

THE TRANSFORMATION OF WORK?

Skill, flexibility and the
labour process

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3 Machinery, labour and location

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Mechanization lies at the heart of industrialization and the wholesale transformation of work and life under capitalism.¹ That is no less true in the last decades of the twentieth century, with the dramatic improvements in machinery made possible by computers, micro-electronics, lasers and others of the new technologies. These innovations have led to new optimism about the ability of machines to transform work for the better, as in Piore and Sabel's vision of 'flexible specialization' or Hirschhorn's 'creative interaction' between humans and machine, or even to eliminate human labour altogether, as in the industrialists' pipe dream of the 'fully automated factory' (Hirschhorn, 1984; Mehler, 1985; Piore and Sabel, 1984). These have a family resemblance to the post-industrial and automation enthusiasms of Daniel Bell and others during the post-war heyday of Fordist mass production (Bell, 1974; cf. Bright, 1958; Coombs, 1985). Against the latter, Harry Braverman (1974) revived Marx's scathing critique of the capitalist factory, and was widely followed in his belief that capitalist management systematically degraded work through the application of Taylorist principles of division of labour, followed by the adoption of machinery to take the place of the diminished worker.

Marx and Braverman are surely right in large measure about the oppressive nature of capitalist class relations, but this must be weighed against three other powerful general Marxian tenets about the labour process: that human labour is the irreplaceable centrepiece of social production, with its own peculiar nature; that human beings must confront the physical laws of nature in order to bring nature under their sway; and that in developing the forces of production, people transform themselves and develop their slumbering powers (Marx, 1967: 177). I take these to mean that human labour sets the basic terms of production, on which mechanization develops; that the physical characteristics of materials, products and machines affect the course of mechanization; and that labour develops as well as loses skills over time, and that despite the best efforts of capitalists, workers cannot be altogether eliminated from production, as Jones also argues in Chapter

2. My disagreement with Braverman's version of Marxism is that it gives unduly short shift to the technological. While Braverman has been criticized by those who protest his objectification of capital and

labour, and who seek to develop the social relations in production more richly (Burawoy, 1985; Wood, 1982), he actually fails to be objective enough in dealing with the technological side of production. We have to take the study of mechanization very seriously, as did Marx; and we must do so to discover its true rather than imagined effects, and to strike the proper balance in the explanatory powers of the social relations and forces of production in the development of the labour process.

This chapter advances a new framework for the study of mechanization, by marrying the social and technical relations of production more closely. It is organized broadly around the three principles just enunciated. In the first section, I look at the multi-dimensionality of human labour and mechanization, and situate various partial views such as Taylorism, flexible mechanization, and just-in-time. The second section draws conclusions about the irregular course of mechanization over time, and the inability of any set of practices to lay claim to the future of automation. In the third section, the role of materials and products in the diversity and irregularities of industrial paths of automation is considered. The fourth section then takes up the question of labour skills and the counter-tendencies to Braverman's deskilling thesis.

In the final section of the paper, I bring geography into the predominantly 'sociological' discourse on the labour process. Geography has been not altogether forgotten in the Braverman debates, especially as regards the uneven diffusion of Taylorist practices (Littler, 1982) and the differential politics of production under different national variants of Fordism (Burawoy, 1985). But the new technologies and the decline of the Fordist regime of accumulation have drawn renewed attention to this neglected cousin of the social sciences.

The dimensions of the labour process and the application of machinery

The labour process begins with the human beings who conceive and execute their plans on nature. Mechanization must first of all be addressed to the labourer in the labour process; machines must be made to do what people do. Mechanization thus has a common foundation across all industries, and defines a certain progression toward higher human capacities of self-regulation and ultimately creative thought. In all labour processes, workers manipulate things, move them about, observe what they do through the five senses, regulate their actions in light of observation, and think, imagining the end-product of their actions, setting their faculties in motion, solving puzzles along the way, taking pleasure from the work and a job well done. They also, as a

group, work together so that their individual, partial labours congeal as a single product. These characteristic facets of the labour process establish the five basic dimensions of production and mechanization: (1) conversion, or the transformation of materials into different forms; (2) assembly, or the combination of parts; (3) transfer, or the movement of materials from one work station to another; (4) integration, or the co-ordination of various subprocesses in complex production systems; (5) regulation, or the self direction and correction of machine performance.

The independence of the five dimensions is not sufficiently appreciated, and hence the problem of mechanization has been considered too narrowly (Bell, 1972). Mechanization is conventionally measured along a unitary scale of 'automation' (Bright, 1958). As a result, new developments in machine production are wrongly imagined to be mere extensions of past practices, as when 'Fordism' is treated as the perfection of 'Taylorism' or even of 'the Babbage principle' alone. Recent innovations in production have made it clear that Fordism is being supplanted more than extended. Yet this has led to the converse mistake of treating 'flexible production' as a complete break with past trends (Piore and Sabel, 1984; Storper and Scott, 1988). Because of the multi-dimensionality of labour and mechanization, people are often talking about quite different problems when they compare, say, Taylorist rationalization of hand motions with Japanese just-in-time methods. It is therefore necessary to consider the specificity of each dimension and the developments peculiar to each. While there is a core social logic to automation – the drive to increase the productivity of human labour (Walker, 1988; cf. Brenner, 1977) – the paths to this end are several.

Conversion

Every production process involves many individual acts of conversion, or the transformation of inputs into new forms. Mechanical advance in conversion has consisted principally of the achievement of greater precision, speed and strength in specific human actions: improvements on the hand, above all, but also on the power of the back, legs and eyesight. For example, a turning lathe allows a rapid and uniform cut; a hand-rest steadies the tool, improving the uniformity; attaching the tool to the machine increases precision even more; a cam-driven tool can cut irregular shapes smoothly. For such advances to proceed, it is usually necessary to break down human action into its component parts through the detailed division of labour – in the manner first enunciated by Babbage (1832) and Ure (1858) – to be repeated speedily and endlessly (Rosenberg, 1976). This is the realm in which Taylorism applies with force: creating simple acts of labour for

mechanical reproduction. Historically it is a crucial moment in the development of mechanization, and is repeated over and over in new fields of work. But it is not the whole story, because of the other dimensions of production and the further development of machine capabilities.

Specialization of machines themselves is a further step in the application of the Babbage principle. A key breakthrough in Henry Ford's system of mass production – which owed its origins to Thomas Blanchard not Frederick Taylor – was the dedication of specialized machine tools to a single task (Hounshell, 1984). (Ford's moving production lines were not all strictly assembly work, it should be noted.) Dedication of specialized machinery has sharp limits, however, because large fixed costs require high utilization to repay themselves, each machine is locked into a rigid system, and alteration of the system demands expensive retooling.

