SKILL BASED AUTOMATION: CURRENT EUROPEAN APPROACHES AND THEIR INTERNATIONAL RELEVANCE

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Within management, innovation and industrial relations literature worldwide there has been widespread debate over new emerging models of best practice production and their implications for global manufacturing. This has been particularly prominent in discussions of post-Fordist and lean production production regimes. This paper extends this discussion beyond industrial relations and management debates and into the sphere of new approaches to production technology design and implementation. The paper provides an outline of the positive European challenge to lean production models provided by skill based design and automation principles and initiatives. The purpose of this paper is to assist the introduction of this orientation to a broader audience by summarising its key components and discussing its international relevance.

Keywords: skill based, systems design, human centred, anthropocentric, cell manufacturing, NC programming, production islands.

INTRODUCTION

In Australia and internationally there has been an extensive debate over the nature of new production systems, whether these are defined as flexible specialisation, post-Fordism or systemation.[1] Within the industrial relations, management and organisational literature, there has been a strong emphasis on the changes in work organisation made possible or even determined by the arrival of new flexible computer based process equipment. The arrival of such equipment it is argued, makes possible highly automated yet flexible production lines allowing diversified quality production.[2] This, in turn, requires intelligent socio-technical systems that enhance operator skill and responsibility in order to ensure rapid and effective changeover between products, built in quality and more rapid product innovation.[3]

Despite this stress upon the implications of new CBTs (computer based technologies), however, remarkably little attention has been paid in this debate to the actual features of different CBTs that facilitate or hinder more intelligent socio-technical systems. Hardware and software, system architecture and human/machine interfaces are often lumped together

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in one category and simplistically portrayed as having a strong affinity with particular types of work organisation or agnostically proclaimed as having no organisational implications.[4] Moreover, there has been even less attention paid within the post-Fordist debate to the social shaping of these different features of CBTs, although there is an increasing amount of research on this issue.[5]

This lack of detailed attention to the shaping and impact of CBTs is in sharp contrast to an alternative research agenda that has attained prominence within the engineering, job design and system design communities and is supported by humanisation of work programs and initiatives in German and Sweden and at the European level. Of particular importance in this research agenda has been the work of such organisations as: the Social Effects of Automation Committee of the International Federation of Automatic Control; the West German Humanisation of Work (now Work and Technology) and Manufacturing Technologies programmes; the Swedish Work Environment Fund and Centre for Working Life; and the European Strategic Programme on Information and Communication Technologies (ESPRIT) and Forecasting and Assessment of Science and Technology (FAST) programmes.[6] Within this general agenda, there have been different debates centring around human centred systems, skill based automation, anthropocentric systems, work oriented systems, and computer supported cooperative work. Yet one common theme unites these concerns: that the nature and impact of new CBTs are influenced by technological paradigms that incorporate images of who will be using CBTs and the purposes for which they are to be employed; that traditional engineering paradigms have a particularly restricted view of the human operator that results in the creation of deskilling and control oriented systems; and that an alternative skill based approach can create new systems that utilise the capabilities of CBTs to improve flexibility, quality *and* working conditions. This represents an important extension of the post-Fordism debate, grappling as it does with the crucial issue of the social forces shaping technology system designs, and how these can be influenced to design and implement systems that support job enrichment, worker autonomy and industrial democracy.

DEFINITION OF SKILL BASED AUTOMATION

Skill based automation is commonly used to refer to production technology, socio-technical production systems, and/or strategic production objectives. In addition, it involves a specific vision of the design process involved in establishing such systems and realising these objectives. While skill based automation is strongly rooted in a technology design strategy, it is thus against any general orientation to technology design that restricts its scope to technical system design. All four features of skill based automation are ultimately interlinked in a vision of new production systems that emphasises the necessity and desirability of developing systems that have as a key component the utilisation and enhancement of direct production skills. For the remainder of this paper, skill based design is to be taken to refer to the approach to system design that adopts this vision of production systems as its main guiding criteria, whereas skill based automation is to be identified as the realised systems.

There are, not surprisingly, crucial variants within the skills based design approach, related to such issues as the relative importance of technology, the type of skills that are prioritised, the degree of autonomy to be given to individual and group work, the nature of participation required in system design, and the justification for the new systems. A certain general consensus can be discerned, however, and needs to be clarified, for the exact meaning of skill based is frequently left unclear. All technologies remove some human skills from production and create others and, of these, different skills are valued and located in the hands of more or less powerful production groups. Which of these skills are prioritised as central and worthy of support rather than removal through automation? It can be legitimately observed that in the particular case of computer based technologies, manual skills are frequently replaced through automated transformation, transfer and control processes. New technical skills are often created to select, programme, maintain, monitor and develop the computer based systems. In addition, the removal of various skills and tasks by computer based automation makes it possible to create broader multiskilled jobs for system users combining a number of previously much narrower jobs specialising in one area of the production system. In face of these shifts in skill and jobs, what criteria can be employed to distinguish and promote particular forms of automation as skill based and deny the title to other forms?

A minimal and conservative response is that the skills that are prioritised are those presently available amongst production workers. The argument for such a priority is made on the grounds of efficient system implementation and development, necessary workforce motivation, and humane considerations in the face of potential unemployment and degraded working conditions. It is emphasised that for these reasons greater attention should be paid to utilising, adapting to, and improving the efficiency of existing skills rather than seeking to replace and automate either as much as possible or what system developers believe to be desirable or necessary. This response informs and explains much of the support given to skill based automation within Europe by craft unions and social democratic government initiated programs.

