementing this factor of managerial control preferences, and often containing the potential to undermine it, the variability inherent in the task functions required, and product and labour market characteristics, also play a part. The variability of tasks necessary in FMS depends on the degree of complexity and uncertainty inherent in the technology and the spectrum of parts machined. As we shall see, this has been significant in denying several managements in the plants studied the opportunity to exrecise the degree of labour control that they originally wished. In confirmation of Sabel's (1982) thesis, product markets were almost universally found to be increasingly unstable, characterised most prominently by requirements for faster delivery, higher quality and lower batch sizes.

Labour market factors were not found to be very important in delimiting management wishes in this study. There are several reasons for this. Firstly, there is a widespread shopfloor acceptance of technical change. Secondly, the considerable weakening of labour's bargaining power in most plants (other than G and K) as a result of job losses during the recession has resulted in the availability of a glut of skilled workers willing to ensure their future security of employment by staffing FMS. Lastly, there was a virtual absence (apart from Plant H) of any organised labour opposition to management proposals regarding the staffing levels of, or working practices to be employed on, flexible manufacturing systems. The few disputes that did occur tended to focus on traditional bargaining matters such as shift systems or the negotiation of a satisfactory price to relinquish control over working practices.

Despite recommendations (Ashburn et al 1986; Thompsone and Scalpone n.d.) job design policies for FMS are conspicuously haphazard, receiving little or no strategic thought, and being treated as a belated adjunct to the technical parameters and purposes of the system. This finding is important within its own terms, for it reveals that allocation of work roles in FMS is normally given little more conscious thought than the installation of any other technical innovation on the shopfloor. The exceptions to this, where some explicit consideration was given to the degree of flexibility required, and the extent of autonomy to be granted to workers, were - significantly - greenfield sites (Plants P and R) or the small, overspill machine shop at Plant M, which had a reputation for considerably more flexible working practices than this company's headquarters plant. The fragility of such enlightened arrangements, depending upon institutionalised industrial relations cultures and contexts, was however demonstrated by the unique example of the transfer of the FMS at Plant R to a more traditional management team.

In many plants, therefore, job design policies continued to be informed by motives of reducing craft control over working methods and job demarcations more substantially than had been hitherto possible with previous technical or organisational changes. These aims were realised by several means. Firstly, workers' access to some higher level operating functions, such as scheduling, could be shut off technically. Alternatively, responsibility for methods decisions could be restricted to a supervisory grade of worker within the FMS crew, or even to external personnel in Production Control and Production Engineering departments.

The allocation of responsibility for part programming in particular is often regarded as the touchstone for questions of who controls the machining process. Most of the plants studied, because of their size and previous NC experience, had established programming departments which already performed the majority or all of the required programming work. Nevertheless, most plants (with the exceptions of B and D) made at least some use of manual data input facilities for operator programming or, even more commonly, subsequent editing of programs. With FMS there came a tendency to reduce the level of intervention permitted to FMS workers in constructing and/or editing the programs for components. We have shown that, where this occurred, it was explicitly intended to increase direct management control over manufacturing methods.

Yet the specificity of such control objectives, depending on firms' particular goals, can be demonstrated by those plants without programming departments (G and K) which chose to retain all programming facilities within the FMS workcrew itself (albeit that not all members of the crews were able to program) and Plants M and R in particular, at which programming functions were actually devolved to the FMS workers.

The advent of FMS was however used by management in several companies to explicitly achieve job design objectives by the promotion of increased labour flexibility. This was the final method by which managers sought to undermine craft controls over the labour process in FMS. The purpose of labour mobility initiatives, as has already been hinted above, was rarely to sanction the formation of the autonomous flexible workgroups described by sociotechnical commentators. A minority of plants (F, M and R) experimented with such extensive labour flexibility; but in the first two of these plants there was only one direct worker anyway, and in no cases were sociotechnical prescriptions explicitly used by managers as a reference point in job design.

It is clear that FMS is seen by many managers as technically forcing a requirement for more flexible working patterns as a result of its automatic cycle times. Labour versatility in FMS most commonly involves varying degrees of increased horizontal and vertical flexibility between system servicing and ancillary functions. The extent of this varies according to the degree of mechanisation employed, and to which the functions of existing indirectly productive personnel can be added to FMS operatives. In general, however, the forms of mobility pursued consist of more than what "regulationists" have termed work intensification through the agglomeration of semi-skilled tasks. The addition to operators' work roles of tasks such as inspection, tool grinding or tool setting will allow them a greater measure of discretion than the assumption of responsibility for, say, swarf clearance.

Having said this, management approaches to labour flexibility often appeared rather half-hearted, as no great willingness could be found to invest in increased skills. There was a noticeable lack of formal training for the additional tasks that operators were supposed to undertake (see also below). Neither, contrary to initial expectations, was there more than a minimum of evidence for the yielding of still strong inter-craft demarcations between production and maintenance functions; and certainly none for the coherent development of the polyvalent, multi-skilled craft worker. This project also finds, in common with other studies referred to in the text, that the much-vaunted flexibility is diminished in practice by workers mutually guarding particular tasks as their own (as at Plants A, L, P and R).

The argument above leads to the conclusion that the innovation of FMS has normally undermined the level of craft control that machinists are able to exercise. But this does not preclude a continued requirement for skills originating from craft training for the successful operation of FMS in nearly all of the systems studied. This was reflected in the fact that managers deliberately recruited craft-trained workers in virtually all cases. The example of Plant H, where the initial recruitment of less skilled workers hampered the efficiency of the system, demonstrates that there is a real basis to the need for such expertise.

In this study craft skills were found to be valuable in providing a ready source of expertise on the practicalities of machine tools and machining in order to facilitate the absorption of FMS technology. The independent problem-solving ability instilled by craft training acts as at least a partial substitute for the lack of thorough practical knowledge on "productionising" technology as novel and complex as FMS on the part of system suppliers and plant engineers (documented in Chapter Nine). In part, machining craft skills therefore plug a gap left by the lack of investment by plants in the formal training of FMS operating staff.

Yet I want to argue here that formal teaching alone cannot dispense with the need for craft skill in most of the systems encountered. One of the crucial points of this thesis is that craft skills contain an all-important tacit element, which cannot by definition be formally expressed. Tacit skills are essentially practical, and must be learnt experientially over time. By recruiting craft-trained machinists (with either previous conventional or CNC experience) to staff FMSs managers are simply trying to reduce the necessary amount of additional - specifically FMS-related - technical expertise that must be digested, and thus enabling curtailment of the necessary commissioning period. This role was found to be important in most of the plants studied, given the early phase of FMS development in Britain. Managers' continued dependence on these skills allows FMS operators to retain an element of control in the production process, even if their primary jurisdiction over working methods is lost and the new skills are more process-specific than generalised.

There is however a more vexed question of whether such skill is still needed when the commissioning period is over, the FMS is in production, and the technological teething troubles have been eliminated. Our evidence suggests that it is still a useful input, and often essential. The opportunity to continue to use craft skills will depend on the purposes for which the FMS concerned is being managed, the variability inherent in the part spectrum being machined, and the continued uncertainty of the FMS itself as a machining process technology.

I have observed that British FMSs have been introduced for a wide variety of purposes. At the outset it must be accepted that a flexible manufacturing system, comprising a number of work stations, is likely to become less adaptable (in terms of the component spectrum machinable) the larger it becomes and the more specialised its constituent work stations. Any FMS is therefore semi-dedicated in comparison with stand-alone conventional or CNC machine tools. Thus there is a need for a choice of manufacturing objectives and the types of technical flexibility sought.

There is no necessary inconsistency, therefore, between an FMS being used as a modified transfer line, with the capability to produce a limited component spectrum at any of a number of identical machine tools (such as Plant D), or to manufacture an expanding range of products on dissimilar machine tools (such as Plant G). Most plants fell somewhere between these two extremes, although there was certainly a tendency to prefer short-term quantitative gains such as reductions in work in progress levels and higher machine utilisation. The point is, however, that the on-going skill requirements of FMS operators are likely to be lower if the system is treated as static in terms of its component profile, as has been found in many American systems. The American-owned Plant D, the only plant to use exclusively semi-skilled operators for production purposes, was the only plant to fit this mould particularly closely. The use of such personnel did not preclude engineers satisfactorily amending programs to incorporate design changes into components machined. This form of adaptability, which I have called modification flexibility, is precisely that seized on by Shaiken et al (1986) and some of the less rigorous prophets of "neo-Fordism" as evidence that versatile marketing strategies do not require a high level of skills and labour flexibility.

But, if one looks at what I have termed product flexibility (the ability to use FMS to expand the product range), evidence from most plants (and particularly G, P and R) suggests that the continued expertise of skilled workers is essential in enabling the use of FMS to respond speedily to changes in product demand. Where the necessary skills are lacking (as at Plant H), or demarcations are hindering the transfer of information between personnel (as at Plant R under its new management), the response times to new flexibility requirements will be slower.

Neither were productivity or overall manufacturing control found to be aided by excessive labour demarcations or management unwillingness to allow operators to employ their skills in problem-solving autonomously. The complexity of FMS has created a profusion of new sources of error in the technology which, because of its unprecedented level of integration, is reflected in the difficulty of detecting the origin of defects in components coming off the system (particularly when identical machine tools are used). Paradoxically, as Blumberg and Gerwin (1984) also find, the cost of attempting to compensate by mechanised means for all possible sources of product error - and thus limit the necessity for skilled intervention to rectify matters - is potentially lengthier cycle times and the creation of new process-related problems.

In practice it is by and large still valuable to permit genuine devolution of FMS control procedures to skilled FMS operatives in order to enable the achievement of productivity, manufacturing control and the more extensive flexibility benefits. To be sure, this is often conceded somewhat reluctantly, particularly in those larger plants (such as A and L) where labour control objectives have become more institutionalised. And certainly managers tend to undertake the policy of devolving labour control in British FMSs very much in response to *ad hoc* production pressures rather than as part of a preconceived plan.

My argument, based on the importance of the particular manufacturing objectives desired from FMS, and the specificity of pre-existing policies for industrial relations and labour control, contradicts the stress of advocates of flexible specialisation, and many of those proposing "neo-Fordism", upon coherent and well-coordinated linked strategies for marketing and manufacturing objectives and work organisation. We can only point to a tendency for the reduction of craft control in FMS, largely due to institutional factors in the firms that have been able to afford such systems, which only in the most extreme (and atypical) cases of mechanisation (Plants B and D) denies an input for craft skill.

The take-up of FMS in British small-batch manufacturing firms has been slack as yet in comparison with the potential for its application in small-batch engineering (see also Jones and Scott 1985). Large-scale systems, which can then be electronically integrated with other parts of the manufacturing process, have been confined to the biggest firms with the necessary financial and engineering resources to undertake such projects. For the majority of batch engineering firms smaller-scale, less mechanised, systems incorporating a pivotal role for skilled workers in extracting the optimum performance are likely to be more affordable and appropriate. Of necessity this study has only been able to draw its conclusions from observation of FMS in its formative stages. However, the indication is that as FMS technology becomes more widespread, and is fully mastered by manufacturing managers and engineers, the value of relaxing direct labour controls is more likely to be appreciated. This does not preclude the likelihood of a polarisation of forms of work organisation, as previously occurred with CNC. This thesis demonstrates that, even in flexible manufacturing systems, the eclipse of craft machining skills is an unlikely prospect for the foreseeable future.

FOOTNOTES

CHAPTER ONE: Introduction

[1] See Avlonitis and Parkinson (1983), Bylinsky (1983), Hatvany et al (1983), King (1984), Mitchell (1984) *inter alia*.

[2] See especially Ashburn (1986), Hirschhorn (1985), Ingersoll Engineers (1985) and US Congress, Office of Technology Assessment (1984) for recent studies of the introduction of advanced manufacturing technology into manufacturing companies.

[3] See especially Berger and Piore (1980), Piore and Sabel (1984), Sabel (1982), and Sabel and Zeitlin (1985).

[4] It is reasonable to assume that the recession and changes in product markets of recent years have further increased the proportion of small-batch production within engineering manufacture. This cannot, however, be conclusively proved owing to the lack of statistics.

[5] A number of recent reports by the National Economic Development Office provide a wealth of detailed evidence of market fragmentation, and changing product and manufacturing requirements, in sectors of British small-

batch engineering. See National Economic Development Office, Diesel Engines Economic Development Committee (1984), National Economic Development Office, Heavy Electrical Machinery Economic Development Committee (1983), and National Economic Development Office, Technology, Skills and Manpower Group (1985) *inter alia*.

[6] See for example Altschuler et al's (1984) discussion of these two possibilities applied to the evolution of the automobile industry in the coming decade for a concrete example of this dilemma.

[7] For discussion about the link between manufacturing and corporate strategy as a whole see especially the pioneering work of Skinner (1978) and the subsequent debate, mainly in the pages of the Harvard Business Review. See the collection of papers in Kantrow (1982). Further discussion can be found in Slack (1984).

[8] The formation of this hypothesis was influenced by Littler and Salaman's (1984) contention that "design space" for alteration of job design exists when a technology is first introduced, but disappears in practice once a particular pattern has been established and accepted as the norm.

[9] Useful discussions of FMS technology can be found in Anon (1983a), Charles Stark Draper Laboratory (1984), Hartley

(1984), Ingersoll Engineers (1982), Jablonowski (1985b), and Ranky (1983).

[10] To preserve the anonymity of case study plants (codenamed from A through to Z) sources of articles in technical journals on named British FMSs visited will not be cited. With few exceptions these articles have in any case proved grossly inaccurate regarding the labour requirements of such systems. To give a not atypical example, one article on Plant A reports confidently that it requires staffing by only two workers for each of three shifts. In fact, when the plant was visited the operating team was found to consist of twelve direct workers on the one shift being operated!

CHAPTER TWO: The research project: flexible manufacturing systems

[1] Definitions of FMS in the literature fall into two classes. Some emphasise the possession of a set technological configuration of equipment. For examples see de Barr (1985), Department of Trade and Industry (1984), and NEDO. Advanced Manufacturing Systems Group (1984). Other definitions prefer the more abstract view that FMS is "a way of thinking" about organising the manufacturing process. These include Charlish (1983), Cranfield FMS Group (1984), Dempsey (1983), Hartley (1984), and Jablonowski (1985b).

[2] In the full sense of the term flexible manufacturing systems are intended to encompass application to a wide range of manufacturing processes, including machining, sheet-metal working, paint-spraying, assembly and others (Hartley 1984; Ingersoll Engineers 1982). To date only the first of these applications has shown growth of any significance whatsoever. This is largely because of the technological maturity of computer numerical control in the metalcutting sector in comparison to the levels of mechanisation currently achievable in these other uses.

[3] This claim to originality has been belatedly buttressed by the controversial granting of a US Patent in 1985. At the time of writing (June 1987) several American firms operating FMSs are in the process of establishing a fund to finance contesting this patent in the courts!

[4] The history of Molins System 24, its demise, and its exact location as a "Fordist", "neo-Fordist" or "post-Fordist" production system are interesting subjects in their own right, although not strictly relevant here. Accordingly, these subjects are considered in a paper currently in preparation by the author. Analysis is hindered both by the paucity of available information and the considerable internal contradictions in the writings of the main source, system designer Theo Williamson, on the system's labour implications. Variously, Williamson seems to put forward

views influenced by Taylorite, "post-industrial" and sociotechnical perspectives. See Williamson (1967, 1968a, 1968b, 1968c, 1972).

[5] Table 1 is compiled from fieldwork evidence and published information in The Engineer, The FMS Magazine, Metalworking Production, and Production Engineer *inter alia*. Thirteen of the projects (ten companies) included in Table 1 had not been announced when fieldwork was completed in August 1985.

[6] The observed diversity of FMS applications has led to what Bignell et al (1985, pp 99-100) rightly consider a largely sterile, though prolific, debate on the classification of FMS which has tended to transfer focus away from the more crucial subject of flexibility in manufacturing. Groover (1980) and Jelinek and Goldhar (1983) have tried to subdivide the practical manifestations of flexible manufacturing systems by contrasting respectively "dedicated FMS" or "programmable systems" (what are really in effect modified transfer lines) with "random FMS" or "flexible systems", which refers to those systems undertaking manufacture of wider product ranges and volumes. Browne et al (1984) and Dupont-Gatelmand (1982) have also introduced their own, similar, forms of classification. Aside from the dubious merits of such endeavours, these classifications inevitably result in a high degree of overlap between the different categories of

FMS proposed. In Jelinek and Goldhar's (1983) classification, for instance, it is never explained when, and under what circumstances, a "programmable system" becomes a "flexible system"?

[7] Benchmark Research (1985, pp 13-14), Bessant and Dickson (1982b), Capes (1985), Harrison and Dunn (1986), Pullin (1986b), Rodger (1986), Ross (1981), and Wyles (1983) among others, discuss the lack of diffusion of advanced manufacturing technologies such as FMS. See also the additional references cited in the body of the text.