General purpose machines, on the other hand, can do several different operations: machining stations can do either milling or grinding, depending on which tool is brought into place. Even mill stones can be adjusted for different grinds of flour. Machines that can do several tasks have long been essential for batch production, which still predominates in many if not most industrial processes (Littler, 1985:19). General purpose machines are the basis for a distinct industrial history that has not depended primarily on the principles of Taylorism and Fordism (Hounshell, 1984). Indeed, the very inappropriateness of crude Taylorist rationalization to machining is what has prompted the outcries of Braverman (a machinist) and his followers, such as Shaiken (1984). The methods needed for advancing the efficiency of generalized 'set up' or oversight of such work are not confined to simple principles of division of labour, repetitive motions, and mindless application of rules.

General purpose machines are what advocates of flexible specialization, such as Piore and Sabel (1984), have in mind. As they have pointed out, such machines are applied most efficiently in situations where one has (and is able) to switch rapidly from one output to another. 'Flexibility', in this instance, means several things: more adaptable machines, shorter set-up times, more broadly skilled workers. (There are other aspects of flexibility, such as better product design and integration of parts production, that we shall consider later.) Better automation of batch production thus embraces quite different principles of machine design and usage than automation of repetitive mass conversion systems. Confusion of terms is rampant here as was suggested in Chapter 1, with Piore now seemingly backing off from 'flexible specialization' and speaking of 'flexible mass production', which may apply either to expanded batch production or reduced runs within Fordist systems. The source of confusion is the misplaced emphasis on scale of output (length of runs) instead of production

methods (type of machinery). One may yet get very long runs out of generalized machinery or short runs out of dedicated machinery, with corresponding effects on overall efficiency of labour and machine use, but the principles of mechanical improvement in each case are different.

Assembly

Most products are combinations of component parts which must be brought together for final assembly (or even a series of sub-assemblies). Some products, such as jet engines, consist of thousands of parts. Assembly is often much more difficult to mechanize than conversion, because it requires motions of joining and fitting which are surprisingly complex and subtle. Therefore, assembly lines for many simple products consist of little more than a belt moving past various manned work stations. Assembly work also frequently involves many small operations over the bulk of large products, such as welds on airframes. These are especially unwieldy to mechanize and do not involve the assembly line of Ford at all. Hence automation in the aerospace industry moves in different ways than in the automobile or machining industries.

Flexibility means something different in assembly work than in conversion because of the complex motions required. The current wave of robots consists primarily of mechanical arms, which are undoubtedly a great breakthrough in the imitation of the human hand, wrist and elbow. In a sense, they are the most advanced form of general purpose machine. They markedly reduce the need to break down human actions into flexible component movements before transferring work to the machine. Many observers have become transfixed by robotics, regarding this as the key breakthrough in modern automation. General Motors appears to have thought the Japanese performed miracles with robots and was 'shaken to the core' to discover that its New United Motors joint venture with Toyota in Fremont, California, is more productive than other, more highly mechanized GM plants (*Business Week*, 1987a: 104). In fact, robot applications are still quite limited, the majority being found in the automobile industry doing welding and painting.

The most important advances in assembly have had little to do with automation of the work itself but with three other developments. One is the preparation of truly interchangeable parts that require no 'fitting', that is, filing into proper shape; this is an overlooked part of Fordism, with deep roots in US machining practices (Hounshell, 1984). Another is the design of products with fewer components to assemble – due in part to more advanced conversion methods such as laser etching in the fabrication of very large-scale integrated circuits or

continuous cutting methods in metals. The third is the rationalization and mechanization of transfer methods, to which we now turn.

Transfer

Because all production involves multiple actions on the same materials, partly formed components and products must be moved from one step to another. There is, in other words, a problem of materials flow through production to which attention must be given. Transfer begins as the labour process of carrying things around. The simplest aids to human labour in effecting transfer are animals or some form of wheeled cart; today most heavy loads are moved with the aid of power vehicles. A surprising amount of transfer work still proceeds in this manner, despite the imagery of the assembly line (see e.g. Pfeffer, 1979). An important advance is the continuity of flow achieved with the help of fixed conveyors from one point to another, by dead-line (rollers, slides), steered line (cranes, locomotives), and live-line (overhead conveyors, belts, chains).

Ford's revolution in assembly is most widely associated with the moving line. This was, indeed, a great breakthrough in transfer methods, although it had been anticipated by the overhead, hand-pushed 'disassembly' lines of slaughterhouses. Ford reduced the labour of hand transfer, but the transfer element in Fordism was subordinate to achievements in work organization and integration, which we shall consider below.

The limits of Fordist moving lines have rekindled interest in the flow of materials through the production process. Improvements here have been labelled 'flexible production', but the meaning of the term in this context has little to do with the flexibility engendered by either generalized machinery or robotics. One concern is adapting to variable product demand. This may be achieved, however, without fancy machinery by simply breaking up assembly lines into smaller units so they can be working on different parts or products (Kelly, 1985: 38-40). Another concern lies in effectively transferring materials to generalized work stations without sequentially linked lines; this can be done with hand carts or aided by more sophisticated machines, such as computer-guided carts with programmable routing. Still another means of improving the transfer function is by more effective coordination of work between stations without the rigidity of the moving line or even sequential ordering on the shop-floor; this, however, takes us into a new realm of the labour process - integration - which will be considered below.

There are other elements of the overall transfer function than the movement between work stations in a factory. The first is the feeding and discharge of machines and on-loading and off-loading of movers.

In the beginning, each piece has to be individually fed and positioned, and each one removed and placed in a bin or on a cart. Machine feeding and discharge are often difficult to mechanize because of the need to position pieces for processing or to avoid harm to delicate materials. 'Pick-and-feed' robot arms can mechanize individual feeding, while in more advanced systems one machine feeds the next as it completes its task. The mechanization of transfer is closely allied to the automaticity of machine function, however; the more automatic become feeding, loading and movement, the more the rhythms of the machines must be unified. Putting together such systems requires close attention to the meshing of different actions, often at different speeds; for example the lathe turns the piece at one speed and moves the tool at another. For this purpose, electric motors are a great help (Hirschhorn, 1984: 21). The transfer function may ultimately be absorbed into the innards of machine systems (Marx, 1967: 381).

Another aspect of transfer is movement in and out of the factory (or department) as a whole, or what is called shipping and receiving, with its attendant functions of stock maintenance and inventory control. Shipping and receiving have languished in lack of attention from management and from mechanization, as compared to core production activities. Most factories are hand-fed by labourers unloading trucks on the receiving dock. Fully automatic processes may be initiated by discontinuous entry of a mass of materials, as when harvested wine grapes are dumped into the crusher. Management's inattention to material flows in and out of the factory and to departments turns out to be very costly, as when finished goods pile up awaiting shipment. Large buffer stocks are expensive to carry: one estimate in 1985 was that 30 per cent of production costs in industry go to warehousing, inventory, carrying and monitoring stocks (*Business Week*, 14 April 1985: 45).