This response is far from sufficient. While explaining much of the political motivations behind skill based system promotion, it fails to address the more fundamental criticisms that skill based design approaches make of traditional views of automation and human operator skills and judgement. Most prominent amongst these are:

the neglect of the intimate connection between manual and mental skills and their interdependence in creating a comprehensive idea of system characteristics and the purposes for which they are employed;

the lack of integration between formal technical skills and tacit practical skills in the effective development and use of computer based systems;

the absence of a reconsideration of system development methods and goals for designing automation appropriate to small to medium sized producers. An over-reliance on those formed in the creation of systems for large firms using expensive centralised computer systems that fail to utilise the potential of human/machine interface advances, programming flexibility and distributed system capabilities;

the lack of attention to the degree to which industries characterised by craft skills, small to medium size producers, and customised products require an alternative form of automation to the mass production and lean production models in order to compete with these models, i.e., oriented towards loosely coupled systems, the responsible autonomy of production groups, and a high degree of continuous innovation and both product and production flexibility; and

the limited and inadequate form in which user skills and experience, in both tacit and explicit forms, are often given a role in the system design and development processes, and the relative lack of attention to facilitative design techniques and system capabilities.

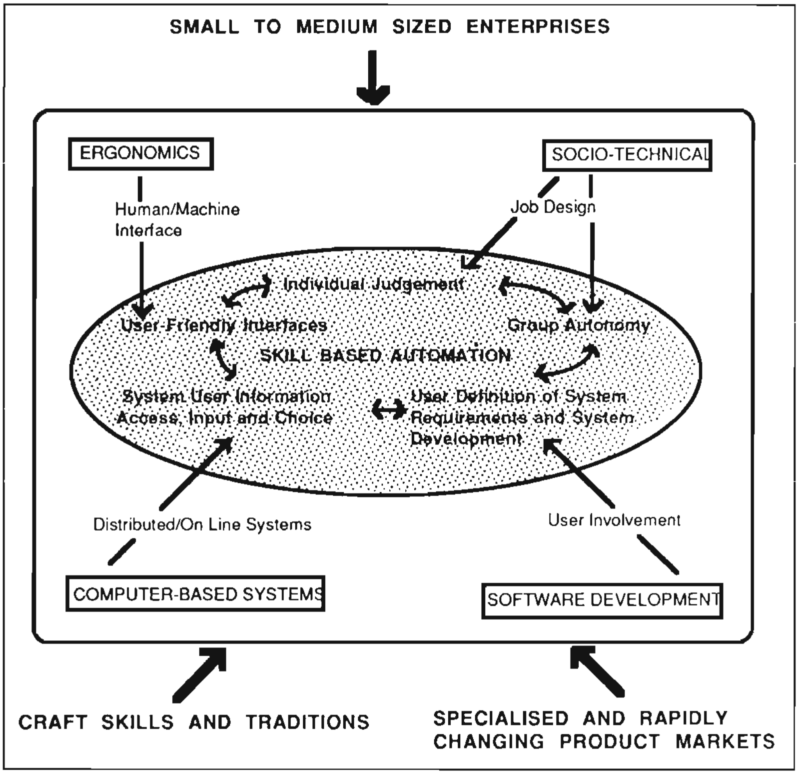
In addressing these issues, the skill based design approach provides a significant extension beyond traditional more restricted approaches to technology and job design. The key elements of the approach are represented in Figure 1.

Skill Based Automation as a Technological System

Skill based technical systems are those which support rather than undermine the utilisation and development of both tacit and formal production skills in both the use of systems and the understanding and development of systems. The design ideal is opposed to Taylorist or traditional engineering/technocratic approaches that (i) identify efficiency with the maximum extraction, codification and automation of all production knowledge and skills, (ii) view the remaining human activities within engineering systems as temporary sources of error or disturbance, and (iii) define human factors issues as training in the requirements of system use and measures necessary to sell systems to users and prevent opposition. In contrast to this view a design ideal is upheld that is committed to the creation of human/machine systems that subordinate the hardware and software of machine systems to the control of the human operators.

In computer system design the emphasis is on computer support of worker initiative and group work, and the creation of transparent tools for use by users skilled in the production area in which they are to be

FIGURE 1
Skill Based Automation and Its Key Influences



deployed. In European initiatives to promote human centred or anthropocentric technologies, the human is placed at the centre of such systems in a vision of production that both draws upon and develops traditional images of craft work and organic forms of production. The image of the skill based factory of the future is centred on computer aided craftspeople rather than monitoring and error recovery personnel maintaining an independent integrated manufacturing system. The informating potential of new technologies is utilised to the maximum to assist skilled operators to make crucial judgements concerning system operation and development. The solution to the problems of manufacture are sought in creating technology to develop and support human creativity, interaction, communication and skills in computer and human integrated manufacturing or computer aided production systems — not removing system dependence upon human skills through maximum automation, computer guided systems or computer integrated manufacture. The specific view of the complementarity between technology and humans embodied in this design ideal is summarised in Table 1.

TABLE 1
Human/Technical System Complementarity in Skill Based Design

TRANSPARENCY:	data bases are accessible to users, system status information is available, information is organised and presented in a manner that is compatible with traditional forms of knowledge and work practices, etc.
JUDGEMENT:	actions are at the user's discretion (even where these are supported, assessed and evaluated with the assistance of computers), machines are controlled by those most directly and immediately involved in their use, the choice between allocating functions to machines or humans is made by the users, etc.
AUTONOMY:	the maximum degree of autonomy must be given to users in controlling their own work and fulfilling the indirect support functions required for their tasks, i.e., maintenance, system selection and development, personnel recruitment, scheduling, incremental process improvement, etc.

This approach is thus directly opposed to approaches that interpret human factors initiatives as either secondary to technological innovation or as legitimatory job design to gain acceptance of new technology. In contrast, it extends the consideration of human factors in three ways. First, it goes beyond the task of allocating functions between jobs and incorporates the design of technological system configurations and the allocation of functions between people and machines. Despite the recognition by socio-technical job designers of the interdependence of social and technical components of work systems, job design projects have frequently failed to pay detailed attention to the character and shaping of the technical system.[7] Yet, job designers that fail to actively intervene in the initial shaping of technological systems are, in a sense, rearranging deckchairs on the Titanic. Key decisions about work are built into technological systems, and given traditional Taylorist management philosophies and technocentric views of human operators as sources of error in automated systems, the potential of modern technology to facilitate individual creativity and enriched group work may be prevented. In Zuboff's terms, systems will have automatic functions built into them and informating capabilities built out.[8]

The human centred capabilities of new systems are thus a potential to be realised in truly interdisciplinary system design, not a consequence of fortuitous developments in information technology and market conditions. The development of the skill based automation approach and the creation of exemplary models, practical design criteria and techniques, is consequently seen to be of crucial importance in influencing technology paradigms.