[8] It has been suggested that payback periods of three to seven years are realistic expectations for FMS (Anon 1984). Certainly FMSs are very expensive investments. Current British systems have cost between about £600,000 and £7 million, with an average figure of probably some £3 million. In view of this an interesting sidelight of the fieldwork evidence was the discovery that the availability of government support for FMS was the factor decisively influencing purchase in a large number of cases.

[9] Evidence from two of the first firms studied in this research illustrates these reasons for the lack of take-up of FMS. Both of these firms originally had a definite plan for the installation of FMS but were subsequently either rethinking the initial concept or had abandoned the plan

altogether. At Plant T a plan for linking a lathe and machining centre by FMS had been abandoned. A number of reasons were given for the abandonment of the FMS proposal. In the first place the project had been "championed" by the company's manufacturing director and general manager, both of whom left the company during an early stage of the planning. There was little support for the FMS idea from the replacement manufacturing management personnel, who viewed the project as overambitious and associated it with other alleged failings of the personnel who had left.

The project was felt to be unrealistically ambitious for a number of reasons. Little expertise existed on the problems of interlinking machining centres and turning machines in an FMS, especially the different handling problems posed by prismatic and turned components. It was also felt that too much of the considerable developmental work needed had been left to the company (who claimed to have insufficient time for this) rather than the supplier. Finally it was also felt that the company's manufacturing environment resembled a job-shop (with average batch sizes of about fifty) too much to derive any benefit from the higher volumes thought to be necessary for FMS. Furthermore the company machined very few parts requiring operations on both machining centre and lathe, and thus no justification could be provided for the proposed interlinking conveyor.

At Plant X lack of planning time, due to an attempt to have the FMS working in time for a machine tool exhibition in mid-1984, resulted in the original FMS plan having to be abandoned as too ambitious. At the time of interview the company was intending to produce a more feasible, scaled down concept. One of the major problems with the initial scheme had been an underestimation of the costs of providing tooling and other services to allow the flexibility to produce the planned components in minimal batch sizes in order to achieve the main aim of reducing work in progress.

[10] Quantitative methods of investigation were felt to be inappropriate for this research project. Quantitative methods seemed to be unable to effectively cope with the complexities and ambiguities of the introduction of new technologies into the production process, or to capture the essential subjectivity of feelings towards the process of technical change on the part of those affected. Such methods also appeared unable to give expression to the uneasy mixture of feelings and contradictory beliefs held even by the same participants in this process. For instance, a questionnaire survey administered by Blumberg and Gerwin (1981) to shopfloor workers on an American FMS informs us that a majority of those surveyed feel they have skills they would like to use but now cannot. On its own, however, this information is not of much use. It neither

tells us what these skills might be, whether all the workers are referring to the same types of skill, nor even gives us any information to judge how justified their claims of redundant skill may be.

[11] It was believed that semi-structured face-to-face interviews would be the best way of gaining the subjects' initial cooperation. It was also felt to be the most flexible way of adapting to the many differences between the plants studied, and pursuing relevant issues in greater depth as they arose. The paucity of conclusions that a recent structured qualitative telephone interview survey (Benchmark Research 1985) was able to draw appears to have subsequently vindicated the correctness of this original decision. This survey aimed to establish details of diffusion of advanced manufacturing technology, understanding of the terms conventionally in use, reasons for lack of diffusion and suggestions to aid introduction. The combination of tightly structured questions, the difficulties posed by a telephone interview format, and a very diffuse subject and range of interviewees, result in merely trivial conclusions, in this author's opinion.

[12] Access proved relatively unproblematic, usually being obtainable by means of a telephone call to relevant production engineers. A certain amount of delay in actually arranging interviews (almost a year and a half in the most

extreme case), owing to the early stages of many of these projects, was however fairly common. Only in one case was access actually refused.

CHAPTER THREE: Understanding "automation" in manufacturing

[1] I am grateful to Mr John Styles of the School of Humanities and Social Sciences, University of Bath, for helping to clarify a number of points concerning the "American system" of manufacture.

[2] Taylorism has been a much discussed and abused phenomenon. Good expositions can be found in Rose (1975), Kelly (1982b) and Littler (1978, 1982). Littler (1982) is particularly useful in questioning the scale of the direct influence of Taylorism. The idea that Taylorism involved the extreme subdivision of labour appears to be attributable to Braverman (1974) and also to claims made by Davis and Taylor (eds.) (1972) (see Littler 1978). Kelly (1978b, 1982b) has convincingly argued that maximum subdivision of labour was no more integral to Taylor's system than to any other management approach. The principle of the division of labour dates back after all to Adam Smith (1974) and Charles Babbage (see Council for Science and Society 1981, pp 12-13). Taylorism did undoubtedly divide up the conception and management of tasks from their execution. To perform the former set of tasks Taylorism introduced a new

bureaucracy of indirectly productive personnel.

[3] Fordism had other unique features also. One of these was payment of high wages to many of the workers (known as the "Five Dollar Day"). This was partly a compensation for the soul-destroying tedium of the jobs Ford had created. Also, though, it was intended to help provide the purchasing power to form a mass market for Ford's cars. A concern quite foreign to Taylor with the moral well-being and behaviour of his employees outside of the factory gates was also a feature of Fordism. See Gartman (1979) and Hounshell (1984) for accounts of Ford's production system.

[4] For all types of automation concerning us in this thesis the source of basic motive power is provided by electricity. Clarity will therefore be aided by discounting power technology as a variable.

[5] In fact the self-acting mule replaced complex human control skills by eliminating the need for them rather than by trying to imitate them (see also the discussion in Chapter Three). Despite giving this example the Council for Science and Society (1981, p18) go on to argue the case for preserving a distinction between mechanisation and automation on the logically weak grounds that the imitation of human feedback abilities is now better understood!

CHAPTER FOUR: Mechanisation, skills and the division of labour

[1] Useful and concise reviews of the debate on the social analysis of skill can be found in Littler (1982) and Rolfe (1986). The following account draws considerably on these sources.

[2] Similiar distinctions have been drawn by Beechey (1982) and Cockburn (1983), who also point out that these are often used interchangeably when in fact they mean rather different things.

[3] Occasionally such approaches have also attempted to incorporate and measure what they term discretionary skills, by which is usually meant the application of discernment and flexibility in the method of achieving a given task. See for example Hazlehurst et al (1969). This is a confusing addition, as it once again introduces extrinsic factors connected to the division of labour and technology used.

[4] Even in this theory some degree of technical basis to skill is rarely completely ruled out. See Littler (1982, pp 9-11).

[5] See Turner (1962), especially pp 110-114) and also Lazonick (1979).

[6] The possession of skill may not lead to control if management also possesses the necessary job knowledge. However, see the discussion in section iv) on tacit knowledge, which may limit management's ability to delimit workers' control over the labour process. Conversely it is possible that the possession of control over one's labour process may not lead to skill, as for example in some agricultural work.

[7] See Stinchcombe (1959) for a comparison of decision-making structures under craft and mass preoduction.

[8] It is ironic that those proposing a generalised deskilling cite as their most frequent and typical example the highly sub-divided labour of workers on car assembly lines in view of the relatively small numbers so employed. In Blauner's (1964) study of the assembly line worker he has to note that in 1959 only 18% of U.S. car workers were employed on assembly lines, a proportion certain to have further declined as a result of the substitution of capital for labour.

[9] Braverman's approach has been subsequently applied to a number of industries (see especially Zimbalist (ed.) 1979). More recently, several writers such as Cooley (1980) and Shaiken (1985) have been responsible for popularised accounts of the application of microprocessor-based

technologies that draw heavily on Braverman's approach.

[10] Braverman's thesis has generated an extensive literature of its own, which has been critically reviewed by Thompson (1983) and Storey (1983). For further criticisms of Braverman's approach see notably Wood (ed.) (1982) and Salaman and Littler (1982).

[11] We wish to differ from Manwaring and Wood's otherwise useful account of tacit skill in their contention that: "Tacit skills are tied to the firm or industry... unlike the craft skills of the apprentice trained worker." (Manwaring and Wood 1985, p190). By so saying, Manwaring and Wood limit the use of the concept of tacit skill as an analytical tool to those semi-skilled workers in a firm's internal labour market. Such workers' skills are firm- and process-specific, informally learnt on the job itself, and not readily transferable elsewhere (Doeringer and Piore (1971). Presumably Manwaring and Wood take this view on the basis that, as Berger and Piore (1980, pp 19-21) say, craft skills are required to be wide-ranging rather than process specific, and are characterised by a need to use abstract principles (usually inculcated by a period of formal apprenticeship) to independently solve a spectrum of problems. Craft workers can thereby exercise craft controls based on social exclusion as discussed above in section ii). Here we agree instead with Wilensky (1964, p149) that

craft control (in the sense of exclusive jurisdiction) is also based on the power conferred by the posession of necessary, but relatively inaccessible, tacit knowledge. Yet the possibility that craft workers may be able to exert craft control over the labour process does not override the fact that they also possess and exercise tacit knowledge over a wide variety of tasks. The bulk of their necessary job learning is acquired practically in the work situation, as is the case with the semi-skilled workers studied by Kusterer and Manwaring and Wood. Where the kind of tacit skills exercised by craft workers will differ from semi-skilled workers is in the greater likelihood that those employed by the former will consist more of "development of perceptual accuracy, predictive judgement, and the knowledge of decision rules" in fault prevention, and:

> the ability to select, and continually review and control, (planning) methods which are appropriate to the successful completion of a given task. (Engineering Industry Training Board 1971, p22).

[12] See also Perrow's (1970, pp 75-80) use of the concepts of "variability" and "search". "Variability" refers to the number of exceptions encountered in production processes. "Search" refers to the either formal or tacit basis of the mental processes that must be employed to manage this

variability.

[13] See for example Jaikumar (1984, p34), Kelley (1984), and Shaiken (1985) for descriptions of this phenomenon. Polanyi (1962, p604) and Polanyi and Prosch (1975, p33) contain further illustrations of tacit knowledge.

[14] Wilkinson (1983) studies this phase of introduction.

[15] One notable and early exception is Williamson (1972), the inventor of Molins System 24, who claims that FMS technology is capable of extending what he sees as the labour benefits of process flow technology to batch manufacturing industries. See also the discussion in Chapter Two.

[16] See Buchanan (1979, pp 13-14), Klein (1978) and Littler and Salaman (1984) for discussion of the wide influence of Taylorist principles on job design. Piore (1968a) and Davis, Canter and Hoffmann (1955), followed up by Taylor (1979), provide empirical evidence of the pervasiveness of this influence among industrial engineers.

[17] The continued existence of these low-skilled manual jobs should come as no surprise. Even at the time of Blauner's (1964) study only 38% of the manual jobs in the oil refining industry comprised skilled grade workers.

[18] For criticisms of the sociotechnical approach see especially Buchanan (1979), Kelly (1978a, 1982a), Silverman (1970), and van der Zwaan (1975).

[19] Child (1985, pp 134-135), summarising previous research, identifies an additional three factors which are likely to influence managerial preferences for strategies for labour control, and therefore forms of work organisation and skill requirements. These factors - government policy, institutional industrial relations frameworks, and national cultural factors - operate primarily at the level of the nation-state and are therefore largely outside the scope of direct investigation in this thesis. Several cross-national studies of skills, managerial control systems and technology have however alluded to the importance of these factors. These studies will be introduced as appropriate in later chapters.

[20] See Burnes (1984) and Wall et al (1984) for a case study of one firm's adoption of two generations of CNC machine tool that illustrates both these points in practice.

[21] Wilkinson argues this against the view that available technologies determine the labour market, which he terms the "impact of innovations" approach. He attributes this school of thought particularly to the work of the Science Policy Research Unit at Sussex University, although he

concedes that their later work moves away from this position to some degree. However, he rather unfairly ignores the fact that his prime example of the "impact" approach (Bell 1972) claims to have found evidence which would support the contrary position. So, although proceeding "on the assumption that technology is a major determinant of the type of employment that is available" Bell concludes that:

> Company and industry objectives to... minimise difficulties associated with the labour market are, to a greater or lesser extent, objectives also of those who develop new technologies.... the labour market may partly determine the technologies in use rather than the reverse... (Bell 1972, p92).

[22] Other evidence (Challis 1982; Sorge et al 1983) discussed in later chapters throws doubt on the accordance of primacy to labour substitution objectives in the adoption of certain technologies.

CHAPTER FIVE: The labour process of small-batch machining

[1] We define mechanical engineering according to Standard Industrial Classification sub-headings 331-349 inclusive.

[2] Harrington (1973, Chapters 2 and 3) and Kelley (1984) provide fuller explanations of these points. Even today, however, considerable informal overlapping of departmental specialisms takes place within machine shops. Shaiken (1985, p19), for example, observes that it is commonplace for craft workers to redesign from component drawings parts drawn by draughtsmen when the practical experience of the machinists suggests that the parts cannot be machined in their originally drafted form.

[3] This section draws considerably on information contained in Burawoy (1979, especially pp 51-57); Engineering Industry Training Board (1980c); Kelley (1984, pp 38-44) and numerous EITB Module Instruction Manuals. It should be treated as indicative of the nature of craft work as research indicates that there are considerable differences in the extent of work planning, use of written information, etc, undertaken by craft workers (Engineering Industry Training Board 1980c). Kelley includes fabrication and assembly tasks as part of the contemporary machining labour process. I have chosen to omit this on the grounds that, unlike the other tasks described, no assembly tasks were performed by machinists in any of the machine shops visited.

[4] See for example EITB. H2 (n.d., pp 10-20).

[5] The information in Table 2 is adapted from various Engineering Industry Training Board Module Instruction Manuals.

[6] See Shaiken (1980, p9); Jaikumar (1984, p34); cf. Polanyi (1958, p101).

[7] See for example EITB. H27 (n.d., p97); EITB. H29 (n.d., pp 104-105).

[8] The militancy of craft workers, documented by Goodrich (1975), Hinton (1973), and Jefferys (1946), has led these and other radical writers (notably Braverman (1974) and some of his disciples) to argue that prospective revolutionary socialist sentiments are part of the craft tradition.

[9] See Jefferys (1946) and More (1980).

[10] Some management commentators have argued in recent years that this division of labour and its effects constitute another disadvantage to the functional organisation of production (Edwards 1971; Skinner 1971; Williamson 1968b; 1972; inter alia). Marglin (1976) argues that such "problems" were accepted as a part of the production system at its outset.

[11] The main craft union in engineering has indulged in increasingly regular name changes as the result of various amalgamations and schisms. The most important of these changes for our purposes are as follows. From 1851 to 1920 the main craft union for machinists was known as the Amalgamated Society of Engineers (ASE). Then, until 1967 it was called the Amalgamated Engineering Union (AEU). After a three-year interlude with another name as a result of further amalgamations, from 1970 it entered into a loose federation known overall as the Amalgamated Union of Engineering Workers (AUEW). The old AEU became the engineering section of this (AUEW (ES)). The new, white-collar, part of this federation became known as its Technical and Supervisory Section (AUEW - TASS). This section recruited white-collar "staff" employees in engineering companies, such as draughtsmen and part programmers. Following a troubled relationship the federation finally dissolved in early 1986, with the craft section reverting to the former name (AEU) and the white-collar section now being simply known as TASS.

[12] The Institute of Manpower Studies' model of the "flexible firm" makes a useful distinction between three forms of labour flexibility. These are functional, numerical and financial flexibility (Atkinson 1985). In this study we are mainly concerned with management attempts to gain functional flexibility, which refers to the ability to more

easily redeploy or transfer employees between a number of types of task or activity. Of the other two types of labour flexibility mentioned by Atkinson (1985, pp 11-12), numerical flexibility is defined as ability to change either numbers employed or shift patterns, etc; and financial flexibility as ability to reflect in wages the state of supply and demand in the external labour market.

[13] The introduction of new technology is one of the most common reasons behind a decision to locate on greenfield sites, combined with a consequent wish to streamline working practices and organisation (Incomes Data Services 1984b). See also Daniel (1987), who finds that changes in working practices (organisational change) are only widespread and readily accepted when they occur in connection with technical changes.

[14] The variety inherent in small-batch production makes it difficult to justify setting up machines to produce components solely in the quantity required. The economic batch quantity (EBQ) for a component is the minimum batch size calculated to be necessary to recoup the costs incurred in the time and skill required to set up machines for a particular part. Those items not immediately required from a batch will of course go into stock. This inventory represents capital unavailable for use for more productive purposes.

CHAPTER SIX: Technical and organisational change in small-batch machining

[1] References to "numerical control" in this chapter concern this type of programmable technology in general (i.e. NC, CNC and DNC). References to "NC" concern solely the original, paper tape-controlled variant of numerical controlled machine tools.

[2] See Gallagher and Knight (1986) and Welch and Enang (1982) for discussions of the role of group technology as a precursor of FMS. For similar discussion tracing the development of FMS through NC and CNC see for example Cook (1975), Gunn (1982) and McKeown (1981).