Poor inventory management has often been identified with Fordism but has little to do with the actual achievements of Ford; they are, rather, the loose ends that Ford and his engineers did not attend to carefully. They are now being challenged by Japanese methods of inventory control inside the factory (e.g. *kanban* boards) and just-in-time methods of integrating work between factories (Cusumano, 1985; Sayer, 1986b; Schonberger, 1982). These methods have been equated with 'flexible production' (Scott and Storper, 1988), but this is probably unwise because while the use of just-in-time delivery and *kanban* yield a certain degree of flexibility with regard to changes in final demand, they also link extensive production systems more rigidly due to lack of buffer stocks and requirements for fully integrated production design and scheduling. What is striking about these methods is the low level of mechanization involved, although computerized records and information transfer can be applied once a determinate method is in place (rather like Ford's need to reorganize the

factory floor before applying the moving line). We see, therefore, that the transfer function and its mechanization are accessory to the integration of production, which we can now take up.

Integration

Under the modern division of labour, production systems are parcelled among many workers and work units, thereby creating the problem of integration. Under this heading should be included all the co-ordinative functions that go beyond mere physical linkage and material flows (transfer and inventory control), such as making parts that fit together, equalization of work loads, and even effective organization for technical innovation. Labour productivity depends not only on the minimization of direct work time – which it was estimated constituted as little as 15 per cent of the cost of goods in the US in 1986 (*Business Week*, 1986: 101) – but on the allocation of labour, time of circulation of capital in materials, machines and products, and production of quality products which sell effectively.

The integration problem is easily overlooked where machines link together several operations in one continuous whole – by rigidly tied mechanisms, by moving line or through continuous feed and discharge. Yet behind these mechanically integrated systems lies a long history of the rationalization of work flow and machine performance to achieve a sequence of operations that mesh properly. Ford's moving assembly line presupposes careful organization of work and machine functioning, the roots of which go back primarily to the genesis of the 'American system' of manufacture in New England armouries in the early nineteenth century (Hounshell, 1984: 25–46), but also to Oliver Evans' continuous grain mill in the eighteenth century, the disassembly lines of meat-packers, and the layout of canneries (Hounshell, 1984: 241). Ford's breakthrough depended on careful dissection and ordering of the work, close machining of parts, and dedicated machine tools and, in addition, the careful positioning of work stations to minimize distance and ease work flow (Hounshell, 1984: 217–61). It also eliminated the waste of excess parts lying around work stations (he was, like the Japanese today, attentive to problems of material flow in the factory, as they then existed).

However, mechanical lines created a new set of problems with flow co-ordination, work pace equalization and fixed work sequencing (Kelly, 1985: 35–6). Once the machine or line is running, it becomes a rigid system that can only vary in speed, and to which workers must adjust their rhythms (Edwards, 1979). Fordist systems of 'rigid integration' are now under assault for poor performance in terms of machine downtime, worker deadtime, bottlenecks, inventory build-up and shoddy workmanship (*Business Week*, 1987b: 132). Japanese

innovations in work organization have reawakened interest in what had long been the forgotten dimension of production (for instance, neither Bright (1958) nor Bell (1972) theorized the problem of integration).

It is necessary to step back from the mechanical integration of the assembly line to reconsider the integration function afresh as a labour process. Most production systems actually consist of 'islands of automation' with substantial breaks between them, labour-intensive bits involving simple tools or operator-directed machines (Mehler, 1985). As a consequence, 'workers still link different parts of the manufacturing cycle' in otherwise highly automated systems (*Business Week*, 27 May 1985: 44). Such 'simple co-operation', as Marx (1967: 322–35) called it, may be achieved by organizing workers in groups with team leaders as in die-making or by formal meetings and consultations; but a great deal of it is still carried out informally through personal contact, mutual stimulation, the exercise of collective judgement and joint problem-solving.

Capitalists have proceeded to divide, simplify and take command of the labour of integration, in the Taylorist fashion. On the one hand, they hand the work of co-ordination and direction over to a special group called 'managers'. Managerial bureaucracy has been refined to a high degree, with company rule books, collective bargaining procedures, and organization charts. On the other hand, management must also begin to record information about the flow of work and materials on routing slips or in ledgers. Information handling, like direction, becomes separated from the rest of productive labour. Both of these new divisions of labour may subsequently become mechanized.

Mechanization of information flow begins with devices such as typewriters and adding machines that help to clarify and organize manual records of inventories, machine repair, work performance, and other data-tracking production. With early computers, data can be electronically stored and processed, but only after tedious hand entry, occupying armies of clericals. A big jump is achieved with on-line monitoring for continuous data collection on the various dimensions of production, directed automatically by computers with sophisticated programming. Major barriers to such integrated information processing are poor monitoring techniques, lack of data standards, incompatibility between computers, inadequate local area networks and the failure to develop powerful enough integrative software. Nonetheless, mechanization of information flows may be more important for overall productivity than mechanization of individual tasks. For example, retailing is being greatly aided by electronic point of sale systems and bar codes on labels, which provide instant information to the stock room on the flow of purchases (*Business Week*, 8 Nov. 1986: 64–5). Neither the labour of stocking shelves, unloading trucks nor moving produce from the stockroom to the floor has changed much,

but overall productivity is elevated by eliminating the time spent on surveying shelf stock, ordering stockboys to fill gaps, and preparing orders to suppliers, as well as by reducing inventories of, and space devoted to, slow-moving items.

Mechanization of managerial direction has proceeded in several ways. One is the ability to monitor workers at their work stations through the machine rather than the foreman (Nelson, 1984). (One may even be able to reprimand the worker and indicate errors automatically.) Another is the programmed operation of a machine or set of machines, which shifts the managerial function over to technical workers in the engineering or computing department. Both these methods depend heavily on computers. Yet even with computer control, workers are still needed to watch over machines, enter information, and intervene as needed (see Chapters 1, 2, and 11).

Where computerized information and machine direction are combined to co-ordinate disparate machinery across the factory, it is called 'computer integrated manufacturing' (CIM). But progress down the road of fully automated systems is uncertain. A leading industrial automation consulting firm in Britain, Ingersoll Engineers, reports that it could not find a single instance of full CIM (*Computer Weekly*, 23 May 1985: 11; see also *Business Week*, 1986; Mehler, 1985). The biggest barrier to CIM is laying sufficient organizational and informational groundwork; a lot of sophisticated machines cannot overcome a failure to rationalize the integrative functions in production. As the author of the Ingersoll report observed, 'manufacturers should not be thinking of bringing computers in to integrate their systems until they have taken a hard look at the way their factories are run without computers' (*Business Week*, 17 June 1985: 39).

Certain Japanese companies have shown the benefits of rethinking integration before throwing machines at the job (Cusumano, 1985; Sayer, 1986b; Schonberger, 1982). This not only means a redirection from the classic Fordist obsessions with specialized conversion machinery or automated transfer toward the integration function in general. Improved integration also requires that management go back to a new starting-point other than Taylorist division of tasks between workers and management, so that workers are more involved in oversight and managers more in production. This may be achieved through new kinds of work teams, less-structured job assignments, reduced management hierarchy or hands-on managerial participation in work. Closer worker and management participation can provide better error detection and correction at the point of issue. Indeed, it is, as Sayer observes, a way of building in 'learning by doing' in place of pre-engineered factory systems. Additional benefits are reductions of set-up times, buffer stocks and downtime. Less stock and fewer errors are mutually reinforcing, in that errors are detected more quickly and cannot be evaded by turning to other available parts.