EXAMPLE[9]

These principles have been explicitly embodied in the design of NC Workshop Oriented Programming (WOP) software in Germany, MDI NC lathe software developed at UMIST Manchester, and DISCOSS (Bremen University) and ACiT (BICC Ltd) decentralised cell based production scheduling software, and the computer aided design (CAD) sketchpad developed in ESPRIT project 1217. If we focus on one example, the WOP system now commercially available on Traub machine tools was developed using research showing that there are economic advantages in allowing skilled workers to develop programs, yet the experience and knowledge of these workers is at odds with traditional abstract programming methods and editing devices. The WOP system provides a unified user interface for new shop-floor programming methods suited for turning, milling, grinding and sheet metal cutting. The software allows the workers to draw upon their manufacturing knowledge, planning capabilities and situational knowledge. In contrast to earlier NC programs, it is up to the worker to plan the program's flow and decide on technological data. The system keeps recurring elements and cutting cycles in a generalised pre-programmed form, and the worker uses his/her initiative in combining these modules and setting parameters. Further assistance is given by a tool data base and graphic real-time simulation of tool movements in a user interface that emphasises the graphic (rather than abstract and symbolic) representation of objects and operations. The user-friendliness of the system is evidenced by the fact that workers can use the system unaided after a quarter of an hour, and that operators with no programming experience perform, after a five-day learning phase, as well as their experienced colleagues did at the beginning. In the case of the UMIST software, further developed in the ESPRIT 1217 graphic interactive CNC lathe project, an added advantage is that it can be turned off and left aside in order for the operator to work in a conventional way if this is appropriate.

As observed by Rosenbrock, head of the UMIST project, this research appears at an important technological conjuncture. In the development of numerically controlled technology, shopfloor/manufacturing manual data input (MDI) systems and integrated computer aided design and manufacture (CAD/CAM) systems offer very different technological visions for the use and development of computer based manufacturing technology. Developments in microelectronics and computer hardware, accompanied by proven downtime and other costs of highly integrated systems, have created a techno-economic opportunity for retaining and developing traditional manufacturing skills and traditions. In this context, the importance of skill based automation developments is that they are designed to reveal and promote the economic effectiveness of the MDI option, thereby enabling the retention and computer assisted development of more traditional workshop oriented production skills. Unlike Noble, who emphasises the defeat of record playback automation models as a result of a capitalist control imperative, Rosenbrock stresses the importance of focusing on the particular use and development of NC and the transcendence of traditional engineering design prejudices. It is this connection with these broader issues that has led the skill based automation approach to a computer as craft tool ideal that extends beyond the design of user-friendly software to assist shop floor operators.

Secondly, in defining human uniquely purposive, tacit and creative skills as the core feature of skill based systems, and designing the technological system as a support for the maximum utilisation and development of these skills, the skill based approach recognises the importance of both general system architecture conditions and the influence on these of wider organisational interests and assumptions.

As Perrow has aptly observed in his discussion of the relevance of organisational theory to human factors engineering, it is of crucial importance to pay attention to "the way 'things' — equipment, its layout, its ease of operation and maintenance, — are shaped by organisational structure and top management interests, and in turn shape operator behaviour . . . a largely unquestioned social construction of reality — one that should be questioned."[10] In contrast to the skill based approach, however, where there has been a concentration on the technical system by human factors engineers and hardware/software ergonomists, this has been largely restricted to the design of human/machine user interfaces. Even the more sophisticated socio-technical approaches have largely been found wanting. As Rosenbrock commented, while "there is a strong tradition in the social science of "socio-technical design", in which the technology and conditions of work are both studied together in the design stage", this is usually only related "to small changes at the fringes of technology". In contrast, human centred projects can be seen as attempting "to apply socio-technical design principles at a deep level in technology."[11]

Skill Based Automation as Production System

As an extension of technical system design and operation, skill based automation also incorporates a specific integration of technology, people and organisations within production systems. The general principles of job and organisation design are similar to those commonly represented in socio-technical theory (See Table 2).

The skill based approach also continues and develops upon the traditional socio-technical and organisation theory contrasts between mechanistic and organic systems,[12] low trust and high trust cultures,[13] Theory X and Theory Y management philosophies,[14] etc. with a strong commitment to the establishment of more organic systems and high trust production cultures supported by Theory Y management philosophies.[15] In this sense there are a number of similarities with the image of the skill based socio-technical integrated factory provided by writers such as Susman and Chase in the United States,[16] and the commitment to post-Fordist production systems in Australia and internationally.[17] According to these views, the contemporary introduction of flexible and integrated technologies in an increasingly uncertain manufacturing environment provides an opportunity for promoting a general increase in the need for worker skills, responsibility and teamwork. Key emphasis by skill based approaches is laid upon: maximum decentralisation of direct and indirect production functions to direct production workers; the creation of semi-autonomous groups in production cells; and continuous incremental innovation in skill enhancement, organisational effectiveness and technical system capabilities.

The production system view of skill based automation also, however, aims to incorporate and transcend traditional socio-technical and work design approaches. Within socio-technical analysis, job design evolved

TABLE 2
Socio-Technical Design Principles

The Principle of Compatability
This states that the process of design must be compatible with its objectives. If the objective is to create a participative social system then this must be created participatively.

The Principle of Minimal Critical Specification
This principle has both negative and positive parts. The negative part is that "no more shall bc specified than is absolutely essential". This means that a considerable amount of discretion is left to a work group. The positive part is that "what is essential needs to be identified."

The Socio-Technical Criterion
This is that variances must be controlled as close to their point of origin as possible. The fewer the variances that are exported from the place where they arise, the fewer the levels of supervision and control that are required.

The Multi-Function Principle
This principle is that people should not be given fractioned tasks. It is more adapative and less wasteful for each individual or group to have a range of tasks.

The Principle of Boundary Location
This principle is that boundary location must be chosen with care and that boundaries require management.