[3] Lack of diffusion has been most marked in the case of GT, where optimistic estimates suggest that no more than 10% of batch engineering companies ever adopted the system, even in its heyday of the early 'seventies. Indeed some of these subsequently returned to functional organisation (Gill 1985; Swords-Isherwood and Senker 1978), often preferring to pursue improvements in efficiency through the use of numerical control. GT and NC were originally pursued as alternative paths of development, despite the fact that some commentators argued - as with FMS now - that the greatest manufacturing benefits came from using GT and NC together. Crookhall (1968), for example, sees the effective

usage of NC being dependent on the rationalisation of the type of components which it is used to machine. By contrast with GT, diffusion of NC machine tools has gradually increased, albeit from a very low base. Despite the particularly severe effect of the recession on the engineering industry sales of this type of machine accounted for some 32% of total domestic machine tool sales in 1984 (Machine Tool Trades Association 1985). Nevertheless one authoritative recent claim suggests that 4% or less of the British machine tool population consists of NC and CNC machines (Holland 1986a).

[4] See New and Myers' (1986) study of British manufacturing competitiveness. This finds that firms' current performance on delivery reliability and manufacturing throughput times is little better (and, in some cases, worse) than in 1975. Overall it concludes that British manufacturing companies are concentrating disproportionately on reducing the costs of production, and especially direct labour costs, to the exclusion of innovating and improving products.

[5] See for example Blois (1984), Gold (1982), Goldhar (1986), Jaikumar (1986) and Jelinek and Goldhar (1983), all of whom argue that deliberate and preemptive use of the "strategic" manufacturing advantages afforded by flexible manufacturing technology is the key to its successful exploitation.

[6] For instance, Crookhall (1968) observes that the availability of intangible benefits from numerically controlled machine tools such as improved product consistency and quality, and the ability to machine more complex workpieces, was often unanticipated by firms using traditional methods of justification for new equipment based on labour cost. In such cases firms found difficulty in taking these new forms of benefit into account, and thus potential business advantages remained unrecognised or fell by the wayside.

[7] Originally, and particularly in the pioneering work of the Soviet engineer Mitrofanov (1966), group technology was conceived of largely as a technical, predominantly mathemetical, aid to part coding and classification.

[8] As Edwards (1974a) says, originally GT was only applied at the level of the individual machine tool, and above all to two-axis, lathe work (which is easiest to classify by shape), as another means of incrementally reducing set-up times. Thus it did not presuppose the abandonment of functional organisation (Edwards 1974b).

[9] Nevertheless Fazakerley (1974) denies that labour flexibility between machine tools, and a necessity for the dispersal of skills related to particular machines, is central to GT applications.

[10] According to Burbidge (1976, p3) such GT production cells share seven common characteristics. A cell should contain a given team of workers (of around ten members); produce a specified "family" or set of products; and be equipped with a specified set of machines and/or other production equipment. In addition facilities should be laid out in one reserved area; the workers in the group share a common product output target; and each group can usually work independently once production materials have been received.

[11] See Burbidge (1979), Edwards (1980), inter alia. Criticisms of GT are considerably harder to find in the engineering literature. Rare exceptions are two articles by former GT proponents Leonard and Rathmill (1977a, 1977b), who give detailed reasons for rejecting the appropriateness of group technology cells in batch production. It is noteworthy that Bornat (1978) and Green (1978) appear to be unaware of these contributions, which nullify some of the latters' conclusions.

[12] This approach originates in Marx (1976) and Braverman (1974). Brighton Labour Process Group (1977) extends the critique to what it considers to be the idealist claims of the socio-technical school and examples of the "humanisation of work". For Brighton Labour Process Group, an appearance of worker control and job enlargement conceals what it sees as the fact that this "humanisation"

can only be enabled by the prior deskilling and fragmentation of labour routines. See Blackburn et al (1985), Bornat (1978), and Green (1978) for an application of these arguments to group technology.

[13] In view of the later argument in this chapter it is interesting to note that Leonard and Rathmill (1977a) believe the same applies to DNC systems.

[14] Of the plants in our study, Plant J investigated the feasibility of GT in the 'seventies but did not proceed further, because of the work thought to be involved in classifying a wide variety of parts into families. Only Plants C and X had actually adopted a group technology approach in their machine shops. As also appeared to be the case with these firm's introduction of FMS, adoption of GT was spearheaded by a small number of manufacturing managers who had been "converted" to the approach.

[15] Proponents of GT have tended to claim, with limited plausibility, that the system failed because of a misunderstanding of what it actually was. See for example Burbidge (1978).

[16] Compare this with Atkinson and Meager (1986), who also find trade demarcations and training costs to be the two factors limiting the wider pursuit of labour flexibility today.

[17] A considerably less common form of numerical control, known as record/playback, was also experimentally developed at this time. Noble (1979, 1985) in particular argues that record/playback was not commercially developed because it retained craft skill in the hands of the machinist, thus denying management control of the labour process. In practice the reasons advanced for the lack of development of record/playback in the past, and its superiority over NC in terms of machinists' skill retention, seem unconvincing. As Sabel (1982, pp 64-65) points out, technical obstacles did exist to the applicability of record/playback in the aerospace sector for which the alternative method of NC was eventually developed. Even though such difficulties would be less significant for the majority of machining applications there remains no reason why labour could not be sub-divided to render the use of record/playback technology "deskilling". This could be achieved by the assignment of one skilled machinist to make the recording of the cutting of the first part. For all subsequent runs of the part concerned the use of this method represents deskilling by virtue of the operator's skill being built into the machine's program, as indeed Rosenbrock (1982, pp 107-108) admits with reference to robots programmed by this method.

Moreover, the extent of the skills exercisable would be variable depending on such factors as the frequency with which new programs must be made, batch sizes, etc. It would be repeating Braverman's mistake of overemphasising equipment suppliers' claims to argue that record/playback technology will invariably be used according to "deskilling" criteria. Yet some suppliers are indeed explicitly marketing machine tools with record/playback facility with claims that they can be used to deskill operators (to dispel any doubts see for example the advertisement by Formtecnic Machine Tools in 'Metalworking Production', March 1986, p98)!

It is interesting, therefore, that in recent years engineers influenced by "socio-technical" ideas, most notably a team at the University of Manchester Institute of Science and Technology, have led a resurgence of interest in record/playback as a means of retaining craft skills on the shopfloor in NC (and indeed in FMS) operation (Boon 1981; Rosenbrock 1981, 1983). In view of this renewed interest it is striking how little (if at all) the above criticisms of record/playback have been taken on board by those endorsing the UMIST project.

[18] At a purely technical level operator programming by MDI is becoming increasingly feasible as more powerful control systems are developed, enabling more of the mundane calculations necessary in programming to be performed by the computer software. Programs are created by the

machinist keying in information as requested in a set sequence of steps. With the latest control systems the machinist can then visualise and verify the program created by means of its simulation in graphic form on a visual display at machine level.

[19] In turning work the four-axis CNC lathe is a parallel development to the machining centre. This lathe possesses two turrets of tools and can thus work on a component with two tools simultaneously. Five-axis lathes capable of milling operations, etc, have also been developed (and indeed were in the FMS at Plant R) but are not yet believed to be commercially available.

[20] Ross (1981, p30) notes that set-up times were normally longer for NC than for conventional machine tools, and thus EBQs were often larger.

[21] See for example Nicholas (1984, pp 233-234), Scott (1985), US Congress. Office of Technology Assessment (1984, p235). Further evidence supporting the argument in this section about CNC machinists' skills in the small-batch environment can be found in detailed case studies by Buchanan (1985) and Wilson (1985).

[22] The everyday control and monitoring of operations with CNC is based upon symbols, numbers and written commands

displayed on the control panel rather than by direct "feel", as was the case with conventional machine tools. Thus CNC presupposes an additional requirement for literacy and numeracy over and above the ability to interpret production drawings and instruction cards, even if machinists do not program or edit tapes.

[23] Overwhelming evidence of the importance of part programmers having previous machining experience was gained during the fieldwork for this study, occasionally as a result of bitter experience with part programmers unversed in machining (as, for instance, in the recent past at the main site at Plant R). The recency of direct experience also seems to be important, as even ex-machinists tend to gradually forget everyday machining "know-how" when they leave the shopfloor for positions as part programmers. This was mentioned by both operators and programmers at a number of plants. For example, at one of the CNC plants visited, Plant Z, the machinists had a standing joke that the more time that passed since a programmer had been promoted from the shopfloor the faster their programs tended to run. As one operator commented:

> They start programming every job, no matter how flimsy and whatever it's made of, as if it were a solid aluminium block.

[24] Sorge et al's (1983) Anglo-German study of CNC applications finds significant cross-national differences in managers' control preferences, which partly determine whether or not operators are allowed to program. They relate the higher incidence of operator programming in German plants to a greater management willingness to devolve authority to craft workers. This, they suggest, is a function of the importance attached to vocational qualifications in Germany, and the greater integration of craft and technician training than in Britain.

For discussion of the importance of cross-national factors in aspects of industrial organisation in the USA and Japan see Jones (1985b, 1986a, 1986b). Other cross-national comparisons of the organisation of engineering firms can be found in Daly et al (1985), and Maurice et al (1980).

[25] Machinists tend to argue as follows: The technical design of CNC allows for operator input, and therefore such intervention must be intended. Furthermore, intervention is appropriate because skilled machinists (rather than programmers) have the best knowledge of machining, the idiosyncracies of particular machines, and the greatest accumulation of practical shopfloor experience. Machinists can therefore be trusted to partake in programming and editing. Programming is not too complex a task for operators, as current control systems are increasingly

simple, relatively easily and quickly learnt, and information is presented in a style with which operators are already familiar. Program construction by MDI is quicker, simpler and therefore cheaper than if office-based programming procedures are invoked. If a fault occurs in a program the operator should know how to rectify it, and is best placed to make the necessary alterations without the delay incurred by waiting for a programmer and having to explain the problem and/or amendments needed.

[26] Part programmers argue that operator programming is slow and creates machine downtime on very expensive capital equipment, as it is normally impossible to program a new job while an existing one is running. This obstacle to higher machine utilisation applies especially to complex jobs, which are more easily programmed away from the distractions of the shopfloor, thus eliminating the chance of programming in potentially costly mistakes. It is believed that programmers have a better technical programming ability than operators as a result of their training, and a greater grasp of the most efficient contemporary machining methods. Operators, it is said, tend to program on CNC using obsolete methods more suited to the conventional machines from which they graduated. Thus, for example, they will run jobs at metal removal rates well below those now possible. Alternatively, if operators are being paid on piece rates, it is argued that they will be

tempted to set dangerously excessive feed and speed rates. Finally, it is argued that changes made by operators to programs may not be communicated to programmers or operators on following shifts, who will waste valuable time in tracing faults that occur as a result of unnotified changes.

[27] Studies demonstrating a variety of possible patterns of skill deployment and the division of labour with CNC include Asher (1983), Burnes (1984), Elsaesser and Lindvall (1984), Rempp (1982), Shaiken (1985), Sorge et al (1983), Wall et al (1984) and Wilkinson (1983). Challis (1982) contains interesting responses to Sorge et al's work by representatives of CNC machine tool manufacturers, which indicates considerable diversity of belief within this influential interest group as to whether CNC is designed for on- or off-shopfloor programming.

[28] Hill (1981, pp 116-117) puts forward an exaggerated account of the "deskilling" of programming techniques to support his case that technological development is geared to the removal of control from successive occupational groups exercising pivotal positions in the production process. It is true that the latest control systems reduce the discretion employable in planning methods. For example, there is a need to follow a set order of procedures and therefore to be more methodical in planning than was the

case on conventional machines. The increase in proceduralisation is a commonly observed phenomenon of tasks centred on computers. However, Hill's example hardly supports his case if, as is argued here, machinists may thereby more easily regain some of the control they formerly exercised.

[29] See Dunn (1984a) for supporting evidence of two conflicting patterns of diffusion of CNC control systems in Britain depending on organisational preferences, and product requirements and range. Typically, companies that are small, operating in a job-shop environment or with a large proportion of fairly simple components are tending to opt for operator programming using MDI. Large companies with predictable production requirements, large batches, or complex components of exacting quality standards prefer the centralised response of off-shopfloor programming, minimal or no machinist intervention, and a preference for downloading programs from a powerful central DNC computer (known as a "host") to perfunctory CNC controls at machine level.

[30] Some idea of the possible scale of the quantitative benefits obtainable can be gleaned from a survey conducted by Bessant and Hayward (1986), who claim to have identified average reductions in lead times of 74%, work in progress reductions of 68% and increases in machine utilisation from

40% of available working time to 90%. These figures should be treated with greater caution than do the above authors, for they are frequently based on incomparable data, e.g. where the FMS is first used to machine a new product. However, such comparisons do establish a general principle that abnormally large manufacturing benefits of this type may be possible through FMS.

[31] Pullin's (1986b, p69) survey (which includes reasons for adoption of other forms of computerised automation as well) strikes a contrary note by downgrading the importance of quantitative aims somewhat. In descending order of importance Pullin cites increasing profits, improving product quality, reductions in labour cost, need to increase output, and inventory reduction as the main aims of introducing FMS. See Appendix Three for how these reasons rate in comparison with the systems in this study.

[32] The Automated Small Batch Production Committee's Technical Study mentions a reduction in lead times in its summary foreword, but actually seems to be referring to reductions in component throughput times if anything (National Engineering Laboratory 1978, p xiii) cf. pp 8-9). Thus quantitative benefits are again stressed.

[33] See Buzacott (1982), Browne et al (1984), Gerwin (1982), Gerwin and Leung (1980), Jaikumar (1984), Zelenovic (1982).

[34] It was thought most appropriate (although perhaps regrettable) to assemble a further classification of flexibility types specific to this research project. This was done because of a number of shortcomings found in the categorisations employed by the above authors. Some types appeared irrelevant (for example, Gerwin and Leung's (1980) concept of "customising flexibility" in the systems studied) or insufficiently precise (such as Jaikumar's (1984) "product flexibility"). Additionally previously unidentified usages were recorded (such as what I have termed "size flexibility").

[35] Rembold et al's (1985) classification of FMSs distinguishes between systems according to the criteria of whether or not parts must be presented sequentially to a set order of work stations. In the former case the FMS would not possess routing flexibility: in the latter it would.

[36] The opposite may of course apply equally: FMS may be found to be insufficiently flexible to meet the criteria for which it was originally specified. This was noted at several plants.

CHAPTER SEVEN: Changes in tasks, skills, and work roles in FMS

[1] The tendency of FMS to force the more precise definition of hitherto haphazard manufacturing procedures was noted at

several plants. At Plant G, for example, production drawings used to be highly idiosyncratic before the advent of the FMS, suffering such mistakes as the omission of tolerances. Matters worked in practice because the craft workers on the shopfloor subconsciously adapted, using their own accumulated knowledge and experience. The FMS is forcing a return to more standard engineering drawing procedure. The method to be followed for part programming has also been standardised at this plant to obviate inconsistencies caused by the different approaches of the two programmers.

[2] As the fieldwork evidence will suggest, the extent to which one can describe any British FMS as "typical" is debateable, as technical configurations vary considerably within the basic specification. The example given in this section is loosely based upon a hypothetical FMS comprising three or more machining centres, transportation within the system undertaken by AGV, and direct numerical control based in an adjoining room. On these criteria one can directly include the FMSs at Plants A, H and L; while most of the other systems studied differ in only minor details (such as type of transport system).

[3] Turned components, as handled by the FMSs at Plants K, M and R, cannot be loaded by this means because of their shape. In such cases components are manually loaded onto

conveyor belts or into loose fixtures for loading to machines by robotic means.

[4] This viewpoint is well illustrated in the following qoute from an engineer at Plant F:

> You try and limit human intervention down to a minimum and that is the idea of FMS to a large degree.... the thing that you're aiming to do is to increase the utilisation of those new machines. And to do that you take away the operator.

[5] See Bainbridge (1978) and Crossman (1960) for studies of the skills of operators of continuous processes.

[6] I am grateful to Dr Mark Dodgson of the Technical Change Centre, London, and to Dr Malcolm Hill of Loughborough University, for comments and criticisms received on this paper.

[7] See Scott (1985) for more detailed information and further discussion on manual intervention in setting-up at these plants.

[8] See for example Jaikumar (1984, 1986), Jones (1986a, 1986b), Jones and Scott (1985, 1986), Kelley (1985), Kohler

and Schultz-Wild (1983) and Remp (1982).

[9] Several firms, and Plants A, B, H and M in particular, observed that demarcations within their maintenance departments between hydraulic, electrical, electronic and mechanical specialisms were proving more difficult to eradicate than any inflexibility among craft-trained machinists.

CHAPTER EIGHT: The problem of labour control

[1] The loader will be allowed access to five data retrieval options. The programmer shares the system manager's password, and can use the whole system excepting the base software information, to which only the system manager himself has access.