Regulation

All workers regulate their labour in three ways: they have a plan in mind beforehand, which can be changed from job to job; they undertake a number of tasks, whose sequence can be altered to fit different jobs or to improve the way a job is done; and they adjust their plans and actions in light of product demands and production results. In craft-type work the regulatory function is subsumed in the continual reflection of the worker. Regulation develops as a problem as machines take over from workers, for no matter how gifted machines may appear at transcending human motions of body and limb, they usually suffer by comparison with such elemental human abilities as versatility, perception and creative reaction. The task of engineers thus becomes one of trying to capture some of the higher capacities of the worker: imagining the result beforehand and observing and reflecting on the results. This is done in two main ways: by *programming*, or the ability to change the sequence of machine operations, and *correction*, or the adjustment of machine performance in light of the outcome. For either programming or correction to be possible, machines must have some general capabilities and degrees of freedom in their operation.

The crudest programming is exemplified by the manual set-up of tools and pieces on a generalized machine tool or the pre-setting of heat on an oven. The machine is told exactly what to do in this simple fashion. With machines capable of variable sequencing of operations, the steps of processing may be predetermined and changed from one run to another. The simplest such programming is mechanical and fixed, as in the rotating drum with movable pins guiding Jacquard's loom or the curved cams directing Blanchard's lathes for making gunstocks. Cams became the standard for more than a century.

The next step is to separate the drive mechanism from the regulation device (a cam is both), allowing the latter to develop on its own (Hirschhorn, 1984: 22-4). The modern history of programmable machines thus commences with numerically controlled (NC) machine tools, where the machine is guided by a program punched into paper tape. Their chief virtue was an improved ability to cut odd shapes to close specifications and reprogramming without changing the parts of the machine itself. But reprogramming was still a slow process of working out sequences by hand and punching tapes or copying the motions of skilled workers (record-playback). NC did not take off until its programmes could be computer-generated (CNC).

CNC is the beginning of computer-aided manufacturing (CAM). Many individually programmed machines can be found in today's factories with an industrial mini-computer by their side or a micro-processor within them to guide them through complex and varied sequences of operations. Flexible robots hold particular promise under computer guidance because of the complexity of their movements, as

in making dozens of welds around a car body, and the possibility of varying the programme in response to the object before them, as in reading a tag on an incoming car body indicating the model number and doing the welds called for on that particular make of car. Much has also been made of so-called 'flexible manufacturing stations' (FMS), which are generalized machine tools that can change programmes for different tasks, change their own tools for different tasks, and adjust and change the parts on which they are working. In their full-blown form, FMS are combined into flexible manufacturing systems that integrate machine feeding by pick-and-feed robots and removal by shuttle carriages and transfer by mobile carts (Coriat, 1983: 24). CNC, robotics and FMS have the potential to revolutionize the economics of batch production in machining, but they still suffer from sharp limits in performance: considerable downtime, a limited range of actions, and little ability to detect or anticipate errors (Shaiken, 1984: 8, 75; Hirschhorn, 1984: 49). As a result, the spread of such techniques has not been as rapid as hoped by their promoters (see e.g. Kinnucan, 1983; cf. Jones, Chapter 2).

The second facet of regulation, correction, is needed because of, for example, limits on machine capabilities and variable conditions of materials. People adjust as they work, but machines repeat the same mistakes over and over. This affects product quality, reject rates, downtime, and machine wear and tear. Correction can be broken down into observation, linkage and response, which may be undertaken as separate acts of labour. Observation (measurement, testing) may be done, at first, by such human methods as eyeballing flaws in glass containers against a light or sniffing the soup. Improvements in manual tests can achieve a great deal: standardized gauges made possible interchangeable parts and Fordist assembly methods (Hounshell, 1984). The simplest form of response is to discard the ill-made product, which is still common in silicon wafer production and apricot drying, for example. One can also try to respond to errors by making ongoing adjustments to production methods, rather than wasting large batches of output, as US semiconductor producers have found. Linkage can be as simple as a pilot reading a compass and changing course.

Observation can be mechanized by means of such devices as thermometers, counters or electric eyes. It is best to get inside the process to measure things as they are happening rather than just measuring final results. Accurate sensory devices have proved to be a major bottleneck to automation (Kaplinsky, 1984: 30). For example, the use of robot arms is still sharply limited by the lack of 'sight': the human eye and brain do amazing things when they see, such as visualizing dimensionality of objects, separating mixed images, adjusting to variable lighting, and following objects in motion (*Business Week*, 29 July 1985: 49). Mechanical response has lowly beginnings

such as Watts' governor on the steam engine, thermostats for furnaces, and toilet-tank floats. More sophisticated adjustment requires not only measuring devices capable of sensing small differences but mechanical linkages able to transform weak signals into strong adjustments. Electronics provided an epochal breakthrough in feedback systems by allowing electric current to amplify, modulate or rectify itself (Hirschhorn, 1984: 34-40).

Computers have raised automatic adjustment to still higher levels, because they can both run complex programmes and modify those programmes in the middle of processing as new information becomes available. Self-regulation at this level is no longer a mute reaction to sensory input but requires an algorithm to interpret incoming data and make an appropriate response. Thus software is increasingly central to further mechanical advance. The regulators must be regulated. Software is needed to create more sophisticated programmes; to speed up reprogramming; to facilitate machine operation by non-programmers; to evaluate sensory inputs in more sophisticated ways; and to provide 'expert' decision systems. Think of the evaluative process required to use robots to pick fruit – a notorious job for 'unskilled' labour – which has been stymied by the random distribution of fruit in the tree, wind motion, uneven ripening, pest damage, and variable weather conditions (*Business Week*, 8 Sept. 1986: 66-7). This emphasis on advanced programming raises the pressure to automate software production. More intriguingly, it opens up questions about 'artificial intelligence' (AI) as efforts turn toward capturing the abilities of knowledgeable workers on computer (*Business Week*, 7 Oct. 1985: 104-5).

Because labour processes, machine functioning and materials transformation are only imperfectly understood by the engineers who design self-regulating machine systems, all possible contingencies cannot be anticipated and designed into automated systems (Hirschhorn, 1984). In practice, workers' experience may be a better guide than textbook formulae, or even sophisticated computer programmes, so people remain at the site of production to monitor and correct machine performance (Shaiken, 1984). With computer-driven flexibility, regulation and in-built expertise in machinery, however, it becomes possible to design machines that interact creatively with workers rather than taking all operative and regulatory functions unto themselves. Such interactive regulation of both the worker and the machine may open up new horizons in automation (Hirschhorn, 1984).