The Principle of Information Flow
Information systems should be designed so that information goes directly to the place where the required action is taken. This will normally be the work group.

The Principle of Support Congruence
Systems of social support should reinforce required behaviour (e.g. group work should have group payment).

The Principle of Design and Human Values
The objective or organisational design should be to provide a high quality of working life for the members. The original socio-technical job design principles were:
— the need for a job to be demanding and varied
— the need to be able to learn on the job
— the need for an area of decision making
— the need for a degree of social support and recognition
— the need to relate work to social life
— the need to feel the job leads to a desirable future

The Principle of Incompletion
The principle that states that design is an interactive and continuous process.

Source: E. Mumford, 'Socio-technical systems design: Evolving theory and practice', in G. Bjerknes, P. Ehn and M. Kyng (eds), *Computers and Democracy,* Gower, Aldershot, 1987, pp. 69-70.

from the recommendation of individual job rotation and job enlargement to a more far reaching examination of job enrichment and group work. It was, however, less effective in intervening in broader organisational and technological preconditions for effective job design.

At the technological level we have already listed some of the weaknesses of this approach. At the organisational level, however, the traditional socio-technical approach of the Tavistock Institute frequently emphasised the key significance of ensuring the necessary organisational supports for the establishment of effective semi-autonomous work groups. Yet, as revealed in a number of reviews of job design experiments, inadequate attention was traditionally paid to such crucial issues as corporate strategic aims and managerial philosophies, inter-departmental structures and interests, the structural system of authority and control in the organisation, job security and payment systems, and even the set of informal cultural expectations and practices of the employees whose jobs are to be redesigned.[18]

In contrast, skill based automation approaches stress, in particular, the significance of addressing broader considerations of labour market conditions and product market characteristics and strategies as a central influence upon production system design and operation. For example, as detailed in comparative international research on numerically controlled technology, a variety of production conditions and socio-organisational influences determine where programming is located, the nature of skills and responsibility at different levels of the company, and the corresponding character of the technical and organisational system.[19] No effective job and organisational design can be made if the production conditions (batch size, production volume, product complexity, programming complexity and capabilities, firm size, etc.) are not integrated into the analysis. More importantly, no effective intervention can be made to introduce skill based design principles if these conditions are not themselves subject to reflection and modification. New approaches to product market, new developments in software and system capabilities, planned segmentation of production facilities, etc. must all be shaped and made compatible with a consistent skill based manufacturing strategy. This necessarily requires skill based approaches to employ interdisciplinary design tools in the creation of systems that: effectively integrate people, organisation and technological factors; ensure the provision of the necessary supports in all three areas; and create an effective complementarity between all three components. In one sense all effective system developments are ultimately based on the integration of all three factors: the skill based automation approach is however founded upon a proposed increase in integration for the pursuit of the technical design and production system principles described above. Moreover, it dramatically extends the range of factors taken into consideration in the process of technical system design, as well as incorporating technical and organisational considerations into areas of strategic product planning in which they have traditionally been very little considered in Western manufacturing firms.

EXAMPLE

Traditional batch production is based on the functional layout of machines into groups of machines performing the same type of operation, e.g. drilling, turning, milling, etc. Products are produced in batches, and are moved from one section to another for the different operations to be performed. This process is, however, extremely complex, costly and time consuming. The time involved in setting up machines can mean that only 15-20 per cent of the time in which a workpiece is on a machine is the machine actually being used. Moreover, most of the time in which a part is in the factory it is not being worked on but, rather, being transferred between the different sections and queuing or waiting to be worked on. In contrast, the concept of group technology was introduced in the 1970s to simplify the workflow path and reduces set-up times through (i) the establishment of separate families of parts (i.e., classification of all components, standardistaion as far as possible, and grouping into families), and (ii) working on these parts in different workcells in which machines are grouped not according to function but rather their ability to perform all the required operations on the part families. Using this technique it is possible to reduce set up times by producing similar parts in one workcell, simplify the workflow by directing different sets of similar parts to their respective workcell, and reduce the amount of time spent in the complex transfer of parts between functional sections.

During the 1980s, under the title of Fertigungsinseln or production islands, the idea of group technology, combined with semi-autonomous work groups and shopfloor computer support, re-emerged as a major initiative in West Germany to meet the demands of small batch production, rapid product innovation, highly costly and risky centralised scheduling systems, and the effective utilisation of craft skill based manufacturing solution to these problems, supported by shopfloor skill enhancing and decentralised software systems.

Since the establishment by the Research and Technology Ministry of its production island project in 1980, there have been four major conferences held by the AWF Association in Eschborn, most recently in 1990, elaborating the principles and case study experiences of production islands. These proceedings represent the most extensive coverage of production island experiments. Some of the most significant projects are those established at Sulzer-Weise (Bruchsal), Felten & Guilleaume (Nordenham), and Kodak, as well as others carried out by such firms as MAN Roland, Heidelberger Druck, Mercedes Benz, Krauss Maffei, Mannesman Demag and others.