[2] The one manufacturing engineer employed only works on one of the three shifts over which the FMS is intended to run, however. Thus this grade of worker is not on continuous call in case of problems.

[3] These low figures are rather deceptive, for of course considerable numbers of indirect labour provide necessary support for FMSs away from the shopfloor, such as in Production Engineering departments, etc. Indeed, one engineer at the FMS supplier, Plant F, categorically stated

that <u>overall</u> labour requirements with FMS were normally similar to those for stand-alone CNC machine tools.

[4] A small number of the workers employed at the plant either on a permanent basis or as temporary stand-ins from the headquarters plant have not found a high degree of flexibility to their tastes and have tended to perform one job only (such as final assembly, benchwork, or plating). In the extreme case a few workers have been deemed insufficiently willing or able to adapt and re-transferred to the headquarters plant.

[5] The evidence below from the author's study of Plant R is an amended version of work previously published in Jones and Scott (1986)

[6] There are two programmers only because of the large amount of programming work while the cell is being changed over. There will only be one programmer permanently with the system, therefore, and in the text below the second programmer, who was drafted in from the main site solely to perform this job, is not considered to be a part of the workgroup proper.

CHAPTER NINE: Productivity, flexibility and labour control

[1] Kelley's study encompasses other forms of programmable

machinery (notably NC machine tools) as well as FMS.

[2] See also Ingersoll Engineers (1982, pp 97-98), Jones (1985c, 1986a), and Jones and Scott (1986).

[3] The "technocentric participative" approach to work role management is exemplified by the American FMS case study codenamed "Alpha" discussed in Jones and Scott (1986, pp 357-360).

[4] Computer simulation packages, which allow personnel to test the consequences of courses of action in articial production situations, are sometimes available for operators to use (as at Plants A and L, for example). These have been found helpful in facilitating the learning process.

[5] It is perhaps noteworthy, in view of these suggested training times, that managers at Plant J conceded that their own FMS operator training programme should have been started sooner than it was.

[6] Compare also the American findings of Thompson and Scalpone (n.d.).

[7] Another important reason for the contemporary preference for an incremental (rather than the so-called "big bang")

approach to FMS installation is the possibility thereby of deferring the costs of introduction over a number of years. This approach allows curtailment of system expansion if expected funds or projected product demand do not materialise.

[8] The evidence below from the author's study of Plant R is an amended version of work previously published in Jones and Scott (1986)

CONCLUSION: The craft worker in flexible manufacturing systems

[1] This is no longer merely an academic point. For instance, the Japanese machine tool manufacturer Yamazaki is currently marketing a small-scale FMS explicitly designed for shopfloor management, programming and control.

APPENDIX ONE: FMS case study plants visited for project fieldwork

i) Overview

This appendix gives background details of the fifteen plants (Plants A to R) used as the principal data source for this study, and of the flexible manufacturing systems they operated. The information given is adapted from the format used in Jones and Scott (1985) (from which more detailed descriptions of Plants A, B, C, F, G, K, M, P and R can be obtained). In each case some basic information is firstly given about the company itself. This is followed by details about the introduction of the FMS and the technical configuration and features of the system. We also give information about the parts produced on the system and batch sizes. Finally brief information is given on the division of labour and composition of staffing within the FMS.

ii) Plant A

This system is one of the UK's earliest planned FMSs. The company is an important manufacturer of underground mining equipment organised into three operating divisions. Its total sales in 1985 were worth £170,000,000. One of the three divisions is responsible for the production of coal-cutting machinery. Its major customer is British Coal (at the time of interview still known as the National Coal Board). Following the end of the 1984/85 miners' strike the company's market has been expanding again, but at a lower rate than the company anticipated. The company would normally expect to produce about 1,000 coal-cutting machines per annum but at the time of interview was still only manufacturing (an averaged out annual figure of) 400 units per annum due to the effects of the strike. Thus the whole factory, including the FMS, is currently only working a single shift, and the double shift operation of the FMS that had been planned will not occur in the immediate future. Nevertheless, the firm has been able to bring back in-house machining work that was previously sub-contracted to outside companies, thus partially offsetting the drop in production volumes.

The coal-cutting machinery division of the company operates from two plants in the same geographical area of Scotland and one plant in Northern England. The company employs about 2,200 workers in total. The FMS in this study is located at the company's main Scottish plant, which is in a region of traditional industries (such as steel production) subject to considerable industrial decline in recent years. There are 1800 workers altogether on the site, of whom some 730 are directly involved in production.

Planning for the FMS started in 1981. The system was originally intended to be commissioned in July 1983 but a number of problems delayed commissioning to the turn of the year 1984/85. At the time of interview the FMS had been running on a single-shift production basis for about eight months. The whole system was supplied on a turnkey basis by the nearby Scottish subsidiary of a major American machine tool manufacturer with whom the customer had already previous experience with stand-alone machine tools. The total project was originally budgeted to cost £6,000,000 although costs ultimately escalated to £7,500,000, thus making it one of the largest FMS projects to date in Britain.

The system consists of six very large identical machining centres capable of handling prismatic parts within a two metre by one metre by one metre "envelope", each with a magazine for one hundred tools. A further three hundred tools are stored in the tool library area of the FMS, giving a total tool inventory of nine hundred. Locations of all tools, both in the machines and the tool library, are stored in the system software. The sixth and final machine in the system is equipped with a horizontal CNC facing head. The component units of the system can be run either automatically or manually. Policy is to run automatically as far as possible. The main exception to this is the facing head machine, the cycle for which must be started manually even though it is connected up to the DNC, from which its machining programs are downloaded.

The line of six machining centres is served by an automatic guided vehicle (AGV) controlled through impulses in the floor. The system has thirteen pallets, four feet by six feet in dimensions, which carry loads of up to two tons. These are coded for identification by the host computer. The FMS has twenty one dedicated fixtures. Behind the machines lies the load/unload area, castings store, fixturing store and tooling area.

The system is controlled by a DEC minicomputer situated in a raised control room overlooking the FMS. Software features are continually being updated both by the firm's own programmers and also students from a local technical college who havė been seconded to the firm as part of a joint scheme between company and academic institution. At the time of interview, for example, a graphics facility for the proving out of programs was being worked upon. In addition the software engineers have written a number of "utility programs" made to aid the running of the system. The biggest of these has been a utility program for the management of the tool warehouse. An extension of the software is also taking place to provide for the possible provision of a sister tool for every one currently in the system.

Parts required and due dates are keyed into the host computer manually. The computer then provides a suggested schedule (which can be overriden if desired) if it calculates that the parts can be produced on the FMS by the stipulated date. If it believes that production cannot be achieved in time then manual rescheduling must take place. When a schedule has been calculated it is printed out for the operators. Parts are loaded in accordance with this and the operator at the loading terminal signals the host that the part has been entered into the system. A crosschecking facility on the loading station (working according to a binary coding on the pallet) checks that the right pallet has been loaded.

Tool life is monitored by the assignment to each tool of a historic life. The DNC computer's tool management program monitors the progress of tools towards this level, and this information is made available to the system's operators on print-out. Probing is now available although its use is limited to checking critical bore sizes and broken tool detection on smaller tools used on the FMS. Further use is ruled out on the grounds that probing adds to the cycle time. Tools are pre-set on a toolsetting machine, which is connected to the host computer and automatically feeds back tool offsets to the latter.

In technical terms the FMS runs almost self-sufficiently from the rest of the plant's production facilities and has no call on outside equipment or personnel. There are two exceptions to this: crack detection and inspection. Quality control facilities have not been located within the FMS area, mainly for reasons of space. At some critical points of the total cycle the castings must be inspected for cracks. However, the crack detection facilities are outside the FMS at the moment and so the castings have to go outside the FMS for this and then be brought back into it. In the medium-term future it is intended to bring crack detection facilities within the FMS. There is 100% inspection on the FMS components. All FMS component inspection takes place on a coordinate measuring machine outside of the FMS, but parts must queue to get onto it. The two reasons for the lack of an inspection machine within the FMS itself are a lack of room in the FMS area, and the fact that there is not really enough work in the FMS yet to keep an inspection machine fully occupied.

Several sizes of coal cutting machine are produced, tailored to different sizes of coal face, and there is considerable customisation of design for particular underground applications. At the time of interview the FMS was being used to produce seven of the larger parts for one model of machine. Components on the FMS include gearbox parts and a boom, which are machined (normally in batches of one) from solid steel castings weighing up to two and a half tons. Cycle times within the FMS for these parts are upwards of four hours per set-up and parts require three set-ups on the FMS in all. The tightest tolerances are of half a thousandth of an inch.

Originally it was intended to put some fifteen parts onto the system. Hitherto, however, the tooling management problems have defeated expansion above the seven currently on the system. Six of these seven parts apparently now run without the need for further adjustment. The aim at the time of interview was to introduce one new part per month onto the system. Some of the new parts have already had their programs proved out on stand-alone CNCs (it is a policy decision to try and do this first), and this will considerably reduce the development work necessary to get the parts running on the FMS. At the time of writing one of the next new jobs will be the electric motor for the same model of coal-cutting machine.

The FMS is currently staffed over an eight hour shift by the following full-time employees: system supervisor; one foreman; ten skilled workers (which includes allowance for a worker for each machine tool to compensate for the lack of adaptive control); and two labourers. Administratively one senior production engineer has taken on the responsibility for project management. In terms of supervision the FMS operates along similar lines to the more conventional areas in the plant (it includes a supervisor for the whole area and a foreman). The semi-skilled labourers' tasks include checking the coolant at least once a week, sweeping up, swarf removal etc. They also drive the forklift truck dedicated to the fixturing store area.

Programming is done by fourteen engineers in the company's separate NC Dept. Of these, five are involved with programming for the FMS although they are not attached to it on a full-time basis. Proving out is conducted jointly by the machine operator and the programmer who wrote the program.

The company's maintenance department, which is divided up on the traditional mechanical / electrical lines, is being used for maintenance of the FMS. If there is a problem the system supervisor is responsible for making initial contact with the maintenance engineers, who are now in the process of learning their functions and the system. They have partly been trained by the suppliers at their own factory. If the maintenance department cannot correct the fault the supplier's maintenance engineers are then called. Some of these engineers still remain on site from the period in 1984 when they debugged and installed the system in conjunction with the company's personnel.

iii) Plant B

This firm is part of one of Britain's leading companies in the aerospace industry. The main company was in public ownership until 1985 when it was privatised by the British Government. Work is related to a wide range of both civil and military spheres. The FMS studied operates on the main manufacturing plant of one of the company's divisions, which is dedicated to military work, in its aircraft group. The division has three plants in North West England employing a total of 10,000 people: one undertakes the design and development function; another tests the products; while the third, by far the biggest employer, is responsible for the manufacturing process. The company's total sales for military aircraft production for the half-year to June 1985 were worth £495,000,000.

The plant concerned produces advanced fighter aircraft (among other products) and thus has always operated at the forefront of advanced technology both in its products and manufacturing processes. Therefore the innovation of FMS is not seen as anything particularly revolutionary, and is actually only the most advanced part of a more general plan for computer integrated manufacturing. Nevertheless this FMS is undoubtedly one of the most ambitious and automated in Britain to date.

The FMS project started in earnest in late 1983. It is planned to take about three and a half to four years to complete (to 1986/87). At the time of interview the plant was already running two cells of machining centres producing prismatic parts: one a cell of ten Japanese machining centres; the other a cell of five now obsolete machining centres of British make, bought second hand, and of a design associated with the original British flexible manufacturing system (Molins System 24). The second part of the FMS will eventually consist of six to eight new machining centres to replace those in the latter cell. Much of the work that might otherwise be produced on these machine tools is currently being sub-contracted to outside companies. Two of the new machine tools in this cell were installed as of early 1985 with the remainder of the machines being introduced during 1985 and 1986. A direct numerical control system links some thirty-five other machine tools in the factory (as yet excluding the FMS at this time), although this is expanding rapidly. Full mechanisation of materials handling also had yet to be added.

Project management is the responsibility of an in-house department of production engineers who are in charge of the implementation of all these changes to manufacturing methods. Because the FMS plans are merely one part of a far more wider modernisation plan interviewees were unwilling to provide a breakdown of the exact costs. It is only known that the FMS part of the plan is a multi-million pound project and almost certain to be in the upper reaches of the ranges of expenditure on FMS projects. It is known that a government grant under its FMS support scheme paid for a proportion of the cost of the project.

The FMS is actually composed of the two machining cells described above, fed by a billet preparation area and automated tool store with transport provided by six automatic wire-guided vehicles. Quality control within the aluminium cutting cell of the FMS will be provided by two coordinate measuring machines, although these had not yet been used at the time of interview. All aluminium parts will be inspected on the first machine, only those failing on this proceeding to the second machine for a more rigorous check to determine whether they can be saved or reworked.

The ten Japanese machining centres have dual pallet change facilities and feature probing for inspection and automatic offsetting, added adaptive control facilities and automatic tool changing. Tools and workpieces were loaded to the machines manually at the time of interview. The tool magazine in each machine only holds forty cutters, which is problematic because each job machined uses about half this number of cutters. Therefore it is rarely possible to machine more than one job at a time before toolchanging is again required. Automatic tool and workpiece delivery when materials handling is added will solve these problems.

For the FMS the company itself also started the development of a new machining centre with a UK manufacturer to replace the old second-hand machines. These are twin-spindle machines capable of carrying sixty two tools (thirty one per spindle). At present these machines are only partly automated, but within the year up to mid-1986 nearly all operations which are still manual will be built into the system software.

The automated cutter store (which services all the NC facilities) stocks 75,000 different cutters, all of which are on file on the host computer and identifiable by bar code labels. Tool life monitoring is employed to ensure that cutters called up to perform a job have sufficient nominated life left to do so. For any given job raw billets (pre-cut to length) are stored on an upper floor level to the FMS. The relevant tools are delivered from the tool stores as required and stacked in a crate capable of carrying up to sixty three tools. When the schedule indicates prepared tools and billets are delivered by AGV to the machine, one journey each being required for billets and tools.

Control of the FMS will be provided by another large DEC minicomputer, the software being a prototype development supported in part by a government grant for innovation. Communication with the machine tools is facilitated by a fibre optic link. The system was already part of a high level of computer integration at the time of interview. Computer-aided design, production control and production engineering data is linked into the host computer.

The work on the FMSs consists of over a thousand relatively inexpensive small parts within a size envelope of 600 x 300 x 120 millimetres machined from either aluminium, steel or titanium for a make of fighter aircraft. Most of the work is in aluminium and this will be machined on the six machines in the new cell. Steel and titanium parts will remain on the ten Japanese machining centres, which means that tool life on these machines tends to be short.

Tolerances are typically three or four thousandths of an inch with five thousandths of an inch being the outside limit. Components are nested together on raw billets in groups of ten with very small ties of the raw material, and are broken off from the raw material in exactly the same manner as one would break bars of chocolate. Low volume and high variety production is characteristic of the aerospace industry. In this case the FMS is intended to accept a very wide variety of part families while production volumes on the FMS are very low. Typically there would be a thousand different components to make on a particular group of machines with a maximum build rate of ten a month. More frequently build rates are as low as two or three a month. In some instances "one-offs" are being machined although, because the new machining centres are of a twin spindle configuration, the minimum batch size would be two. The general policy adopted, however, is that half a machine load is the minimum order quantity acceptable to the company. Thus the larger the component the more likely it is that a lower batch quantity will be permitted. Batch sizes vary in the FMS from about one to a maximum of about forty, but a batch size of forty would only be on very small components representing part of a machine load. The average batch size towards which the company is working in the FMS area is four, compared to a more average figure of twenty in the rest of the factory.

In the cell of Japanese machining centres there is already multi-machine manning with a team of five operators working on the ten machines. The move to unmanned machines was considered quite a significant one, however. Within the Japanese machining centre cell, there are currently two manual jobs: loading and unloading raw billets and attending to the fixturing of parts. These tasks will remain manual. One operator patrols the ten machines.

The FMS workcrew will consist firstly of a transport worker ferrying raw material cut to the right length of billet across to the factory from the company's dockside warehouse two or three miles away. This worker will simply deliver the material and load it into the cell. At the output end of the cell the AGV will deliver work onto a buffer zone which leads into a manual area. A number of manual operations, which are also under computer control, have to be carried out after the prime process, and before the parts are delivered to the next stage of production.

There are currently two types of operators, the first of which works on the upper level of the FMS and is currently responsible for loading of work onto billets, preparing cutters, and selecting appropriate cutters under computer instruction. That job is however planned to be superceded during 1986, and then the only job remaining will be the loading of the Japanese machining centres, for which one worker will be employed on each of two shifts. The second type of operator will enjoy a more supervisory or technical position, and is reponsible for patrol, first-line maintenance and inspection of, and adjustment to the machine tools. Two operators work in the cutter preparation area; one primarily looking after tool regrinding, the other mainly responsible for tool setting and storage.