Irregular paths of automation in a multidimensional labour process

Because the labour process is not a singular entity, mechanization proceeds along several different fronts: conversion, assembly, transfer, integration and regulation. Automation cannot, therefore, be

measured unambiguously as a sequence of steps on a unitary scale, in the manner of Bright (1958: 45). The multiple dimensions of the problem mean that mechanical progress will trace an irregular path as the leading edge of innovation shifts from one axis to another (cf. Bell, 1972). Furthermore, the path of mechanization does not always trace a steady upward course because progress in one dimension can require dismantling gains in another. Japanese work teams represent a retreat from strict assembly-line principles and a certain demechanization in the transfer dimension to explore the productivity gains possible with an alternative method of work organization. Just-in-time delivery methods mean less inventory to move, hence less need for mechanical storage and retrieval devices and more use of hand carts (*Business Week*, 13 Jan. 1986: 69). Computer-controlled machine tools can produce complex parts from a single piece that once was assembled from several components, rendering previous advances irrelevant. In short, there can be one step back for two steps forward. This phenomenon has been called 'dematuring' of an industry, but it bears no necessary relation to age or product cycles (Abernathy *et al.*, 1983). Rather, industrialization proceeds in ways that are often unexpected, and caution is called for in extrapolating from past experience without attention to the development of the labour process as a whole.

Given the generally unanticipated 'crisis' of Fordist production methods, it is not surprising that various observers, whether critical or optimistic, have seized upon advances in different realms of the labour process as the key to contemporary mechanization. Unfortunately, they are frequently not referring to the same things, and end up talking past each other. A multidimensional approach makes the opposing stances of students of the labour process mutually intelligible. For example, the Braverman school is occupied with the detail division of labour in basic conversion activities and the disintegration of craft-type jobs in the face of Taylorist rationalization. Advocates of flexible specialization, on the other hand, are entranced by the possibilities for sustaining craft traditions due to advances in generalized machinery; but this, too, remains firmly within the sphere of conversion labour by the individual worker or small workshop. Fordism is neither Taylorism writ large, as Braverman implies, nor oblivious to problems of work integration. Nonetheless, it was a strategy of production rationalization that had as its focal point the problems of manual assembly and mechanization of the transfer function. And Fordism still represents a powerful model of transfer, specialization and work integration at the level of the factory, with continuing relevance to certain kinds of mass production.

Students of Japanese work organization today stress innovations largely within the realm of production integration involving better relations between workers and managers, improved feedback between steps in a complex process, closer monitoring of material flows, and

tighter co-ordination between factories. These strategies bear surprisingly little relation to the classic concerns of Taylorism for the dissection and rationalization of individual tasks, or Fordism with the sequential ordering and mechanical linkage of steps in the assembly process. Indeed they often involve a measure of retreat from extreme forms of Taylorism, Fordism and other conventional solutions adopted in the Anglo-American world over the last fifty years, and they have often surprised outsiders by their relative lack of mechanization. But Japanese manufacturers have not entirely forsaken Fordist assembly-line principles, as they have pushed forward in other dimensions of labour process improvement (see Chapters 1, 9, and 10). Nor have they ignored discrete or complementary advances in machinery.

The Japanese are also far advanced in the realm of robotics, which combines advances in flexible conversion (chiefly assembly motions) with sophisticated computer regulation of robot arms. Confusion of robotics with work reorganization led General Motors badly astray, as noted above. General Electric (GE), on the other hand, has emphasized FMS and CIM as most appropriate to its needs, giving it a certain kind of flexible mass-production capability. This has led to claims for 'the fully automated factory' (e.g. Kinnucan, 1983) redolent with the same excess of enthusiasm that first greeted the computer in the early 1950s (Bright, 1958). Nonetheless, GE's particular combination of generalized work station and computer-driven programming is not generalizable to production problems in which either large-scale assembly or small-scale customization is the crux.

At the frontiers of machine regulation, exemplified by nuclear power plants or petrochemical facilities, very different considerations arise. The kind of problems and possibilities presented by such machines are worlds apart from those of small machine shops or auto plants. Similarly, discussions of AI and expert systems put one into areas of great uncertainty about the implications of automation, to which the categories derived from the study of manual conversion and transfer processes can be applied only with great care.

Mechanical progress is open-ended, and the level of automation achieved at any point is never the last word. This evolution involves the discovery (and rediscovery in new ways) of dimensions of the labour process and machine capabilities not previously thought possible. For Adam Smith, the pin factory and its division of labour was at the forefront of modern industry. For Marx, it was the textile mill. For Braverman's generation the car assembly plant was the paragon of automation to which machine shops and offices would also eventually conform. Smith, Marx and Braverman each contributed important insights into the process of capitalist industrialization. But capitalist production continues to revolutionize itself in unexpected ways.

Now Fordist production is under fire from several directions, due to both its inadequate treatment of certain problems and to new

capabilities of machinery, workers and management. It has been supplemented by robotics, FMS, CIM and other exemplars of a new age of computer-driven, 'flexible mechanization'. Which of several budding machine architectures will become the basic technology of tomorrow? Some (Piore and Sabel, 1984) have seized on a tendency toward a new workshop-scale flexibility as found in Italy's Emilia-Romagna region as the future of automation. Others (Schonberger, 1982) see Japanese methods of work organization as reconstituting the bases of factory production. Still others (*Business Week*, 1986) argue that developments in machine creativity through neural net hardware and AI software make our present computers seem as archaic as the vacuum tube. One simply cannot know either how far or down which branch mechanization will proceed, and we shall forever be pressed to come up with new concepts with which to grasp the course of machine technologies.

Materials and products, or the objects of the labour process

The materials basis of production

Since production involves both people and nature it has two sides: human labour and the material objects of labour. The labour process is therefore also a materials transformation process, and means working on nature in accordance with the physical properties of things. Marx was well aware of this second side of the labour process, yet he and its most modern students have failed to pay sufficient attention to the material differences among labour processes and the implications of materials and product changes for industrial development. Although the human actors are still the starting-point for any dissection of production and enhancing labour productivity is the touchstone for industrialization, mechanization involves more than automating the physical and mental actions of the worker. Technological change cannot proceed without reference to the evolution of materials processing.

One dimension of materials processing is that nature can transform itself without direct human intervention, and this can be improved without otherwise altering the labour process; for example, oxygen-injection to remove impurities in steel making. A second dimension is that improvement in materials is frequently crucial to advances in machine processing; for example, high speed machining depends on better steel alloys and lubricants. A third dimension is that one must grasp the nature of materials in order to transform them; advances in the study of crystal structure in metals permit better types of alloys and stronger-cast pieces. Lastly, machines are physical entities whose

technical development is structured by their material form; hence, improvements in the shape of mill wheels or steam engines rest on the principles of flow and condensation of water.