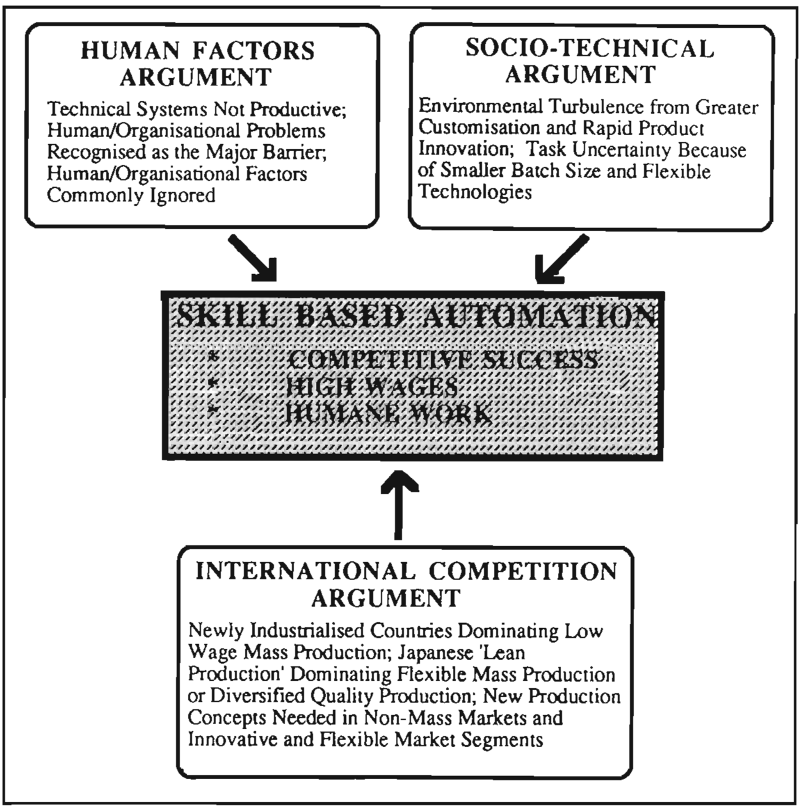
The development of the computer based and organisational supports for production islands has been assisted in Germany by a strong array of technical and social science institutes, as well as government programmes. There are at present more than 10 major university research institutes, Fraunhofer institutes for applied research and consultancy firms specialising in this area. These include: Fraunhofer IAO, Stuttgart; Institut fuer Arbeit and Technik, Gelsenkirchen; Fraunhofer IPK, Berlin; LPS, Rhein Ruhr University, Bochum; BIBA & FB, University of Bremen; AWI & IAW der RWTH, Aachen; IFAO; Technical University, Berlin; Fraunhofer ISI, Karlsruhe; ISF, Munich; SOFI, Goettingen; IHAA, TU Berlin; GITTA, Berlin; GfAH, Bonn; FgAT, Berlin; AwFi, Berlin; GhK, Kassel. (Badham and Schallock, 1991). The experiences and discussions about German projects have had a considerable effect on human centred CIM designs throughout Europe, represented at the European level for example in the semi-autonomous production islands produced by ESPRIT projects 534 an 1217.

Following from the technological research, there are presently a wide variety of German computer based production planning systems to support islands, in addition to the WOP programming software described in the earlier example. These systems operate at various levels from strategic production planning (PPS/MRP systems and mainframe support), to medium range co-ordination planning (Shop Floor Control SFC systems and workstation/pc support), and short term local planning (Local Area Cell Controllers and pc support). The basic decentralising principles of these systems are that: first, operators tasks are widened as far as possible; secondly, computer aided planning facilities are located at shop floor rather than planning department level and thirdly, as far as possible planning and scheduling functions are supported at production island rather than foreman/area control level.

Strategic Production Objectives

As mentioned briefly above, skill based automation approaches are strongly committed to providing systems appropriate to more organic production systems characterised by high trust cultures and Theory Y managerial approaches. In part this is a consequence of assumptions made about the increasingly rapid rate of product innovation and process change, the increasing reduction in batch sizes, the lessening of lead times, and the increasing requirement for customisation and quality in high-value added industries (See Figure 2).

FIGURE 2
Arguments for Skill Based Automation



This approach is also, however, explicitly oriented to nations with higher levels of skills, established trade union structures, competitive advantages in higher quality and more customised manufacturing products, and cultures and political systems based on individualism and democracy. These conditions, it is emphasised, provide real resources that can be deployed in the shaping of new production systems in a manner that builds upon and develops rather than undermines human skills. It is not assumed, therefore, that every industry in every country will (or can) follow the same route but, rather, that the above economic and political conditions broaden the range of options for some firms and nations. Those countries with, for example, higher trust production cultures and producing for more quality oriented customised markets, will have substantial advantages.[20] The promotion of human centred approaches is explicitly based on this assumption, especially by the FAST and ESPRIT programmes.[21] The objective is therefore the design and implementation of competitive strategies and supportive technological and organisational structures that will adapt to, rather than undermine, these advantages. Moreover, and this is a point of crucial importance to countries such as Australia, where there is a range of uncertainty of choice in product and production strategy, a commitment to choices that support skill based automation is advocated.

At the level of an individual firm, therefore, an important component of skill based automation systems is the presence or creation of appropriate labour market and product market strategies. Production strategies that focus on rapid product and process innovation, reductions in batch size and lead time, the effective utilisation and development of a valued workforce, and increasing quality and customisation are consequently a key feature of skill based automation systems.

Skill Based Design Process

In order to introduce skill based automation approaches, therefore, traditional production system planning and decision making processes have to be reconsidered and altered. If we take the particular case of production technology strategy many of the traditional assumptions of sequential technology-driven approaches to systems design, Tayloristic work design techniques and restricted ergonomic/human factors engineering methods are rejected, in favour of viewing new technological configurations as socio-technical systems in which the technical and social components are designed in parallel to be fully complementary. The minimal specification is that:

1. *parallel design* should a cyclical and iterative process of simultaneous planning of both human and technical aspects of the new systems; a process, moreover, in which system users should be fully involved as experts in the design and testing of system designs appropriate to the requirements of their work (i.e., system design is not a centralised sequential process of technological system design followed by the adaptation of work routines to system requirements and consultation with the workforce on detailed implementation and traditional industrial relations issues);

2. *new system design techniques* are created to overcome designers' lack of understanding of operating requirements, and the traditional problems facing user involvement in design and early consideration of social factors in the design process. Some techniques suggested have been: the establishment of practical design process procedures and design criteria guidelines utilisable in system development; the use of alternative scenarios to make concrete general socio-technical design principles; the utilisation of exploratory, experimental and rapid prototyping techniques to facilitate early consideration of concrete system models in a form accessible to system users, etc.