Programming is done off-line by part programmers, operators not being permitted to edit or intervene in programs. The management's argument against operator involvment is that the industry has such strict quality requirements. Parts are proved out on the machine by the production engineer who programmed the job, and any change which is required to that job will be carried out off-line and then re-proved by the same person. Maintenance will principally be the responsibility of the company's own maintenance department, although industrial relations problems remain in this area.

iv) Plant C

The company concerned is a manufacturer of shoe-making machinery based in the Midlands. It is owned by a holding company, which is in turn owned by a vertically structured American corporation with interests in diverse industries. This corporation has factories in both the USA and a number of newly industrialising countries, although most domestic production seems to originate from the British plant rather than these other potential sources. The parent corporation is now trying to develop a more high technology image.

Until 1981 the company had had very little investment put into it for a long time. A rationalisation exercise was then initiated from corporate level which included the hiring of new manufacturing management and severe reductions in staffing levels (from four thousand employees in 1981 to 1,700 - and still falling - in 1984). Turnover in 1984 was £41,000,000. Floorspace occupied has also dramatically declined and offices have moved to a new building.

As part of the rationalisation exercise the parent corporation decided that even if the products made were not high technology products then at least they should be manufactured using high technology processes. Key new members of the company's manufacturing management were already convinced of the merits of group technology from their previous jobs and involvement in the British Government's (ASP) Committee. From this FMS was viewed as a natural step. In September 1982 the company first started looking at the possibility of producing by FMS, and in February 1983 an FMS proposal was put before the Department of Industry with a request for financial support. The project was intended from the outset to be introduced in a modular fashion over several years, and is still at a relatively early stage. Full computerisation and machine complement is yet to be achieved. Total cost of the full project was estimated at £2,500,000.

The first machine was installed in 1984 followed by a second in mid-1985. The next stage of the project was an installation of the host computer in November 1985, although finance from the parent company to support this stage of the project was reportedly hard to obtain initially. Eventually two further identical machining centres will be added. Three different suppliers are involved in the project: one for the computer hardware; another for the software; and a third for the machine tools and transport system.

When finished the FMS will consist of four identical machining centres, each with an eighty tool capacity, fed by a rail guided vehicle transport system. As of mid-1985 one of these machines had been installed together with the rail guided truck and approximately eight pallet stations to feed the machine. This first machine is now being operated on a twenty four hour basis. It is being used for development purposes on the two dayshifts and for production work over the nightshift and operated on a stand-alone basis. A second machine was about to be installed at the time of interview, and the number of pallets has been approximately tripled in anticipation of its arrival. This second machine will then be used for development purposes, the first machine being used solely as a production machine. Computer control will be provided by a model supplied by IBM, who have also supplied the computers for the tool management and computer aided design and manufacture (CADAM) packages. Present computer plans are restricted to the linking into DNC of the two machining centres.

When the host computer is installed tool condition management will be conducted by a system of the assignment of historic tool lives (at the time of interview tool wear was monitored purely manually).

The machining centres are equipped with probing facilities, but it is not intended to use these any more than necessary on the grounds of the addition to cycle times.

The company is intending to put a minimum of sixty and a maximum of four hundred products on the FMS per year. The average will be one hundred and sixty products per annum. As of mid-1985 one hundred and ninety parts have been specified for the system: given the number of products eventually intended for the FMS a lot of parts have therefore still not been introduced. A "product" in this sense means all the cubic parts for a particular type of shoe machine, so the number of actual parts is considerably higher. As mentioned before, though, the company's manufacturing engineers are advocates of group technology, and production of these wide variety of numbers of part is rationalised by the fact that they fall into a number of distinct part families. All the products on the system are part of a new range of shoe-making machines.

Most individual components fall within a six inch cube, are fashioned from castings or bar, require few operations and are of short ,cycle times. Average tolerance is eighty seven microns, although the tightest tolerances are of about sixty eight microns. Operations usually involve mainly drilling and tapping rather than extensive milling, although some larger parts (such as machine bases, etc), which do require more metal removal, are also machined. There are a small number of fairly complex pieces requiring more operations also. The cycle time for all the components on each pallet averages out at one hour.

The level of flexibility between parts intended for the FMS (that is, production in batch sizes of one) has not yet been achieved. Using only the first machining centre on a stand-alone basis the company are producing in batches of ten. The control problems of producing batches of only one component manually (i.e. without scheduling via the host computer) appear to have defeated the company's abilities to keep track of parts. Producing in batches of ten is intended to be a temporary compromise, which increases cycle times to a workable figure. It is hoped that the arrival of the host computer will overcome this production control problem. Even so, this is still cheaper than producing in batches of (typically) sixty on conventional machine tools.

The FMS will be staffed on the basis of one operator per machine per shift, so at the time of interview there were three operators. At the moment operators are responsible for loading the part programs into the machining centre level control and monitoring tool wear by physical inspection. Once the DNC link is installed, however, they will be relieved of the former job, and the larger part of the latter will be performed automatically. The current procedure for inspection is that every part is inspected by separate inspection staff. In the future the production engineers want to move to random inspection. By moving to new methods of inspection on the FMS the company will be able to further its aim of reducing indirect labour by cutting the number of inspectors. At present the occasional inspector and the foreman are now the only indirect labour in the FMS area, although of course there is quite a lot of indirect labour backing up the FMS elsewhere in the production engineering department, and so on). However, on the FMS operators are also now doing their own inspection.

Maintenance will initially be the responsibility of the suppliers of the machine tools under their warranty period although eventually the firm's own maintenance department will take over. Operators are not responsible for maintenance itself but they are responsible for calling the maintenance workers when necessary.

v) Plant D

This plant is the main UK production facility of a large multi-national company that produces earthmoving and other automotive equipment. 1984 sales were £155 million. The plant has been badly affected by the economic recession. In the years 1980-85 the numbers employed on the site fell from 2,500 to 1,200 (comprising 800 direct and 400 indirect workers) at the time of interview, mainly as a result of voluntary redundancies.

For some years now the parent company has been developing expertise in advanced manufacturing facilities, including the running of FMSs in some of its other plants in Europe and America. Since 1984 manufacturing engineers at Plant D have been planning the introduction of FMS into this plant designed to produce components for a new range of tractors coming onto the market during 1986.

Plant D itself has experience with stand-alone CNC machine tools, but most production has traditionally been undertaken on transfer lines and high volume dedicated machinery using semi-skilled operators. Initially it had not been specifically intended that FMS should be the solution to producing these components, and indeed given the lack of expertise in FMS at the plant there was some reluctance to use a technology so experimental. Engineers decided that FMS was the biggest technological step that they felt they could justify taking given their state of knowledge.

Three FMSs are being installed at the plant at a total cost of just under £5,000,000. All three FMSs have been supplied on a turnkey basis by two German manufacturers, the second and third FMSs having the same supplier. Overall control of each cell is maintained by a DEC mini-computer which performs all necessary management functions and schedules components. If a day's production requirement is not met the host computer simply adds the shortfall to the following day's production requirement.

The first and second FMSs (catering for different stages of operations for the same components) were first installed in 1984 and were producing parts at the time of interview. These were being worked on a single shift, and were not expected to be in full production until the end of 1985 (when it was hoped that they would run on three shifts like the rest of the shopfloor). The first of these FMSs comprises three CNC vertical turning machines each with a tool magazine capable of carrying 120 tools. A rail guided pallet transport system carries components between loading stations and the machine tools and the FMS contains sixteen dedicated fixture / pallet combinations. Components are then moved onto the second FMS. This consists of a line of four machining centres, each holding a magazine of eighty tools, and served by a rail-guided pallet transporter. This system uses eleven dedicated fixture / pallet combinations. A manually-operated shaving machine is also a part of the latter cell. This cell runs unstaffed over lunch and tea breaks.

The third FMS was still in an early stage of development at the time of interview although it is believed to be in operation at the time of writing. This FMS machines chassis components and comprises two very large machining centres, each holding 110 tools and served again by a rail guided pallet transport system. There are three pallets within this FMS.

One of the features of all three FMSs is that within each cell the variety of tooling on each machine is identical and so any component in a given cell can go to any machine. Thus the host computers simply schedule parts to the next machine that is going to become available. Moreover tooling requirements for the range of parts are sufficently frugal to enable each tool magazine to hold a supply of sister tools; and in the case of the first FMS ten entire sets of tooling.

Tool wear is monitored on the second and third FMSs by means of historic life monitoring, adaptive control through torque consumption measurement, and laser beam detection for breakage in the case of smaller tools. The first FMS uses historical tool life monitoring and also compensates for tool wear in-cycle. It does this by conducting a probing operation after the first rough boring operation. This feeds back any change in required tool offsets for the roughing tool to the host computer. The finishing boring operation then takes place and compensates for any inaccuracy in the first roughing operation. The FMS area has a separate tooling section, which includes an automatic toolsetting machine. This is connected up to the host computer and automatically feeds back tool offsets to update the part programs. All tool setting is done by the operators. All inspection in the FMSs is performed automatically by in-process probing cycles, which check certain critical dimensions.

The components produced on the first two FMSs are five final drive and steering clutch components fitting approximately an 800 mm cube for each of two new models of tractor. Thus there is a total of ten components on these two FMSs. The first FMS turns internal diameters and has a cycle time of about thirty minutes. Operations on the second FMS are mainly drilling and boring of the same components with cycle times of between ten and fifty minutes. The third FMS machines from fabrications very large chassis case and frame components up to three metres long and weighing over two tons. Approximate cycle times for cases are three and a half hours and one hour for frames. It is believed that eventually eight different parts may be produced on this FMS. There are some very tight positional and boring diameter tolerances to be held on all cells, although there is no closed environment. Tolerances of up to six tenths of one thou were mentioned on the second FMS. On the third FMS tolerances go to plus or minus a thou. Production will be in batches of one. It is estimated that on the first two FMSs overall throughput times have been reduced from one month to two days, with an even greater reduction on the third FMS.

The first and second FMSs are staffed by a team of four workers (who will alternate between necessary tasks), while one operator will be responsible for the third FMS. As regards system supervision one of the engineers has been familiarised with the system and will be working as supervisor in the DNC control room, although this will only cover one dayshift). As regards maintenance the company engineers have been sent to the suppliers' works to learn the systems. To date, though, the suppliers' engineers are frequently on site and provide back-up service.

vi) Plant E

This company is a wholly-owned susidiary of an American corporation whose main business is aircraft production but which is involved in a number of other areas of manufacturing. The firm concerned is the only European plant in the multinational's industrial hydraulics division and was set up in 1961. 1985 sales were just under

£4,500,000. After considerable rationalisation in recent years the company now employs 193 workers, of whom approximately half are direct. Plant E manufactures gear pumps, hydraulic control valves and cylinders in separate areas of the factory.

At the beginning of 1982 the company was ordered by the corporate headquarters to undertake a major reorganisation and rationalisation exercise in order to cut losses. As a result of this the company returned to profitability by the end of the same year but still lacked sufficient sales to solve the problem of gross underutilisation of capital equipment. It was decided to strengthen the sales team at the company and to take this opportunity to launch a new range of gear pumps to try and improve sales. Despite a minimal but largely unhappy previous history of NC experience it was decided to use an FMS to produce the new range of pumps.

The project was financed by the company's own borrowing together with a Department of Industry grant under the FMS Support Scheme, approval for which was gained in July 1983. An Italian supplier, who took on the project on a turn-key basis, was chosen for the FMS. The first two machine tools were introduced into the plant at the beginning of 1984 to facilitate the training of staff while the part programs were written and the remainder of the equipment debugged at the supplier's premises. The system has been running on a production basis since mid-1985.

The FMS itself is completely partitioned off from the rest of the shopfloor in a temperature-controlled environment to help keep within the tight tolerances required. Within the FMS area the DNC control area and host computer are further partitioned off. The FMS consists of three identical machining centres. Operations carried out are mostly drilling, tapping and boring. There is also one milling operation, which is done using a special cutter. All machines are tooled up identically, each machining centre holding thirty-two tools. Sequencing is thus simple: as any part can go to any machine the host computer will normally schedule consecutive machines for each new set of parts. Tool wear is monitored by manual means only (although operators can check on developing problems by examination of print-out from the inspection machine - see below).

The machine tools are fed by a rail-guided robot, which loads sets of the five parts into identical fixtures (two per machine). Fixtures are permanently attached to pallets. A rail-guided robot picks parts for loading to the machine tools from the upper half of any of a row of five conveyors initially loaded with blanks by the system operator. Finished parts are deposited by the robot on the lower half of the conveyor and fed to the conveyor rear for manual unloading. At the end of each of the conveyors is a photo-electric cell. This tells the robot which of the conveyors has a part on it for loading. (Conversely it also tells which of the lower conveyors is empty for unloading purposes). One loading of the conveyor will suffice for about four hours system running time. The robot has to turn parts over halfway through the machining cycle to enable machining of all faces.

Also linked in are an inspection and washing machines. The inspection machine is linked to the host computer and feeds back the necessary dimensional data to enable the automatic correction of offsets on the machine tools as necessary. Inspection is carried out on a statistical sampling rather than 100% basis on critical dimensions. Finally the FMS contains a secondary special purpose cell. This latter performs cross-drilling and bush insertion - bushes are loaded by the operator into this cell for automatic insertion into the gear pumps. There is a tool pre-setting machine within the FMS area, but this is not connected up to the DNC because it was felt that the cost of the software to do so would be unjustifiable, especially considering the facilities contained on the inspection machine.

The parts machined on the FMS are five families of aluminium gear pump components. The basic parts are bodies, backplates, frontplates, adaptor plates and mounting, each of which type of part can have between three and nine variations. Tightest tolerances are of three-tenths of eight microns. Interviewees were unwilling to divulge cycle times but analysis of secondary literature sources (which will remain anonymous here for reasons of confidentiality) indicates a likely total cycle time of only a few minutes. It is soon intended to introduce a new type of gear pump onto the FMS, for which a production engineer at the plant was adapting master family programs at the time of interview. Gear pump components are produced in sets of five components on the FMS rather than batches.

The system is staffed by one operator per shift (with additional operators trained for back-up purposes). At the time of interview three operators had been trained to manage the system, although one of these had recently left. As regards other personnel the system is run by a production engineer and a quality engineer, both of whom were sent to the supplier's premises for a training course. At the time of interview it was intended to send a further one of each of these classes of personnel to the suppliers. Overall scheduling planning of components is the responsibility of the Production Control Department. One of the supplier's engineers has remained on site and is responsible for advising on maintenance. Over and above this the firm has three maintenance electricians with electronics knowledge capable of servicing the FMS.

vii) Plant F

This company is the British subsidiary of a major American machine tool manufacturer which has made extensive moves into the supply of advanced machining and materials handling technologies. Main products are computer numerically controlled machine tools, robots, control systems and programmable controllers. The plant is the UK headquarters of this company. It chiefly manufactures vertical and horizontal CNC machining centres, the turnover in 1984 being about

£23,000,000. The UK subsidiary has been hard hit by the economic recession of the early 'eighties and the workforce has been reduced from 2,300 in 1980 to 770 in 1984.

However, since 1983, investment of about £6,000,000 has been taking place in capital-intensive facilities such as material requirements planning computers and computer aided design and manufacture. The company's FMS, which cost about £700,000 (partly financed by a government grant), is an additional part of this modernisation programme. The FMS is comprised almost entirely of equipment supplied and marketed by the company itself. Thus it is a turnkey project and was installed at the company's plant in late 1984.

When visited the FMS comprised one machine tool, a dual pallet change horizontal machining centre of the company's own make. Eight pallets located at a loading station hold the fixtured work to be fed into the system. The machining centre has a toolchanger capable of carrying up to ninety tools on two chains. A number of tool management features are built into the machine level control software. The machining centre is equipped with adaptive control, facilities for sister tool replacement and probing for broken tool detection. It is intended to add another machining centre of the same model to the system, but the current low workload does not yet justify its addition. The FMS also includes a washing station which incorporates a robot (again of the company's own make), washing components from four fixed and one variable position jets. A horizontal coordinate inspection machine has been supplied by a firm now owned by the company. Inspection cycle times on this machine vary between two and eighteen minutes. Transport is provided by an automatic vehicle of Swedish make which is guided by wires buried in the floor.

Computer control is provided by a modular controller designed and marketed by the electronic systems division of the same company. The controller is divided into three separate modules. The right hand controller handles data management on a ten megabyte personal computer capable of holding tooling data and about six hundred part programs. The central unit deals with the scheduling of work in the system, while the left hand module monitors the operation of the system.

All parts produced on the FMS are prismatic workpieces within a five hundred millimetre cube machined from steel and cast iron. Operations performed are milling, drilling, tapping, reaming and boring. The parts produced were originally designed and manufactured in the company's American facilities. This was part of a deliberate policy to maximise economies of scales and batch sizes by producing all parts on one site. A number of factors, chief of which was the fall of in value of the pound against the dollar in 1984 and 1985, combined to reverse this policy as it was now calculated to be cheaper to produce parts for UK machines domestically. Thus it has now been decided to try and move towards one hundred per cent local content.