Because materials differ in their properties every labour process has a distinctive cast. The way labour pushes, pulls, cuts or watches the materials depends on whether they are solid or liquid, hot or cold, living or dead. Polymerization, grinding and growing are so disparate as to defy easy generalization about the way machines might be involved in the process. While harvesting may involve a cutting action similar to metal working, there is nothing in the latter comparable to hybridization. As a first cut, one can distinguish the following general material realms. For the inanimate world, there is the mass level (solids, liquids and gases) to which 'mechanical' action can be applied as in lifting, moving, cutting or squeezing; the molecular level, at which chemical reactions take place, especially operative in liquids and gases, less so with solids; and the atomic level, a catch-all that includes electromagnetic radiation, heat and nuclear reactions. For the animate world, there are organic systems, in which biological processes are at work; human beings, as the object of managerial labour; and the immaterial substance, knowledge ('information'), which must be applied in every labour process.

In most discussions of mechanization there is an implicit assumption that one is treating of essentially 'mechanical' processes, and that the machine tool industry is the exemplar of the process (see e.g. Braverman, 1974; Noble, 1979; Shaiken, 1984). Ordinary language is confusing here, because 'mechanization' connotes the mechanical world that predominated in nineteenth-century industrialization. But with twentieth-century developments in petrochemicals, electricity and electronics, agriculture, office work and telecommunications, the fixation on mechanical industry seems rather outdated. It is also odd to see Piore and Sabel (1984) herald the arrival of a 'second industrial divide' on the basis chiefly of improvements in mechanical processing when there have already been major revolutions in chemicals, electricity and agriculture that have utterly changed the face of industrialization in this century. Similarly, the current love affair with electronics-based 'high tech' industries (e.g. Hall and Markusen, 1985) ought not to blind us to the differences among all the supposedly 'low tech' sectors.

In terms of conversion and assembly the various material realms are quite distinct. Chemical processing deals chiefly with the initiation of molecular reactions. Workers only assemble materials; they do not convert molecules by hand. Early batch-processing involved such actions as mixing, heating and filtering of natural – usually organic – ingredients, which in time could be aided by machinery. But the major advances of the late nineteenth and early twentieth centuries came with the shift in material base toward coal, oil and gas feedstocks,

electrolytic processing, and catalytic conversion. Machinery's role was to contain, move and regulate the increasingly intense, rapid and fine-tuned chemical reactions with better pumps, valves and pressure vessels (Freeman, 1982: 28). The key to further advance lay, above all, in grasping and operationalizing the principles of chemistry, hence science and engineering entered the picture very early. Electricity is similar to chemistry in this. There were no 'electrical handicrafts' to mechanize and deskill. Machines entered from the beginning with the generation of power, and mechanical advance consists chiefly of more sophisticated manipulations of electromagnetic signals, beginning with amplification. The biological level is very special indeed, as has been implicitly recognized in the separate treatment always accorded agriculture, despite a history of mechanical advance as old as any industry. Mechanization in agriculture has required, in addition to machinery to help farmers till, plough, milk or harvest, improvements in growing conditions and alteration of the organisms themselves. In short, by moving away from labour processes involving simple solids, the internal physical processes of materials transformation loom much greater in the mechanical calculus.

Transfer in non-mechanical industries also cannot be treated in the same terms as the assembly line. Continuous flow processing is a commonplace in handling liquids and gases in the chemical industries, but a distant hope in the production of furniture or cars. Indeed, for certain flow industries such as water, gas and electrical power supply, storage and distribution are the central tasks, not conversion. The development of the machinery in a power grid is a far cry from the problems met by pick-and-feed robots. Agriculture's transfer problems such as herding animals, irrigating and moving the harvest from the open field have no parallel in other industries. In order to use moving lines, for instance, one has to breed living animals that sit in one place all day, such as the continuously laying hens of the modern automated henhouse.

In the realms of integration and regulation, current advances in the control of mechanical processes are still usually far behind those made long ago in chemistry and electronics. When petroleum refining moved to continuous flow processing in the 1920s, automatic controls for close supervision of processing and rate of transfer became necessary because tighter integration of processes meant a closer meshing of rates of flow and greater potential for failure in one step leading to overall failure (Hirschhorn, 1984: 43-4). The first controls were not electrical (for fear of fire) but mechanical, based on springs, thermometers, thermostats and floats, whose signals were amplified by simple principles of hydraulics and pneumatics. But control was decisively separated from the rest of the machinery where it could be easily modified without other changes in the equipment.

Self-regulation came to the electrical industries with the invention of the vacuum tube, by which one electrical current could be used to modify another. Thus was born electronics. The *differeus specifica* of electronics is that electric current can be used to regulate itself. Self-regulation has therefore proceeded by leaps and bounds in electronics in a way unimaginable with strictly mechanical devices. Solid state, microcircuitry and digitized information have subsequently carried the revolution in automation to greater heights. A digitized telephone signal, for instance, has no parallel in solid or liquid flow, because the medium has indeed become the message!

Agriculture is the most resistant to mechanical regulation because it depends on organisms which have their own rhythms of growth and activity (MacLennan and Walker, 1980). Interventions here have followed two courses: greater control of growing conditions through fertilization, irrigation and use of pesticides, and altered the state of the organisms themselves through the use of synthetic hormones, antibiotics, and selective breeding (and soon genetic engineering). The modern feedlot, dairy or henhouse depends for its success on the changes in the animals as much as on those in the preparation of feed or removal of egg produce.

We can draw some conclusions from the above points for the general course of mechanization. First, industries develop along distinctive pathways owing to their fundamentally different material foundations. Mechanization has a logic based on the way things work, as well as the way people work. The course of mechanization is fundamentally altered by the contours of the product and the nature of the material transformations required to make it. Hence, industries do not all mechanize in the same way. While mechanical progress shares certain features across sectors, owing to the universality of labour, inappropriate generalization collapses profound material differences and does violence to the distinctive histories of industries. The technological breakthroughs that made possible the great eras of steel, home-building, air travel, railroading, textiles, or electronics may be so different as to defy abstractions such as Taylorism, Fordist production or flexible specialization as means of grasping the whole (or perhaps even the main part) of mechanical advance and transformation of the labour process.

Second, all industry does not mechanize equally fast or equally far. It is easy to forget how dilatory mechanical advance has been in so many important industries, from lumbering to house-building. This 'backwardness' derives not from a lack of capitalist motivation, abundance of cheap labour or absolute rent, but from the fractious nature of particular materials, work tasks and machines. Woodworking, for example, cannot ever hope to attain the liquid flow properties of oil refining. On the other hand, seemingly small mechanical breakthroughs in such industries may make a big difference in production

capabilities, for example the lathe or the sewing machine. The corollary is that often too much attention is given to highly automated industries in our understanding of industrialization. Textiles and railroads were not the whole of the industrial revolution. There were many workshop industries that do not fit the cyclopean stereotypes of weaving factories or steam engines (Sabel, 1982; Samuel, 1977). Crucial advances in making dyes and other chemicals were also propulsive of nineteenth-century industrialization (Schumpeter, 1939). In the twentieth century, Fordist mass-production practices, for all their importance, were always concentrated in a few industries: autos, appliances, radio/TV, cameras, toys/sporting goods and watches/clocks. Perhaps only 1 in 30 employees in Britain circa 1980 were classic line workers (Littler, 1985: 19). Batch- and custom-production remain extremely important today in industries as disparate as electronics, aeronautics, shipping and garments.