User participation is more crucial to this approach than many others for three main reasons. First, no objective method can ultimately be employed to detail the specific characteristics of skill based automation systems separate from the evaluations and opinions offered by system users of desirable skills, important areas for judgement and creativity, and the conditions necessary for effective work autonomy. Secondly, system users, as the subjects of the production process, cannot be restricted to a consultative role in the system design process, providing information on production to be incorporated into the system and informing system designers of the kinds of changes to work practices that users will tolerate. A key component of the jobs of users in skill based systems is to continually innovate and improve production and this includes the development of transparent computer systems. Where external expertise is required, this is regarded as assistance to the real decision makers, the system users in charge of the production process as well as the system design process. It is this assumption that underlies European ideas of user ownership of system designs in appropriate design processes and work oriented design of computer systems.[22] Thirdly, many of the traditional problems of user participation in system design have been resolved by either assuming an underlying harmony of interests or restricting either the users involved in the process or the degree of influence that users have. Skill based design processes, not characterised by such traditional assumptions and resolutions of the problem, are consequently more centrally concerned with the complexity of ensuring adequate user oriented design.

SKILL BASED AUTOMATION AND LEAN PRODUCTION

Lean production as outlined by Womack, Jones and Ross,[23] is a generic term encompassing amongst other things: the use of techniques such as just-in-time and total quality control to simplify production, identify sources of waste, and attack these problems at source; establishment of new forms of group activity and team work to stimulate cooperation and overcome conflicts and divides within manufacturing organisations at both intra-departmental and inter-departmental levels (e.g., new product teams); and methods for creating innovative and tightly integrated sub-contractor networks. At the level of products and product strategy, lean production is closely identified with the Japanese automobile sector, and strategies to increase product variety, range and innovation, while creating mass production methods capable of gaining all the benefits of economy of scale yet being flexible enough to cater for the new variety. At the workplace level it is strongly associated with organisational restructuring involving multiskilling, team work, group problem solving and delegation of quality control and other indirect tasks to production workers.

Like skill based automation, the model of lean production assumes that new systems are based upon meeting product market demands for reduced lead times, higher quality, more customisation and product variety, more rapid product innovation, and reduced design-for-manufacture times. It is also assumed in both cases that this requires broader job tasks, increased job rotation, decentralisation of a variety of indirect tasks to production workers, reduced hierarchies, increased group work and contribution to decision making. In both cases this requires an increased degree of self-regulation on the shop floor and simultaneous increases in the competence and willingness of production workers to accept this enhanced responsibility. New technological systems are required to support these new arrangements, whether simple pull kanban systems or sophisticated computer based systems. Yet there are a number of features of lean production that conflict strongly with skill based design principles.

One of the concerns voiced about models of skill based design such as production islands is the possibility of new forms of social control and group pressure emerging to replace traditional Tayloristic control systems. Thus some attention has been paid to the constraints of peer group pressure, increasing visibility of production processes, management using the island experiments as more sophisticated forms of speed up, and the retention of old hierarchical forms with the continued dominance of supervisors or middle managers now renamed as group leaders or facilitators.[24] These criticisms are minimal, however, compared to the new forms of surveillance and control built into a number of new Japanese lean production methods. Since Dohse *et al.* made this point most strongly, the lean production system has been criticised for observed high levels of stress, detailed monitoring of employee performance, continued pacing of work through short production cycles, relatively little group autonomy as a result of buffer minimisation, and extensive degrees of management prerogative as a result of the absence of industry unions or legislation to protect workers.[25] More recently, Sewell and Wilkinson, using a general theory of surveillance in the disciplined society, detail a wide range of new forms of social control embodied in total quality control systems in UK firms implementing Japanese techniques. They reveal various types of both horizontal and vertical surveillance, as the location of all faults in the work of individual operators is more easily identified and new forms of management sanction and group pressure are applied to offenders.[26] Following Foucault, and the more recent work of Zuboff,[27] they view the new production arrangements more in the light of an 'information panopticon' of total micro-control than an autonomous group work.

As a result of a recognition of these dangers, there have been a number of attempts to distinguish between skill based and lean production approaches, Thus we have, for example, the contrast drawn up by Jurgens between the Japanese and German models of production organisation (schematically represented here in Table 3), and the distinction between Anthropocentric and Lean Production in the conclusion to the FAST project on international experiences in anthropocentric systems (Table 4). Moreover, advocates of lean production have been keen to distinguish themselves from craft romanticism or outdated models of production as carried out in, for example, Volvo's assembly plant at Uddevalla and Saab's new Malmo plant.[28] It is interesting to observe, however, that the term romantic has also been applied to the romance of simplicity often found in evangelical proclamations of lean production.[29]

TABLE 3

MODELS FOR PRODUCTION ORGANISATION	
German	**Japanese**
skilled worker infiltration in production	semi-skilled worker with generally high starting qualifications
work uncoupled from the production cycle	work tied to the production cycle
enlargement of task volumes	cycle bound tasks
mixed team of specialists	homogenous teams
large degree of partial autonomy for teams through structuring technology and the course of work (buffer formation)	little partial autonomy for the teams through JIT design (buffer minimisation)

Source: Ulrich Jurgens, Alternatives presented by new technologies and production concepts, *Discussion Paper, Wissenschaftszentrum, Berlin* 1991.

Important as these distinctions are, they are still problematic as an effective means for distinguishing between more or less humane forms of automation or, in particular, separating desirable production islands from authoritarian information panopticons. In the Lean Production/APS contrast, distinctions between training and education or leadership and participation are too general to use as operational categories for system design or classification, whereas the shared aims and organisational characteristics obscure nearly all the meaningful decisions to be made between humane and inhumane forms of these characteristics. In Jurgens' contrast, the distinction is more precise in many of its pointers about uncoupled versus tied work and lengthening or shortening of production cycles, and the implications of decreasing buffer stocks. The usefulness of these distinctions has been brought out by Klein in a contrast she draws between traditional semi-autonomous group principles and the modern just-in-time group work, where the former presumed substantial buffers in order to allow group discussion and participation in higher level indirect activities.[30] The distinction still requires clarification, however, as the degree of work tied to the production cycle and length of the production cycle varies within Japanese forms of organisation. Moreover, Jurgen's emphasis on the degree of uncoupling needs to be clarified when all forms of loose coupling are always only relative autonomy[31] or semi autonomous group work within broader forms of tight coupling.[32] What contitutes real autonomy is a crucial question but one that has not yet been answered.