Initially thirteen parts for one of the company's tool and cutter grinding machine were put onto the system. The part range has expanded to encompass parts for two other machine tools, one being parts for the same model of machining centre that is in the FMS. Typical parts include slideway bearing wiper plates and bearing blocks. Most of these parts are machined on fixtures holding multiple numbers of the part. Cycle times per pallet vary between fifteen minutes and one hour. Most components are machined in multiples on fixtures, typically giving a batch size of sixteen to twenty four for smaller parts.

The FMS is normally run by two operators on each of the two shifts, although only one is usually in attendance if the cell is working satisfactorily. One supervisor per shift is also in attendance. Scheduling within the system is manually performed by the operators, who decide on work priorities. Operators also perform all other operating duties within the system: loading and unloading of parts, changing of tools in toolchangers, swarf clearance, etc. As a supplier the company normally give operators of their FMSs a training course of a week's duration. It is believed that the operators of the in-house FMS received similar training.

A number of indirect functions add to the total labour associated with the FMS. Four part programmers in the production engineering department are dedicated to program writing for components planned for manufacture on the FMS. In total six production engineers are more or less devoted to servicing of the FMS. Maintenance is the responsibility of the company's own maintenance engineers, none of whom is specifically allocated to the FMS.

viii) Plant G

The company is a small manufacturer of propellor shaft seals for ships. It is owned by a British parent firm, which is in turn owned jointly by an American multinational company (49% shareholding) and a major British group specialising in metal and domestic goods (51% shareholding). A subsidiary of the latter has been responsible for the supply and project management of the FMS. Based on the South Coast the company employs eighty workers, of whom some twenty are on the shopfloor.

Moves towards FMS started in late 1982. The system cost slightly above £500,000 in total, one third of this being paid by the government in the form of a grant under its FMS support scheme. It was built, installed and tested at the machine tool supplier's factory during 1984 and early 1985, after which it was moved to the company's new plant during March 1985. The system is now working on a production basis.

Machine tool hardware consists firstly of a CNC vertical turning and boring machine carrying twelve tools. This performs first operations, components having to be turned over manually to machine the second side. This machine turns outside and inside diameters of propellor shaft seals. Second operations (drilling, tapping, and a lesser amount of milling work) are carried out by a vertical machining centre supplied by the machine tool division of the British parent group. This is equipped with a thirty tool carousel. There are twelve circular coded pallets of one and a half metre diameter. Transport is provided by an automatic guided vehicle directed by underfloor wiring. Computer control is provided by a DEC supervisory minicomputer.

On the vertical boring machine tool wear is monitored at the level of the machine control, as the on-board controller has its own tool life monitoring package. This package is shadowed by the host computer, which analyses whether tools exist on that machine with sufficient assigned lives left to machine the next job. Tool life management on the machining centre is performed purely at host computer level.

Components machined are about twenty families of propellor shaft seals for ships. These are semi-circular, being made in two halves (to facilitate refitting at sea). Materials used are gunmetal and occasionally cast iron. Cycle time on each machine average forty minutes on the vertical borer and twenty minutes on the machining centre. Tightest tolerances are about four thousandths of an inch on some of the diameters, although this will only occur exceptionally. Positional tolerances are no lower than plus or minus ten thousandths of an inch. The most normal batch size will be one, high batch sizes being irrelevant to the company's type of work.

The FMS is staffed by a team of three, designated as system manager, cell technician and programmer, and cell loader. Routine maintenance is undertaken by the company's maintenance man, while machine problems are tackled by the suppliers. At the time of final interview the company still had not formally accepted the system, so the suppliers' one year maintenance warranty was not yet operational.

ix) Plant H

The company is one of the larger subsidiaries of a major group with interests in diverse fields of capital goods manufacture. Turnover in 1984 was £80 million. The firm which is introducing the FMS produces coal cutting and hydraulic pit support machinery and employs about 1,400 workers on a site in Western England. At the beginning of 1984 the company was reorganised into three separate product groups: chock assembly, leg and ram manufacturing, and valves. The valve division of the company is responsible for the employment of a total of some four hundred people. Two major types of valves are currently produced, and a new type is to be introduced shortly (which will also be manufactured on the FMS).

In recent years the market for mining equipment has contracted overall, although the company's market share appears to be stabilising. The company is dependent on one major buyer, British Coal (formerly known as the National Coal Board), to which it sells about 60% of its output. Production was hit quite badly by the

1984/85 miners' strike, which affected orders and morale considerably.

An in-house study on possible technological choices was conducted within the production engineering department in 1983. After a discounted cash flow analysis FMS triumphed as the most financially viable option, but only because of the availability of a Department of Industry grant (which was assumed in the calculation), and the proviso that the FMS option promised the least rapid return on the investment). The original idea of installing the project by stages was abandoned when it was known that a grant would be available. The FMS represents a total investment of £3,200,000. The company received a Department of Industry grant in May 1983. Acceptance trials were conducted on the shopfloor during August and September 1985 and the project was handed over for production purposes in January 1986 (about three months later than first intended).

The system consists of four identical machining centres, each with capacity for 110 tools. To enhance total tool inventory in the FMS the tooling carried on each machine is different, although there is a limited amount of duplication involving perhaps two of the machines. Tool life is monitored by means of historic life monitoring, adaptive control, a broken tool detection facility controlled by a proximity switch near the spindle. Probing is also used to detect broken tools and to probe components before the start of a cycle to ensure they are in the correct location agianst the end-stops of fixtures. This operation was not performed initially but was found to be necessary to be certain that parts are produced within tolerance and was thus programmed in. Probes are not used for performing inspection. The reason given for this is the unwarranted addition to machine downtime while probing takes place. A stand-alone coordinate measuring machine (one of two in the factory) is located next to the system and is used to measure parts coming off the FMS although it is not part of the system per se.

Each machining centre has two input/output stations. A rotary table transfers pallets between these and the machine. The machining centres will be served by two automatic vehicles guided by underfloor wires, although one of these will mainly be used for back-up capability in case of the other's breakdown. The AGVs bring workpieces to the machine. Tools, on the other hand, are carried to the machine tool magazines on a manually-controlled trolley and must be loaded into the magazines manually. There are four stations for loading and unloading components. Shop data entry units (SDEUs) are stationed at each of the loading stations.

Overall control of the FMS is provided from a raised control room overlooking the system which houses the two identical DEC PDP 11/44 minicomputers used as host computers. One of these computers provides back-up capability in case of breakdown and will be used to run simulation packages. The management information system on the FMS will give on-line production data, which is an improvement on what currently exists with the stand-alone CNC machines:

utilisation figures on these are one week out of date by the time they have been collected.

The FMS also includes a dedicated tool store, fixture store, tool setting area, and tool regrind shop. An automatic tool presetting machine is part of the tool setting area and automatically feeds tool offsets into the DNC with no further manual intervention being needed.

About twenty five families of valve component parts were considered suitable for production by FMS. By the time the system was ready to go into production the FMS had been tooled up to produce a total of fifteen part families. Of these nine families have little internal variation, while the remaining six contain a lot of different variants. One of these part families contains over one hundred variations on the basic shape. Materials used are high tensile brass and steel. Components need machining on all six sides and thus need loading twice (in order to machine the remaining faces). Tolerances can be close: up to 0.015 mm true positions, 0.05mm on hole diameters and 50:1 length/diameter ratios on holes. Cycle times vary from 22 minutes to 2.4 hours with an average cycle time of 45-60 minutes. Batch sizes vary from five to one hundred.

There are three distinct grades of job contained in the system. Staffing of the FMS is intended to be on the basis of four workers per shift as follows: system manager, two skilled setter/inspectors, and one loader / unloader. Additionally one manufacturing engineer responsible for tool and fixture design and programming and two maintenance engineers are assigned to the FMS.

x) Plant J

This plant is the base of a major British machine tool manufacturer which is now one of the largest domestic suppliers of CNC machining centres and flexible manufacturing systems. It is the subsidiary of a British-based multinational company with interests in most branches of the engineering industry. 1983 sales were nearly £14,000,000. However, the company has been running at a loss for some time and severe rationalisation has been imposed in order to try and achieve a return to profitability. The workforce was reduced from 1,100 in 1982 to 450 in 1984 and this decline was still continuing at the time of interview. A considerable number of the less critical parts have been contracted out. A labour flexibility agreement has been negotiated with the main shopfloor engineering union, the AEU.

The system is believed to have cost just under £1,000,000, part of which was paid for by a government FMS grant. The intended configuration for the FMS has changed several times and has also been subject to considerable delays, although nearly all the equipment has been supplied by component firms within the parent group.

By the time of final interview the FMS still consisted of two groups of machine tools, each served by its own transport system, being used for development purposes. Interlinking of the two transport systems was intended to occur by the end of 1985. A tool setting machine was about to be added but overall host computer control was still some way off.

All equipment in the FMS is of the company's own make, except for the host computer and the toolsetting machine which was about to be delivered. These latter are supplied by German companies. At the time of final interview the FMS consisted of a large prototype machining centre with a capacity for holding 200 tools. This machining centre was fronted by a pallet railway. Also included in the FMS but not yet linked to this machine at the time of interview were two smaller machining centres, each with a toolholding capacity of eighty. When the toolsetting machine is installed tools will be identified by means of a laser-read bar-code label which will enable the random assignment of tools to pockets.

Tool wear is monitored by means of torque sensing, assignment of historic tool lives and probing for broken tools (on critical operations only). A tool rationalisation exercise is being carried out to reduce the need to employ tools likely to suffer breakage, and therefore to reduce the need for probing cycles.

The products machined on the FMS are approximately twenty five families of prismatic components for the company's machining centres. Typical parts include headstock castings, tool housings and pallet tables. Cycle times for components vary widely, ranging from as little as ten minutes (although such components would be multi-loaded on fixtures to give an overall pallet cycle time of one to two hours) to seven hours in the case of machine tool heads. A variety of materials are used including aluminium, boilerplate, cast iron, steel and fabrications. The tightest tolerances are of plus or minus thirteen microns. Batch sizes are variable depending upon the type of component but are thought to average about twelve.

The FMS is under the overall control of a system manager. One machinist (classed as a setter/operator) is responsible for getting each of the two cells of machines operational. Part programming is undertaken by the company's NC Department. All inspection is conducted off-line by the company's Inspection Department.

A day-to-day schedule of basic maintenance is carried out by the operators. Operators will be responsible for maintenance tasks not involving dismantling the machines or the use of specialised equipment. As the company are also the suppliers of the machine tools major maintenance will also be an in-house responsibility. Indeed the machine tools in the FMS were currently being used to allow the development of the company's own maintenance recommendations for these machines.

xi) Plant K

This firm is the largest of a small independent group of companies operating on a total of four sites, mostly in South East England. The company started in 1976 with only five employees. Its main business is a sub-contractor for volume production of machined parts for the automotive industry. At the time of interview in 1985 the company employed in total some 510 persons. Thus the company has expanded rapidly since it was formed. It has also started a business for stripping down and refurbishing machine tools, originally only for in-house use, but now also for outside customers. Most recently the group has taken over a machine tool company. Turnover in 1984 was just over £9,000,000.

The main business however remains sub-contract machining principally for the car, bus and truck industries. Over half the company's business is conducted with one of Britain's major car manufacturers, which exercises a dominant influence over its production plans. Business is also conducted with foreign subsidiaries of the same automotive companies. About eighty five per cent of the work consists of turning operations, the remainder being mostly slot milling, grinding, gear hobbing and broaching. Materials are usually steels of various grades.

Most of the company's work is high volume production, and the production facilities are geared up to match this requirement. However, in 1981 the company bought its first CNC lathe to machine a gearbox main shaft. CNC was chosen because of the tight tolerances required on this job. Although it would have been theoretically possible to achieve these tolerances on a conventional centre lathe it would take about ten hours to carry out work of this precision for one component. By using CNC the company had achieved the same results first in six minutes and now in four and a half minutes. Since this first machine the stand-alone CNC complement has expanded to seven, including Japanese stand-alone four-axis CNC lathes of the same models that have subsequently been used for the FMS.

Both the high volumes and high proportion of turning operations would seem at first to make the company unlikely to be a candidate for venturing into purchase of a flexible manufacturing system. The initial idea for the move to FMS was spurred in 1983 when the company won the contract from its major customer for a new type of gearbox. The tolerances for the components on this job would be much lower than any work encountered previously, and furthermore high volume production coupled with quick changeover between parts were considered important production requirements. The company decided to adopt FMS on this contract for the two criteria of volume and accuracy. Unfortunately, once the decision had been made to order an FMS the customer decided to cancel the gearbox contract. After some hasty re-thinking the company decided to continue with the plan to buy an FMS and to find other work to put on it instead.

Having made this decision a second problem occurred when the financial management of the company refused to accept the worth of the investment, valued at about £1,200,000, because payback was not anticipated to be achieved within the company's normally accepted period. The British Government's FMS support scheme then contributed one third of the cost of the project (this being confirmed in January 1984), however, and thus the project was allowed to go ahead. The availability of the government grant was the clinching factor in deciding to adopt FMS.

The machine tool hardware was supplied by a Japanese company, of whom the firm had previous experience. The English agent for this supplier took on management of the whole project, and no development work at all was done by the firm receiving the FMS. This role included the supply of machine tool and computer hardware, software, transport system and training of employees. The first machines were installed on site during the summer of 1984 and the rest in the late autumn of that year. This facilitated in-house training on the machines and a build-up of experience. Following this the transport system and then the computer equipment was installed. The FMS finally began work on a production basis in mid-March 1985.

The FMS consists basically of two separate machining cells, each with two turning machines within a perimeter fence. Both cells are linked up under DNC but each performs quite distinct machining duties. The first cell consists of two Japanese four axis lathes interlinked by conveyor, and this cell turns blanks of up to 150 millimetres in diameter. The second cell consists of two larger four axis lathes by the same manufacturer also interlinked by conveyor which handles turned parts of up to 250 millimetres in diameter.

Each lathe is equipped with an on-board robot for the purpose of loading and unloading parts, and two turrets: containing twelve tools in the top turret and eight in the bottom turret. As far as possible a standard tooling philosophy is employed for each job: on average three roughing tools and one finishing tool. Two continuously moving belt conveyor systems, one for each cell, link each cell's machine tools so that the component's first operation is performed on the first machine, replaced by robot on the conveyor, ferried to the second identical machine where the part is turned over and the second operation performed.

Computer control is located in a room adjacent to the FMS, which covers a large corner of the machine shop. In this room are two Octopus computers. The first is the host computer, which holds all the system data on a disc file. The second, a computer of the same make, is used to perform part programming and editing. In addition each machine tool has its own VDU and printer which logs the current status of its machine and prints out quality control information for each part produced.

Tool lives are monitored by two methods: 1) programmed tool life, with a warning point triggered off at a certain percentage of expired life; 2) probing of critical dimensions, automatically feeding back offsets to the host computer for updating in order to keep dimensions within seventy per cent of the allowed tolerance band. A probe will shut a machine down if it detects a dimension as being over two thousandths of an inch oversize. In this instance it assumes such a large disparity is the result of a broken tool and calls for manual attention.

So far only six main parts have been run on the FMS, exclusively forged or billet steel gear blanks. The cell of larger lathes has tended to keep running on only one of the larger of these jobs (a camshaft gear). The FMS components feature tight tolerances, with the least tight tolerance on the gears being one thousandth of an inch (twenty five microns) and some bore tolerances being half of this. The FMS has not been used to run small batches of prototypes so far. Despite the fact that changeover times are relatively short the production engineers prefer to keep batch sizes as high as possible to minimise downtime. Batch sizes currently run were given as often 10,000, with a minimum of 3,000. Component cycle time on the FMS is approximately two minutes.

The FMS is run by three direct personnel per shift. One skilled setter is responsible for programming and management of both cells. Loading and monitoring of each cell, and quality control, is carried out by a semi-skilled operator.

xii) Plant L

This plant is one of the main production sites of a manufacturer of buses and is now a wholly-owned subsidiary of a British-owned automotive company. Sales in 1984 totalled £430,000,000. The site as a whole employs some 1500 people and is split into facilities for the production of chassis on the one hand and gearboxes and axles on the other. The latter business employs 550 direct workers and 250 indirect workers and is now responsible for the introduction of a FMS to produce a new range of gearbox components.

Management were unwilling to divulge the cost of the FMS, but it is known that 10% of the cost was covered by a government grant. It is noteworthy that the availability of this grant was the deciding factor in enabling the adoption of a FMS specifically. At the time of interview the FMS was still being introduced: a tool pre-setting machine had just been delivered and a minority of the machining centres were still to be delivered. It was intended that the system would be running on a trial basis by September 1985.

The FMS consists of five identical machining centres of West German manufacture laid out in linear fashion. Each machining centre has capacity for 160 tools. Thus the provision of both sister tooling and duplicate tooling between machines will be quite high, which enables the satisfaction of one of the company's main requirements that any workpiece should be able to go to any machine within the FMS.