Product shifts

Up to this point we have assumed an unchanging product as the production process has been mechanized. This is frequently invalid. Product change can redefine the problem of process mechanization and mechanization can redefine the nature of the product. Product and process change are deeply wedded. On the one hand, product design modification can alter the need for machines. For example, as more and more circuits are crammed on a single semiconductor, fewer external leads are needed and assembly work diminishes; in some cases, the latter has fallen below 5 per cent of costs. At this point mechanization of assembly ceases to be an important issue. The focus of mechanization shifts to design, in fact, because the immense circuitry of present-day microprocessors exceeds the capabilities of manual engineering and drafting. On the other hand, advances in mechanization can alter the product (cf. Chapter 15). Owing to computer-aided design (CAD) and laser cutting, the semiconductor industry has been branching into a whole new area of specialized and customized chips. While everyone has been waiting for the industry to 'mature' to mechanized mass production – which it has done to a large degree in random access memories – it has just as rapidly sustained its 'youth' by the proliferation of new products. An even more graphic case of product proliferation due to automation is in the petrochemical industry: high-temperature cracking of oil generates a host of exotic organic chemicals, for which uses are subsequently found – or foisted on the public (such as artificial turf). The products only come into being because of the highly advanced state of modern refining (Commoner, 1976: 183–97).

Dramatic instances of the dialectic of product and process can be found throughout the history of industrialization, as the search for improvements in the performance or manufacture of a product leads to the creation of a new one, sometimes quite tangential to the original purpose. Machines themselves can become new products and the basis for whole new industries; textile machinery broke off to become a separate industry around 1840, eventually moving into locomotives and other large devices. The same thing can happen by altering the materials; after a century of incremental improvements in spinning and weaving machines, the textile industry was deeply transformed by the introduction of synthetics and knitted fabrics. Or the product and process can change together as a whole technology is revolutionized: cast iron became steel at the same time it was being made in bigger machines. In the twentieth century, transforming electricity into light images yielded the picture tube, giving rise to oscilloscopes and televisions; storing information electrically in binary form gave birth to the computer.

The dialectics of product and process change make for a path of mechanical advance,³ which conflicts with organic models of industry growth and maturation. A new product may appear to metamorphose continually, preventing evolution to more standardized machine production; or it may only appear at a high level of automation, completely skipping a craft stage; or it may split off a new product at a lower level of mechanization; or it may be replaced by a better substitute and die out before all the mechanical processing problems are solved. In short, industrial production is not a set problem to which machines are applied with predictable results. The nature of the problem shifts due to the technological capacities unleashed by the machines themselves. This means we can never have a fully closed model of industrial maturation and mechanization that holds for all industry and all times, even under the general guiding hand of capitalism.

Braverman and many others implicitly accept a 'maturation' or 'product cycle' model of the development of industries. In this model, first formalized by Simon Kuznets and Arthur Burns, industries proceed organically from the birth of a new product to a youth of handicraft production to an old age of machine mass production (Burns, 1934; Kuznets, 1930). That is, every industry is expected to mechanize fully, to follow the same general technological path and to eventually exhaust its possibilities for further mechanization. But industrialization does not work that way. It was shown long ago that industry growth paths do not follow the S-shaped pattern expected by the life-cycle model (Gold, 1964). It should now be clear why. Mechanization proceeds along several dimensions not a single line of advance, and can even run backward at times. Mechanization is open-ended, so there is always the possibility of further renewal of an

industry. Industries are terribly diverse in their material bases, and either never mature or never have a proper youth. And just when an industry seems over the hill, a new product may burst from within to set down a fresh path of development. Ironically, the originator of the product cycle theory, Raymond Vernon, took as his model the US radio industry (Vernon, 1960), which promptly went through a revolutionary kink in its development path by the introduction of transistors – and moved to Japan. It appears that Kuznets, Burns and Vernon's notion of standardized progress from hand labour to mass production was a mid-century idealization of what happened in automobiles and a few other large consumer durables, as Fordist methods diffused (Coombs, 1985).

The effects of mechanization on workers

The transformation of work which Marx identified – jobs divided into minute, motions rationalized and work transferred to machines (Marx, 1967: 359–68, 418–26) – has happened in many industries with the development of mass production. But the deskilling of work and unemployment due to automation have not been universal tendencies, owing in large part to the technological nature of the labour process. This has been true for three principal reasons which relate to the nature of production and mechanization as just described: the resistance of many labour processes to rationalization, division and mechanization; the ability of machines to enhance, as well as demean, the powers of human labour; and the development of social labour as opposed to individual skills in the transition from craftwork to the machine age.

The supplanting of people by machines has been limited by the simple technical difficulty of mechanizing many labour processes. This has several dimensions, but the essential point is straight-forward: capturing the powers of living labour in the machine is not easy because human beings are incredibly 'skilful' animals by their very nature. Even what is commonly considered 'unskilled' labour – because almost everyone can potentially do it – is still beyond the reach of machines. Therefore, if machines are to do the things that humans do, the tasks must be made very simple or the instructions to the machines made very clever. But how far has the emulation of the human hand gone and how far does this replace human beings with machines? We forget how clumsy machines can be, where human fingers are supple; how blind they are, how sharp the human eye; how oblivious to noises apparent to the human ear; how stupidly the computer follows orders without the slightest glint of imagination! Reality was inverted by Frederick Taylor to make the problem appear to be one of fitting uneducated workers to clever machines, rather than the reverse.

The principles of Taylorism and Fordism just do not apply to many kinds of jobs. Consider basic acts of conversion and transfer to begin with. Garments are difficult to machine produce, for example, because the human body comes in such odd shapes. Clerical work is less amenable to mechanization than office managers hope because, among other things, of the infinite variety of things to be filed. Telephone operators have been hard to displace owing to the unstructured nature of caller requests. Bigger trucks can raise the productivity of labour in transport, but it is impossible to dispense with the driver. All these are, furthermore, quite venerable jobs whose fractionousness cannot be explained away by reference to the youth of the industries involved. Several writers have noted the importance of 'tacit skills', or the concrete know-how accumulated by the worker after ten years on the job, as forming a barrier to worker displacement (Cressey and MacInnes, 1980; Manwaring and Wood, 1985). The persistence of such concrete skills is not, however, a quirk to be easily overcome, for it is grounded in the very diversity of the division of labour itself. In general, too much attention has been given to changes up and down a single scale of abstract skill (as if all work could be directly compared as more or less skilled) and too little to the persistent variations across the division of labour that make skills incommensurable. Furthermore, machinery itself creates concrete skills consisting of the knowledge of particular machines and their quirks.