TABLE 4

COMPARISON OF LEAN PRODUCTION AND APS		
	LEAN PRODUCTION	APS
AIM	Productivity increase, modernisation of industrialised manufacturing built on human resources and organisation	
SKILLS	Training	Education
TECHNOLOGY	No specific technology needed	Technology has to be shaped
ORGANISATIONAL PRINCIPLES	Business, plant and workshop organisation	Plant and workshop organisation
ORGANISATION	Group work, integration of groups, holistic tasks, responsibility at execution level, collaboration between departments	
VOLUME SIZE	Volume production towards batch production	Small batch production towards one-of-a-kind production as well as towards batch production
CORE INDUSTRIES	Automobile	Mechanical engineering and related industries
INDUSTRIAL RELATIONS	Leadership	Participation

Source: W. Wobbe, *Science and Technology Policy: What are Anthropocentric Production Systems? Why are they a Strategic Issue for Europe?*, EC-FAST/MONITOR Final Report EUR 13968 EN, Brussels, 1992.

There is at present no clearly defined distinction between skill based design and lean production approaches. Advocates of lean production have, however, tended to adopt universalistic and historical views of the triumph of a new best practice.[33] Skill based design, in contrast, is concerned to locate new system designs in their cultural context, with specific attention paid to the adaptation of systems to cultural contexts. Whereas, lean production is often presented as a technique best adapted to market determined changes in products skill based design is closely linked to European concerns to promote systems appropriate to culturally and politically influenced labour markets.[34] In addition, skill based design is clearly and directly linked to values of improving working conditions and increasing individual and group autonomy from centralised authority, and this finds clear expression in the commitment to lengthening cycle times and the uncoupling of workers from machine pacing. This, in turn, requires technological changes ranging from automatic loading and unloading equipment for machine tools to computer assisted group scheduling and production simulation software. A clear distinction remains to be made, however, and needs to address crucial questions concerning the changing significance of theoretical/practical skill interdependencies, the significance of different degrees of relative autonomy, and how the commitment to improved working conditions can be transformed into greater productivity through improvements in motivation and the stimulation of continuous learning and creativity.[35]

CONCLUSION: INTERNATIONAL RELEVANCE

A key question facing any discussion of skill based automation is the degree to which this form of automation of production is generalisable to countries outside such European core nations as West Germany, Scandinavia and the Netherlands, especially to less highly skilled or developed manufacturing countries, often with less highly developed employee involvement and participation than that present in countries such as West Germany and Sweden. This is a discussion prevalent not only within countries outside Europe (including the United States) but also within Europe, especially between the core and peripheral member states, and from within England from critics sceptical of the German approach.

This remains a key question despite the statements by some proponents of skill based automation that it should be a universal solution. This is particularly the case given the emphasis of the skill based design approach on the importance of considering the cultural context of technical and production systems, and the stress upon the particular significance of the approach for European, or at least core European, conditions.

No simple answers can be given to this question for three main reasons. First, there is presently a widespread degree of management and corporate uncertainty about best practice production and the appropriateness of foreign models to local conditions.[36] Secondly, radically new innovations in technology and work organisation have still been undertaken in only a minority of companies, even within the most favourable industries in core countries. There can, therefore, be no simple outline of national conditions favouring such developments given that they still remain the exception rather than the rule. Thirdly, there are ambiguities or contradictions in the conditions conducive to skill based automation solutions. For example, the development of a successful manufacturing base may provide the economic strength and the dynamism to explore new options, yet the Tayloristic structures of the mass production era may provide a strong barrier to skill based automation that is not so present in smaller scale networks of firms in less developed countries. This latter point has sparked a significant degree of discussion on the applicability of regional cultures and small scale firm organisation in less developed countries to the diffusion of skill based automation solutions, and the degree to which the Taylorist stage can be bypassed.[37]

An effective approach to this question must incorporate a sophisticated analysis of: national policy networks and their ability to create conditions conducive to appropriate forms of innovation;[38] national patterns of skill formation that provide much of the sociological inputs into the production equation;[39] and national systems of innovation in both large and small countries and their ability to influence national rates and directions of technical change in an increasingly globalised techno-economic order.[40] An attempt has been provided elsewhere, with a specific focus on Australia, to provide a preliminary analysis of national conditions facilitating skill based design solutions in less industrialised countries,[41] and the European Commission FAST project on anthropocentric systems has produced a range of European and international studies on this general issue. If further research on skill based design alternatives receives the attention it deserves from science and technology studies researchers, then the conditions facilitating their development will increasingly become a key area of inquiry for studies of the social underpinnings of production innovation and the range of manoeuvre available to influence their direction.

NOTES AND REFERENCES

1. See R. Badham and J. Mathews, 'The new production systems debate', *Labour and Industry*, 2, 2, 1989, pp. 194-246.
2. See W. Streeck, 'Industrial relations and industrial change: The restructuring of the world automobile industry in the 1970s and 1980s', *Economic and Industrial Democracy*, 8, 1987, pp. 437-62.
3. See A. Sorge and W. Streeck, 'Industrial relations and technical change; The case for an extended perspective', in R. Hyman and W. Streeck (eds), *New Technology and Industrial Relations*, Blackwell, Oxford, 1988.
4. See J. Child, 'Managerial strategies, new technology and the labour process', in D. Knights, H. Willmott and D. Collinson (eds), *Job Redesign: Critical Perspectives on the Labour Process*, Gower, London, 1985.