These machining centres are served by two automatic guided vehicles which collect parts from and deliver them back to two load / unload stations fed from a line of forty-two dedicated pallet / fixture combinations. The aim of having so many pallets is to enable twenty four hours unstaffed machining work to be lined up for the system. The loading of this work on the pallets will take four hours (of the twenty four). A tool pre-setting machine, which will communicate tool offsets directly to the DNC, is to be installed beside the machining centres. An FMS control room is situated along a raised balcony directly overlooking the system. The control room contains the host computer terminals, a VDU connected to the system, a system layout diagram and a terminal for the simulation system on which the FMS has been modelled.

The machining centres have power monitoring facilities to monitor tool wear and also probes, which will be used to test tool integrity at the end of an operation. The addition to the cycle time is felt to be a minor inconvenience compared to the necessity of manually checking tools that tools are not broken.

Initially the part spectrum consists of five separate components fopr one existing and a new type of gearbox, each of which types is produced in in-line or angle drive forms. This produces a total of fourteen component variations to be machined on the FMS. These require machining on at least five faces. Batch sizes appeared to be undecided at the time of interview but it seems likely that they will be large by FMS standards. Some complex work is involved and tolerances are very fine, especially on bores. Cycles times per pallet vary from thirty to ninety minutes, with an average of forty minutes. The only material is aluminium, which facilitates fast machining times.

The FMS is staffed by a team of four opèrators per shift (all picked from the company's existing CNC machinists and subsequently upgraded). These will share the necessary system responsibilities of loading, tool-setting and "roving operator". Three engineers have been allocated to the project and these are responsible for development and running of the overall computer software.

Part programs are written by a manufacturing engineer but are proved out jointly by this person and a setter. There will be two types of inspection employed within the FMS. The operators are partly responsible for their own inspection will carry out a "jig check" every so often on components using standard measuring instruments. On first-offs components will be sent to a special area behind the machining centres. Separate inspection staff will be involved here in a more thorough check. Also, the machines themselves are equipped to perform a more rigorous inspection on components than that performed by the operators. This process will also be employed although at the time of inteview the intervals for this had not been decided.

As regards maintenance, two members of the existing maintenance team have been hand-picked by management to be the FMS maintenance crew as an additional responsibility to their normal maintenance duties.

xiii) Plant M

The company is a large manufacturer of medium and high speed diesel engines for industrial and marine applications. Sales in 1984 totalled £72,000,000. It is a subsidary of a British parent company which also owns a number of other firms manufacturing diesel engines. At the time of interview the company operated on five sites in South West England employing a total of 3,000 people. Subsequently, however, to rationalise production it closed two of these sites, one of which was the small machining shop which contained the firm's first FMS. The plant at which the FMS was installed prior to the move functioned purely as an overspill machine shop. About twenty five people were employed on the site in total, of whom about ten to fifteen were on the shopfloor on each of the three shifts worked. Since the time of interview this FMS has been dismantled and reassembled on the shopfloor at the company's headquarters plant, which is located about ten miles away. Two further FMSs are in the process of planning and installation at the headquarters plant.

A study team composed of customer and supplier representatives was formed in 1982 to investigate the feasibility of the FMS project. Orders were placed in mid-1983 when the British Government's Department of Trade and Industry confirmed that it would pay for one third of the cost of the project. Total cost of the system is about £750,000, the remainder of the investment being internally financed. In the period January to October 1984 the system was commissioned and integrated. The FMS has been running on a production basis since late 1984 with a break for removal of the system to the headquarters plant at the end of 1985.

All components on the FMS are delivered by robot to a set sequence of machines as follows: 1) CNC lathe, 2) gauging station, 3) part orientation station, 4) broaching machine, 5) machining centre, 6) balancing machine (for flywheel components only). The first robot transports components from the pick-up bin as far as the third station, at which point the second robot takes over.

Machine tool hardware consists firstly of a four axis CNC lathe which performs the initial operation on components. The lathe carries six tools in both its top and bottom turret. The top turret has room for twelve tools but only six are carried to allow sufficent room for proper clearance. A tool rationalisation exercise has been carried out to reduce toolchange requirements with the result that there is now no need for any tooling changes for the manufacture of components within the flywheel component family. Tool life is monitored in two ways: there is cutting force monitoring on the machine and there is also a tool index counter: the operator can signal the system when a new tool is put in and the computer will count down its assigned life as it machines each component. The lathe was originally equipped with in-process gauging, but this has now been removed because it was found that the probing added to the total cycle time by about four minutes.

The second machine tool is a four-axis vertical machining centre of British manufacture which is used mostly for drilling and tapping operations. The machine can carry up to eighteen tools. Tool wear monitoring on the machining centre is performed by probing at the beginning of cycles, and the offsets are transmitted for future up-dating back to the CNC control cabinet. Broken tool detection by probing also occurs. Once again probing cycles have been reduced from roughly every operation to one in thirty components in order to diminish cycle times.

One further machine tool in the FMS is a broaching machine, onto which components are loaded after gauging and before going onto the machining centre. Preliminary inspection, originally performed by probing facilities on the lathe, is now done by a post-process gauging machine, onto which components are loaded after both sides have been machined on the lathe. The lathe has two links: one to the host computer and one to the post-process gauge. The gauge measures a number of critical dimensions. The deviation of every gauged feature from the ideal size is fed back to the host computer, which then will update tool offsets on the lathe. Balancing of flywheel components is carried out on a balancing machine of German manufacture. This performs any final correction of component dimensions required by measuring the component, determining how far it is out of balance and removing surplus metal with a drill-head. The FMS also includes a camera-based vision system to correctly orientate turned parts for presentation to the machine tools.

Computer control is provided by an IBM minicomputer. Output is displayed on three visual display units and a printer located in the FMS control room directly beside the system. The system is "menu-driven". All files have a series of sub-menus called up by depression of a given key on the keyboard.

The FMS is designed to produce three different families of large turned components in a set order of operations for an existing range of small 500cc engines. Some tolerances (particularly bores) can be as tight as half a thousandth of an inch. The component families (which have cycle times of between six and nine minutes) are three types of bearing housing, eleven types of flywheel, which in turn divide into disc wheels and spoked wheels, and one gearwheel blank. The materials machined are cast iron and spherical graphite. Three new types of flywheel (two spoked and one disc) have been introduced into the system since production started in late 1984, although only one of these is fully "proved out". There is considerable capacity for future expansion of the part range as a number of types of bearing housing and gear wheel blank are still being sub-contracted to outside manufacturers. An average batch size would probably be one hundred.

The only direct labour in the entire cell is one worker, who is classed as a setter/operator, for each of the three shifts. Scheduled and breakdown maintenance were formerly the responsibility of the equipment suppliers. Now scheduled maintenance is mostly done by the company's service engineers based at the headquarters plant, who are on twenty four hour call-out to the FMS.

xiv) Plant N

This plant is one of two sites owned by a manufacturer of large diesel engines for power generation and marine applications. The company is a subsidiary of a British-owned multinational firm, which also has an interest in other diesel engine manufacturers (including Plant M above). In 1983 the company's sales were £47,000,000. The company has been badly affected by the recession. The plant has suffered heavy redundancies in recent years, declining from a peak of some 1200 employees to approximately 950 at the time of interview. Also it was trying to reduce the amount of floorspace owned in order to reduce the rates bill. Ability to contract floorspace is hindered by the company's very wide-ranging production requirements in a batch mode. It is necessary, for instance, to retain a lot of older special purpose machinery for certain jobs rather than being able to just switch to a smaller number of CNC machines.

From the outset the company was intending to purchase some form of FMS anyway to solve its production problems, particularly that of tooling variety. The FMS being supplied is very much a relatively cheap and proven off-the-peg system, employing a minimum of development work. For this reason the firm has used the services of a German company with which it has considerable previous experience as a supplier of stand-alone CNC machine tools, which has taken charge of the project on a turnkey basis. This company had the advantages of offering a standardised FMS "package" which could also cope with the high tooling requirements at Plant N. The system cost a total of £1,900,000 and 10% of this cost was supplied by means of a government grant.

Installation of the FMS was planned to take place in a number of stages as follows: 1) Operational by September 1985 - two machining centres and a rail guided pallet system; 2) 1985/86 - third machining centre and a washing station, plus extra rail guiding for pallets to be added as necessary; 3) 1986 - fourth machining centre and possibly an inspection machine.

Thus the system will eventually consist of four identical machining centres each holding seventy-two tools, which will be fed by a rail-guided pallet system incorporating pallets of various sizes according to the components on the system. In the first phase two of the machining centres will be fed by six pallets loaded from three loading stations, one of which is for special purposes. The tool presetting unit is connected to the DNC computer and automatically transmits tool radial and length offsets to the latter. This then updates and automatically compensates the part programs as necessary. The machining centres are equipped with historic tool life monitoring, probing and adaptive control facilities. As with other FMSs, however, it was unclear at the time of interview whether the probing facilities would actually be used.

The most original feature of the FMS will be a central tool library behind the machining centres, to which tools will be robotically downloaded. Tools will nevertheless have to be manually loaded into the tool library in the first instance and barcoded to enable recognition of their position by the host computer. The host computer is most sophisticated at tool management duties. It also undertakes automatic scheduling (although emergency manual scheduling is also possible).

As regards overall process control the company is working towards a two-tier DNC system. The FMS will have its own host computer but this will also be connected into a higher-level DNC link-up which will control all the CNC machines on the shopfloor. This level of DNC will be controlled from the Production Office. A CAD/CAM system will also be linked up to this level of direct numerical control.

The system will initially machine in four set-ups some twenty to twenty five parts common to all models of engine. These parts are fashioned from cast iron, aluminium and steel and have cycle times varying between five minutes and two and a half hours per set-up but averaging an hour and a half. Positional tolerances average one thousandths of an inch and the tightest tolerances are half of this. The tightest boring tolerances are of three-tenths of a thousandth of an inch. It is intended that a mixed range of new parts will gradually be added to the system over time until there are about sixty parts running. Included in these new components will be some parts that are currently sub-contracted. Examples of planned reductions in batch size on some of the components to be machined on the system include: cams - from forty down to eight; cylinder heads - from thirty down to one; pistons - from forty down to ten. In this last example very high fixturing costs (£30,000 per fixture) preclude lower batch sizes on economic grounds.

It is intended to run the FMS with two operators per shift. Management consider the important requirements for workers within the system are initiative and flexibility in the sense of being willing to undertake a variety of jobs such as tooling activity, loading, and editing of NC programs. The remaining skill areas relate to the setting of particular components to go on the FMS, which in certain cases is quite complicated; and to knowledge of tooling. It was not clear at the time of interview what procedure would be employed for part inspection. The plans for the FMS possibly include an automatic inspection machine but some members of management feel that its utilisation level would be low. It is nevertheless possible that operator inspection using gauges may be retained. Alternatively (as with Plant A), if a coordinate measuring machine is purchased, it may be sited near the FMS so that it could be used for other work as well. Maintenance will be performed by the existing maintenance staff, who will be sent to the supplier's premises in Germany for a training course.

xv) Plant P

This company is in the aerospace industry, nearly all work being defence-related. It is mainly owned by a major British aerospace group, the minority shareholding being held by an American corporation. 1984 turnover was £63 million, and the company employs in total some 2,000 persons. It operates on two sites in South West England, the headquarters being part of the same site as those of the parent company. Both in the main plant (where two FMSs are now either running or in the process of installation) and in its satellite plant - where the small-scale FMS studied here is located - the company has also been an early British user of flexible manufacturing technology.

The company's first FMS, costing about £1,800,000, was installed in this satellite plant, which is located only some ten miles from the headquarters to which it is linked on-line. A government grant supplied about one-sixth of the cost of the system, the remainder of the finance being internally generated. Production began in 1981 although the linking of machine tools, transport and host computer comprising an FMS was not completed until late the following year. A contract from the British Ministry of Defence to produce ejector release units (ERUs) for a fighter aircraft was won and it was agreed to use this contract for an experiment in FMS manufacturing methods.

At the outset the shopfloor was re-equipped for production of the ejector release units. This involved the installation of a bar-fed lathe, two grinders, a mill, drill, spark eroder (nearly all of which are stand-alone CNC machines); as well as deburring, crack detection, heat treatment, cadmium plating, assembly and testing facilities. Two identical four pallet stand alone machining centres were bought from a major British manufacturer of such equipment and installed at one end of the shopfloor to perform the majority (about 70%) of the preliminary machining work needed on the components.

The developmental work for the FMS was performed largely by a project team comprising representatives of the company and also staff and research students based at one of the nearest British universities. The development process from stand-alone machining centres to their linking into an FMS to manufacture these components nevertheless seems to have been a piecemeal process. Gradual improvements to productive efficiency were part of the original production engineering philosophy for the facility. As explained by the plant's superintendent particular production problems meant that first automatic tool changing was found to be required followed by automatic pallet loading. These facilities were engineered in association with the suppliers of the machining centres. Additionally the company itself engineered a hydraulic system. Finally computer hardware was added and linked into the computer databases of the main plant.

The hardware of the FMS consists firstly of two identical machining centres fronted by a circular four-pallet table. Each machine carries forty tools with an auxiliary conveyor capable of storing a further eighty tools. Tools are loaded to the magazine by the operator. In front of these stands a rail-guided transport system which carries thirteen pallets with dedicated fixtures. The FMS is controlled by a large DEC minicomputer of a type with which the main plant had already gained operating experience. This controls and optimises the loading of the machining centres, controls production, and produces a variety of management information on production statistics, "downtime" and maintenance information, etc, which can be printed out on-site. Although the host computer has facilities to monitor the wear of tools (though not their breakage) through tracking the progress of each tool towards a pre-programmed life previously assigned, our information indicates that this is not used in practice. Operators instead monitor tool wear manually.

The FMS is used to manufacture the eight components out of maraging steel for ejector release units with the highest value added. Each ERU contains a total of some one hundred parts (mostly of low value and machined on other facilities). The eight components on the FMS are small but complex in shape and require about six or seven machining operations each. Components consist of a main casing plus a number of hooks and plates requiring extensive milling, drilling, reaming and tapping. Tolerances are as low as four thousandths of an inch. The maraging steel of which they are made is a very difficult material to machine because of its extreme hardness. Additionally, its swarf tends to stick on to the tools and has to be pulled off by hand. Cycle times can last up to four hours or even more.

At the time of interview a new set of components unrelated to the ejector release units but fitting within the machines' specified part size capability were being programmed and proved out. The new parts consist of seven aluminium alloy components for a small engine, all of which are machined on one fixture. Total cycle time is forty minutes. Subsequently the FMS has now been used to produce these items on a commercial basis.

Versatility in terms of batch sizes remains questionable. One limitation is that the original aim of producing components on the FMS in sets seems to have been unofficially abandoned. The necessary resetting time for such continual changeover between components was considered to take too long. Monthly production requirements are fairly steady and predictable at seventy units per month, and thus components are usually now machined in batches of approximately this number in order to minimise changeover time. Because this arrangement allows a small reserve stock ("buffer") to be built up, scrap problems arising from particular faulty components, which might otherwise mean failure to meet output targets, can be minimised.

Administratively the plant is run by a superintendent who acts as a general overseer as well as a supervisor of the FMS part of the facility. Due to the small size of the plant there is little formality or hierarchy to be observed in the relations between superintendent and workers. The superintendent's role is basically "human resource management" and he is responsible for selection of new workers at the plant when required.

All the shopfloor workers at the plant were originally skilled workers employed at the company's headquarters plant, from where they applied for and were granted a transfer. Most have now been working at the plant since it was originally set up in 1981, and this is true also of the personnel tending the FMS. As there are some 775 skilled workers on the shopfloor at the main plant there was no difficulty in obtaining workers with the right skill levels willing to transfer. To varying degrees the FMS operators take a role in first-line maintenance in the case of minor breakdowns in order to avoid having to wait for a maintenance engineer from the main plant. Final inspection after the testing of assemblies is still performed by two inspectors (indirect labour) based on-site, although the FMS workers do help to inspect the work that comes off the machining centres. Toolsetting for the whole plant is performed by a worker dedicated to the toolroom.

xvi) Plant R

The company concerned is one of Britain's first users of a flexible manufacturing system. The FMS was originally set up as a separate company by the parent firm, which is a British-based multinational with about forty trading subsidiaries operating in three main business areas: scrap metal, cranes, and machine tools. The group's machine tool activities made an overall loss in 1983 and 1984 as a result of the economic recession but returned to show a slight profit in 1985.

Of the nineteen companies comprising this latter group two are manufacturers of centre lathes, one based in Northern England and the other in Eastern England. Originally destined for the site of the Northern company the FMS was actually installed in a spare building owned by this other subsidiary East England company, a major British manufacturer of standard centre lathes employing about five hundred people. 1984 turnover was £14,000,000. For some time the FMS was not integrated into the business activities of the other firm on the same site, although this process of absorption has been taking place since the beginning of 1985. Originally the FMS was formed into an entirely separate company (although recruiting managerial, technical and operating personnel from its partner).