5. See D. Mackenzie and J. Wajcman (eds), *The Social Shaping of Technology,* Open University Press, 1985; R. Badham, 'Systems, networks and configurations', *International Journal of Human Factors in Manufacturing,* Special Edition, January 1993 (in press); R. Kling, 'Computerisation and social transformations', *Science, Technology and Human Values,* 16, 3, 1991, pp. 342-67; B. Pfaffenberger, 'The social meaning of the personal computer: Or, Why the personal computer revolution was no revolution', *Anthropological Quarterly,* 1989, pp. 113-27; M. Lynne Markus, *Systems, Bugs and Features,* Cambridge University Press, 1985; and I. McLoughlin and J. Clark, *Technological Change at Work,* Open University Press, Milton Keynes, 1988.
6. See R. Badham and B. Schallock, 'Human factors in CIM development: A human centred view from Europe', *International Journal of Human Factors in Manufacturing,* 1, 2, 1991, pp. 121-41; R. Badham, 'Computer integrated manufacturing: The social dimension. A comment', *International Labour Review,* 130, 3, November 1991,pp. 373-92.
7. See C. Clegg and G. Symon, *A Review of Human-Centred Manufacturing Technology and a Framework for its Design and Evaluation,* MRC/ESRC Social and Applied Psychology Unit, University of Sheffield, Memo. No. 1036, 1989.
8. S. Zuboff, *In the Age of the Smart Machine,* Heinemann, New York, 1988.
9. See P. Brödner, 'In search of the computer aided craftsman' *AI and Society,* 3, 1989, pp. 39-46; H. Gottschalch, 'Examples of human-centred work design in CIM structures', paper presented to the International Federation of Automatic Control Symposium on Skill Based Automated Production, Vienna, November 1989; Rosenbrock, *op. cit.;* and D. Noble, *Forces of Production: A Social History of Industrial Automation,* Knopf, New York, 1984.
10. C. Perrow, 'The organisational context of human factors engineering', *Administrative Science Quarterly,* 28, 1983, p.540.
11. H. Rosenbrock, *Designing Human-Centred Technology: A Cross Disciplinary Project in Computer Aided Manufacturing,* Springer, London, 1989, p. x.
12. T. Burns and G. Stalker, *The Management of Innovation,* Tavistock, London, 1961.
13. W. Streeck, 'On the institutional preconditions of diversified quality production', in E. Matzner and W. Streeck (eds), *Beyond Keynesianism: The Socioeconomics of Production and Full Employment,* Elgar, Brookfield, Vermont, 1991.
14. D. McGregor, *The Human Side of Enterprise,* Penguin, Harmondsworth, 1960.
15. R. Badham, *Anthropocentric Systems and the Australian Production Culture,* European Commission Monitor/FAST Report, Brussels, 1992.
16. G. Susman and R. Chase, 'A sociotechnical analysis of the integrated factory', *Journal of Applied Behavioural Science,* 22, 1986, pp. 257-70.
17. Badham and Mathews, *op. cit.*
18. See J.E. Kelley, *Scientific Management: Job Redesign and Work Performance,* Academic Press, New York, 1982.
19. See L. Bengtsson, 'Work organisation and occupational development in CIM: The case of Swedish NC machine shops', *New Technology, Work and Employment,* 7, 1, Spring 1992.
20. Sorge and Streeck, *op. cit.*
21. See M. Warner, W. Wobbe and P. Brödner, *New Technology and Manufacturing Management: Strategic Choices for Flexible Production Systems,* Wiley, Chichester, 1990.
22. See P. Ehn, *Work Oriented Design of Computer Artefacts,* Arbetslivcentrum, Stockholm, 1988; Clegg and Symon, *op. cit.*
23. J. Womack, D. Jones and D. Roos, *The Machine that Changed the World: The Triumph of Lean Production,* Rawson Macmillan, New York, 1990.
24. Badham, 1991, *op. cit.*
25. See K. Dohse, U. Jurgens and T. Malch, 'From 'Fordism' to 'Toyotaism'?: The social organisation of the labour process in the Japanese automobile industry', *Politics and Society,* 14, 2, 1985, pp. 115-46; C. Berggren, *Lean Production: The End of History?,* STA Working Paper Series, University of Wollongong, June 1992.

26. See G. Sewell and B. Wilkinson,' Someone to watch over me: surveillance, discipline, and the just-in-time labour process', *Sociology*, 26, 2, 1992, pp. 271-89.
27. Zuboff, *op. cit.*
28. Womack, Jones and Roos, *op. cit.*
29. P. Zipkin, 'Does manufacturing need a JIT revolution', *Harvard Business Review*, 36, January-February 1991, pp. 40-50.
30. J. Klein, 'A re-examination of autonomy in light of new manufacturing practices', *Human Relations*, 43, 1990, pp. 123-37.
31. A. Friedman, *Industry and Labour*, Macmillan, London, 1977.
32. Badham, 1992, *op. cit.*
33. See B. Dankbaar, 'International competition and national institutions: The case of the automobile industry', in C. Freeman and L. Soete (eds), *New Explorations in the Economics of Technological Change*, Pinter, London, 1990; Berggren, *op. cit.*
34. See Streeck, 1987a, *op. cit.;* M. Elam, 'Markets and morals,' unpublished monograph, ADD-TECH Program, University of Linköping, Sweden, 1992.
35. This is an area of research currently being undertaken by the author in an Australian-German collaborative project to introduce production islands into Australian companies. See R. Badham, 'Smart manufacturing techniques: Project outline', Research proposal submitted to the Department of Industry, Technology and Commerce, Canberra, May 1992.
36. See. W. Streeck, 'The uncertainties of management in the management of uncertainty: Employers, labour relations and industrial adjustment in the 1980s', *Work, Unemployment and Society*, 1, 3, 1987, pp. 75-92.
37. See C. Piore and C. Sabel, *The Second Industrial Divide*, Heinemann, London, 1988; S. O'Siochru, *Prospects for Anthropocentric Production Systems in Less Industrialised Member States*, European Commission/FAST Draft Report, NEXUS, Dublin, 1991.
38. See P. Katzenstein, *Policy and Politics in West Germany: The Growth of a Semi-Sovereign State*, Temple University Press, Philadelphia, 1987.
39. Streeck, 1991, *op. cit.*
40. See R. Nelson and N. Rosenberg (eds), *National Systems of Innovation*, Oxford University Press, Oxford, 1992.
41. See R.Badham, 'Skill based automation: Promotional issues for less industrialised countries', *International Conference on Advanced Manufacturing and Hybrid Automation*, Institut fuer Arbeit und Technik, Gelsenkirchen, Germany, August 1992; R. Badham, 'Guest Editorial: Technology, Work and Culture', *AI and Society*, 5, 1991, pp. 263-76.