In 1976 the then Labour Government, through its Department of Trade and Industry's (DTI) Automated Small Batch Production (ASP) Committee, was presented with a report recommending the development of a flexible manufacturing system within British industry. The Government sent out a letter to all machine tool manufacturers seeking companies prepared to develop some form of FMS with the aid of government finance to do so. The parent company was the only one to respond positively to this letter at that time. The Chairman of the parent group took the DTI's letter as an oppportunity for the company to expand its hitherto rather traditional base in machine tool technology.

The Group put a figure of £100,000 on setting up a feasibility study, and the money for this was granted by the government in mid-1977. The feasibility study was presented to the British government at the beginning of 1978. The parent group put a figure of £3,000,000 on the project, and in early 1979 a three-year contract was signed with the government for the design and implementation of an FMS. The parent group formed a new subsidiary company for this purpose. The Government paid 75% of the cost of the project, which was finally completed - slightly overdue - at the end of 1983. During 1984 the new company used the FMS for teaching and demonstration purposes, plus some sub-contracted production from other machine tool subsidiaries of the parent group. By the end of 1984 the parent group felt it had reached the point where it had gleaned as much knowledge on FMS for learning purposes as it needed. The knowledge gained and the system itself is now being passed on for production purposes to the sister company, to whom the management of the FMS has been turned over, while the original company is using the knowledge gained to become an FMS consultant and supplier instead.

The FMS is contained in the whole of one shed and comprises nine machine tools laid out in linear fashion. The first four machines are two two-axis CNC lathes and two five-axis CNC lathes (an adaptation of the previous type, employing a robot vision feature for part orientation), which perform first operations. These tools were supplied by the company which has now taken over the FMS. The two-axis machines were prototypes for a new range of CNC lathe the company now markets. The five-axis machines were also prototypes but have not been commercially marketed to date. There are sixteen tools in the two-axis lathes and twelve per turret in the five-axis lathes. The turning machines are followed by five second operation machine tools: a gear chamfer; a gear shaping machine; a cylindrical grinding machine; a hobbing machine; and finally a horizontal broaching machine. The latter two are non-NC machines but function automatically, being initiated and stopped by relay switches. Parts are delivered to the tools by eight robots (the last two machines being served by one robot) supplied by a new division of the parent group and specially developed for the system in association with a Japanese machine tool supplier. The robots pick the components from pallets, and also perform the crucial role of counting components on and off the machines in the system: this data is fed back to the central computer from the robots so that the host can keep track of the progress of a batch. Pallets are transported from any of six loading stations to the machine tools upon a continuous roller conveyor. All the above is under direct control from an adjoining room by a pair of Systime host computers (one of which is used as a back-up). Much of the software is now being changed as the purpose of the FMS has changed from a demonstration and teaching to a production facility.

Since the beginning of 1985 the FMS has been fully absorbed both for production and administrative purposes within the sister company. At the time of final interview, however, considerable work was recognised as still being necessary to meet the revised production requirements. Direct computer linkages into the production databases of the main company are still very limited, however.

The FMS produces a range of the low value turned components incorporated into the company's range of lathes within an envelope of 220 millimetres diameter by 420 millimetres length. Such parts produced on the FMS include gears, discs and shafts machined out of steel, cast iron and aluminium. Parts produced on the system have both changed and increased since the change of ownership. Work sub-contracted to the FMS from outside plants is being phased out in favour of freeing the capacity for concentration on in-house work. Ultimately the FMS may produce one third of the company's suitable small turned parts.

At the time of interview the FMS was still very much in the process of conversion to new work, with about four-fifths of the adaptive process still to be undertaken. Programs for one hundred and seven different components had been "proved out" for the system, forty of which had been written since the change of ownership at the turn of 1984/85. The time required to change tools, machine settings, etc, over between different batches of components is about half an hour. The average batch size is approximately fifty.

The FMS is now supervised by a system manager, and there are four other personnel employed within the FMS: two direct workers and two programmers (one of whom is a temporary addition). The labour issues arising in the FMS are comprehensively discussed in the main body of the text. The workers are responsible, to the degree they feel competent, for minor maintenance on the FMS. More major maintenance (machine breakdowns, etc) is the responsibility of the company's maintenance department, whose responsibility it will be to develop a planned maintenance policy for the FMS.

APPENDIX TWO: Additional plants visited providing supplementary information

i) Overview

A number of other plants were surveyed in addition to the fifteen plants supplying the main information in this study. These were initially visited as they were believed to be installing flexible manufacturing systems meeting the Department of Trade and Industry's definitional criteria. In the event this proved not to be so. In two cases (Plants T and X) plans to install FMS had become subject to either cancellation or to significant delay and revision. In the remaining four cases press reports suggesting the purchase of FMSs proved inaccurate when the plants were visited. The systems seen being operated in these cases consisted of stand-alone CNC machining centres or DNC systems and, in one case, a CNC flow-line.

These plants did however provide some extremely useful background information about the use, problems and capabilities of CNC and DNC systems in small-batch engineering companies. Further, these plants allowed some interesting insights into the difficulties of applying FMS (as defined by the DTI) to small-batch production. For these reasons brief background details on these supplementary companies are given here.

ii) Plant T

Plant T is the home counties headquarters plant of a manufacturer of control and instrumentation equipment for power stations. It employs approximately 800 people, of whom some 200 are direct workers. Sales in 1984 were £24 million.

In 1983 the plant was planning to install a FMS based upon an interlinked CNC lathe and machining centre under host computer control to produce an undecided number of electrical signature transmitter components. An FMS Support Scheme grant was awarded for this project. The FMS plans were however scrapped during 1984 after the purchase of these two machine tools, which were thus operated in a stand-alone fashion. Each machine has its own operator. Simpler jobs on the machining centre are programmed by manual data input, whereas all work on the lathe is programmed thus. Long-term plans were afoot to put these machine tools under direct numerical control pending the necessary investment funds being granted.

The planned FMS was abandoned for three reasons. Firstly, it was felt that too little expertise existed at the time of interview on the difficulties of combining machining centres and lathes in FMS, especially the materials handling problems. Managers argued that the machine tool suppliers had been unwilling to perform enough of the necessary developmental work. Secondly, it was argued that the plant's batch sizes, mostly less than a hundred and more commonly as low as twenty, were too small to allow a reasonable level of system utilisation from an FMS. Lastly, it was felt that too few of the plant's components required operations on both the lathe and machining centre to justify interlinking the two.

iii) <u>Plant U</u>

This company is an expanding family-owned machine tool manufacturer based in East Anglia. Most of the output consists of CNC vertical milling machines. 1985 sales were £6,500,000 and the firm employs roughly 200 workers.

In the period between 1983 and 1986 the company has been introducing a CNC transfer line to machine from castings fourteen different base, column, saddle, and headstock components for machine tools. Reducing lead times on these parts was the main reason for the introduction of the system. The system consists of two plano mills, CNC milling machine, a slideway grinding machine, CNC milling / drilling machine and induction hardening facilities. All tools were of the company's own make, or bought secondhand and reconditioned in-house. Transport of parts within the system is the task of cable-operated wheeled trolleys. The system is not under direct numerical control and therefore no government grant from the FMS Support Scheme was available. The system is staffed by three workers on each of the two shifts run. Part programs are written and edited by the company's own specialised programmers.

iv) Plant V

This company is a small home counties manufacturer of drinks-dispensing equipment such as handpumps. It employs some 200 people and its turnover in 1985 was £5,250,000.

The system studied was supplied on a turn-key basis by a German company, and consists of four bar-fed CNC lathes under direct numerical control. The lathes are in two groups of two, one being used for initial cutting and the other group for second operations. The DNC system is used to machine a variety of the company's turned components. The system's main aims are to reduce setting-up times for low batch size runs and to overcome a shortage of skilled labour which was felt to be holding back the expansion of production.

The company has never had a separate programming department and, for this reason, control of the DNC system is entirely devolved to craft-trained personnel. Six skilled setter/operators have been trained to program and operate the system.

v) Plant X

Plant X is a northern machine tool manufacturer, and for some years part of a group with various interests in machine tools. Considerable rationalisation and retrenchment was taking place within the group during the period of fieldwork. The company's speciality is very large general purpose CNC milling machines, of which four main types are produced. Sales in 1984 totalled £12 million and the firm has 390 employees.

The company originated a plan in mid-1983 to build an FMS to machine twelve large parts (such as columns, rams and gearboxes) for its range of machine tools. The main aims were to cut the level of work in progress, increase machine utilisation and reduce set-up times. The system was to comprise two of the company's own CNC milling machines linked by a rail-guided vehicle and under direct numerical control. One of these machining centres would be the first phase of the FMS.

At the time of interview these original FMS plans were in a state of suspension. It appeared that the development of the system had been rushed with a view to exhibition of the FMS at a machine tool show in 1984. Interviewees now thought however that the initial design concept was too grandiose, and the project was being replanned with a view to the eventual installation of a rather smaller scale system.

vi) Plant Y

This firm is a southern England manufacturer of tobacco- and cigarette-processing machinery. It is owned by an American multinational company which keeps tight budgetary control over this subsidiary. Rationalisation measures affecting design, assembly and inventory-holding were under way at the time of interview. The company has 650 employees on the site, of whom 212 are directly productive. Its sales were £38 million in 1983.

Inaccurate press reports suggested that the company was intending to link a number of horizontal CNC machining centres to form an FMS. In the event only stand-alone machine tools were planned. The machine tools studied included two new German horizontal CNC machining centres with dual pallets and automatic tool change. These were staffed by an operator on each shift. Programming was carried out off the shopfloor by part programmers although operators helped to edit these. Also studied was one CNC vertical milling machine, also with automatic tool change, which (unusually for this company) was programmed by manual data input.

vii) Plant Z

The plant is an engineering subcontractor in the home counties, specialising mostly in aerospace and defence work. It has five hundred employees and sales in 1982 (the most recent figure available) of £10 million.

At this firm a DNC link was gradually being installed to ten of the CNC machine tools on the shopfloor. Interlinking of materials handling was considered out of the question because of the small batch sizes and continually changing nature of the jobs machined.

The machine tools studied at this firm included an advanced Japanese horizontal machining centre with quintuple pallet change, adaptive control, a three hundred tool magazine and computer controlled inspection facilities. Many of these "automatic" features were not actually used in practice, partly because of the time required to programme them and also because of a lack of technical knowledge within the firm as to how they worked fully. Also studied were two vertical CNC machining centres with limited automatic tool change and a horizontal machining centre without this facility. All of these tools were staffed by skilled machinists. Programs were constructed away from the shopfloor but operators were permitted to edit programs.

APPENDIX THREE: Reasons for FMS introduction, and types of flexibility demonstrated by FMS case study plants

PLANT A

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Reduction of lead times

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Yes. Little need to retool system due to high overall tool capacity.
Mix	Yes. Production of components in batches of one.
Routing	Minimal because very limited tooling duplication between machines. Now receiving attention.
Volume	Probably, but at present running significantly below capacity.
Size	No room for expansion.
Modification	Yes. Some modification undertaken, particularly as result of poor programs and materials supplied.
Product	Limited to small range of new components because of tooling management problems.

PLANT B

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Rationalisation of machine shop facilities between sites to benefit from economies of scale and updated technology.

Increased overall control of production process by extension of DNC and machining in-house.

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Yes, but currently limited due to high tooling inventory. To be improved by mechanisation of tool delivery to FMS.
Mix	Yes
Routing	Yes
Volume	In practice production requirements are of fixed volume.
Size	Yes
Modification	Theoretically yes, but in practice part specifications are fixed by Ministry of Defence requirements.
Product	Theoretically yes.

PLANT C

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Cut inventory and work in progress by production in sets

Cut indirect labour costs

Further reduce unit cost of components

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Yes. Need for toolchanging considerably reduced by rationalising tooling and part designs.
Mix	Yes
Routing	Yes
Volume	Unknown
Size	Yes. Being expanded as finance becomes available.
Modification	Yes, although unknown if used.
Product	Yes, although new products are of same basic type.

PLANT D

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Manufacture for following day's assembly requirements

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Yes. Considerable tooling duplication
Mix	Yes. Production in sets as necessary
Routing	Yes. Identical machine tools and tooling.
Volume	Yes.
Size	Room for further expansion unlikely
Modification	Yes. Minor design modifications incorporated during early stages of product cycle.
Product	No.

PLANT E

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Cut inventory and work in progress by production in sets

Cut labour cost

Improve quality standards

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Yes
Mix	Probably, but not known wheter this is used in practice.
Routing	Yes. Identical machine tools and tooling.
Volume	Yes.
Size	No
Modification	Yes. Unforeseen design changes to pumps incorporated. "Master family programming" macro facility eliminates need for full reprogramming when new pump designs introduced.
Product	No

PLANT F

MAIN STATED AIMS FOR INTRODUCTION OF FMS

In-house demonstration of FMS capabilities

Reduced lead times

Reduced batch sizes

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Limited
Mix	Not at time of interview
Routing	Not at time of interview, but will be available when second machine tool added.
Volume	At present running below capacity.
Size	Limited scope for expansion because little space available to house additional pallets and fixtures.
Modification	Unknown if used
Product	Limited (see size flexibility above).

PLANT G

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Increased control over production process

Ability to expand machining capacity at low labour and organisational cost

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Limited by low tooling capacities
Mix	No
Routing	No
Volume	Yes in theory, but almost always unit production in practice.
Size	No
Modification	Yes. Macro facility eliminates need for full reprogramming when new seal designs introduced. Also rapid ability to modify existing programs, e.g. through manual operations.
Product	No

PLANT H

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Reduce economic batch quantity

Reduce throughput times

Increase levels of machine utilisation

Increased control over labour and production process

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Yes. Toolchanging possible while machine tool cutting.
Mix	Limited. Policy decision to minimise number and variation of pallets in system at any one time.
Routing	Yes (but see mix flexibility above)
Volume	Limited.
Size	Yes
Modification	Yes. Part redesigns and prototype components can be incorporated. However, part modifications are limited by need for National Coal Board approval of modifications.
Product	Limited to new ranges of valve.

PLANT J

MAIN STATED AIMS FOR INTRODUCTION OF FMS

In-house demonstration of FMS capabilities

Reduction of work in progress

Modernisation of production facilities

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Yes
Mix	Not used at present
Routing	Yes
Volume	Unknown
Size	Being expanded as finance becomes available
Modification	Yes, but not known if used in practice
Product	Yes, but limited by expense of dedicated pallet/fixture combinations

PLANT K

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Reduce economic batch quantities to adjust to smaller volume market

Improve product quality

Reduce labour costs

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Limited in practice
Mix	No
Routing	No
Volume	Yes (although batch sizes high by FMS standards)
Size	Plans for expansion in medium-term future
Modification	Yes, but not yet used in practice
Product	Yes, because components currently produced are not those originally planned. At present no known plans for production of new products on FMS in practice, however.

PLANT L

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Increase machine utilisation, introduce unattended running

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Yes. High tooling duplication
Mix	Unknown
Routing	Yes
Volume	Probably
Size	Unknown
Modification	Yes, but unknown if used in practice
Product	Possibly new work to be added in future, but no firm plans.

PLANT M

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Increase control over production by machining in-house

Manufacture according to needs of following week's assembly requirements

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Limited. Rationalisation of tooling has reduced need for changeover of tooling <u>within</u> families of parts.
Mix	No
Routing	No
Volume	Yes (although batch sizes high by FMS standards)
Size	Yes. Intended to be able to expand or contract system as necessary.
Modification	Yes
Product	Limited ability to introduce further families of parts

PLANT N

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Reduce set-up times

Reduce economic batch quantity

Increase machine utilisation

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Yes. Aided by central tool delivery
Mix	Yes
Routing	Yes
Volume	Limited due lack of fixture duplication
Size	Being expanded as finance becomes available
Modification	Unknown if used
Product	Yes, but limited in practice by fixture costs

PLANT P

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Reduce inventory and work in progress

Increase machine utilisation

Reduce labour requirements

Familiarisation with FMS technology

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	Yes
Mix	Yes
Routing	Yes
Volume	Production level requirements per month fixed
Size	No
Modification	Yes, but in practice part specifications are fixed by Ministry of Defence requirements.
Product	Yes, although so far only one major change in product manufactured.

PLANT R

MAIN STATED AIMS FOR INTRODUCTION OF FMS

Originally: experimental and demonstration FMS; reduction of throughput times.

Now: proof of commercial justification of FMS; increased machine utilisation

TYPE OF FLEXIBILITY DEMONSTRATED

Machine	First operation lathes very flexible. Set-up times on second operation machines high. Second operation machine tools due to be modified or changed at time of interview to increase flexibility.
Mix	Yes
Routing	Yes, on first operation lathes. Not on second operation machine tools.
Volume	Limited
Size	Yes, within limitations of site.
Modification	Yes
Product	Yes, within certain families of parts.

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