Assembly labour is even more intractable than most acts of conversion. Despite Ford, the bulk of assembly has never been automated because joining odd-shaped parts is exceptionally difficult for machines, because they can neither see, feel, nor make the subtle adjustments necessary not to jam or damage close-fitting pieces. We forget how difficult it is to fit a square peg in a square hole without jamming it, although it is the merest child's play to most human beings. Robotics finally allow a machine to carry out the extraordinary movements of the hand and arm as a complete, integrated unit.

The more sophisticated dimensions of the labour process are the hardest to rationalize, divide and mechanize. Most mechanization has been confined thus far to such actions as cutting, squeezing and moving, which barely scratch the surface of many production problems. Process regulation, consisting of initiation and response, requires powers of invention, observation (sensation) and reflection that are extraordinarily complex. The art of building machines that 'see', let alone those that 'think' is still in its infancy. Computer-aided product design is making great strides, but the acts of imagination that guide the process are still the province of the fashion designer, engineer or architect. Braverman was wrong to think that where this sort of 'mental labour' is concerned Taylorist principles will work effectively, because human self-regulation and creativity are not amenable to crude strategies of fragmentation and mechanical repetition (Varaiya, 1987).

Even basic acts of work integration also involve the not unsophisticated skills of communication, organization, co-operation, and competition. Marx and others have passed too quickly over the analysis of 'simple co-operation' to the division of labour without appreciating sufficiently that the one must be balanced against the other. In Taylorism work integration is almost completely absent. Fordism did achieve certain advances in work integration, to be sure, but it did so at the expense of ignoring others, such as the inventories on the loading dock, slow response time to errors, and worker interaction – precisely because its main focus was on continuous transfer and specialization in jobs and machines for simple acts of processing and assembly. The Japanese have achieved high levels of productivity by exploiting this 'lost dimension' of production. Japanese innovations in work organization show that Taylorism and Fordist assembly lines can be a barrier to greater productivity in the integrative dimension of work, and that a reconsideration of the basics of the labour process is needed before applying machinery indiscriminately.

Different material bases of industry pose further problems for capitalist rationalization and mechanization. Time and motion studies have had little to offer agriculture, electric power or oil refining. Moreover, the industrialization of everything from steel to pharmaceuticals has been propelled to a significant degree by the mastery of natural materials through metallurgy, chemistry or engineering, using scientific and technical labour that is itself highly unrationalized in Taylorist terms. Even the Taylorization of seemingly ordinary office and sales labour, which presents such a pressing need for twentieth-century capitalists, has proven surprisingly resistant to mechanization, for the reason of the kind of work involved – manipulation of information and personnel.

A second major difficulty with the Braverman thesis is that working with machines creates as well as destroys skills (Adler, 1985a). Machines have made possible many jobs and skills that were hardly imaginable before, whether for pilots, recording engineers or tool and die makers. In more humble fashion, even relatively unskilled machine operatives must intervene in the areas where machines remain helpless, as in set-up, speed and pressure adjustments or reactions to variable materials and wear and tear (Shaiken, 1984: 87–92). At the other end of the spectrum, new levels of creativity, responsibility and flexibility are required for the handling of immense machine systems whose malfunctioning can be terribly costly, even disastrous (Hirschhorn, 1984: 71–86). In between, one finds machines augmenting the capabilities of many workers in more or less traditional jobs, even where some of the previous functions of human labour have been moved into the machines: machinists can cut better parts with more advanced lathes; word processors can help the secretary type, edit, print and store work in ways not possible with typewriters; power tools have

made the carpenter's job easier. In some cases, new 'flexible' machinery has greatly enhanced the competitive standing of more craft-like, multi-skilled labour in small workshops (Piore and Sabel, 1984). In general, the 'machine culture' that pervades modern industrial societies creates a certain broad technical literacy of its own (Adler, 1985a). Truck driving is not considered skilled work today, but it would have amazed a citizen of the nineteenth century.

A third and final point is that the analysis of deskilling and reskilling labour cannot proceed on the basis of the individual worker. Both Marxist critics of the Braverman school or technological optimists such as Sabel and Hirschhorn err by generalizing too widely from limited experience. Many people are, of course, grievously hurt by capitalist rationalization, division and mechanization, while others benefit, but neither tells us what has happened to what Marx called the 'collective labourer'. It is increasingly imperative to evaluate the transformation of work at the level of production systems and their complex divisions of labour within and beyond the factory, because of the widening scope of industrialization and social labour.

To begin with, mechanization creates masses of new jobs at the same time as it eliminates old ones. Even within the factory, the introduction of machine processes is usually markedly uneven. Between the 'islands of machinery' may be found large numbers of workers engaged with manual tasks such as sorting, testing or moving. As a result, the most advanced and most primitive kind of labour still go on cheek by jowl. Indeed, machinery may actually create more jobs at the labour-intensive bottlenecks by virtue of its expanded throughput: in the chemical industry, for example, one can still find gangs of common labourers filling, tying, carrying and loading bags of chemicals generated by highly automated processes (Nichols and Beynon, 1977: 11–12). More broadly, machinery creates a host of new labour-intensive jobs in repair, packing, shipping and design. Indeed, this effect is felt far beyond the factory in the legions of sales, advertising or managerial workers (cf. Walker, 1985a). Finally, as entirely new products and materials processes are brought into being because of the advancing front of machine technology, as in the case of plastics or silicon chips, wholly new industries grow up on the basis of new realms of know-how and practical skills.

The matter is more complicated than numbers of jobs and average labour-intensity across the social division of labour, because of the shifting nature of skills involved. Not only have new spheres of work arisen to be perhaps attacked anew by capitalist rationalization, as Braverman notes, but the centre of gravity of collective labour has changed, so that old skills and old capitalist conquests matter less than they once did. The production process has been extended to new spheres, from pre-production design to post-production repair, and the productivity of labour depends on all spheres, not just direct hands-

on work (Kaplinsky, 1984; Varaiya, 1987; Walker, 1985a). Industrialization has advanced to successively higher planes of technological competence, a process closely associated with the development of new industries; while this is widely acknowledged in misleading terms such as 'high-tech' or 'science-based' industry, the process goes back at least to the invention of steel, steam engines and coal-tar dyes, and the new industries they spawned (Walker, 1985c). When we look at the whole division of labour the living tissue of production is little diminished. But its look has changed as has its point of entry, its skills, its tools, and its venue – to drafting boards, computer terminals and fixing installed machines on site (cf. Jones, Chapter 2, above).

It is enormously difficult to assess the moving average of skill across the shifting division of labour in single industries, let alone the whole industrial system. Computer processing, for example, can involve a mix of tedious data entry (transfer) work and creative programming (regulation) work, but the average skill level of word or data processing can be quite high. Furthermore, skills will move in several dimensions at once as new machinery is adopted. The overall tendency appears to put greater and greater stress on the higher kinds of labour capacities such as observation, regulation, integration and creativity that are, as argued above, the least susceptible to machine domination at this time (Varaiya, 1987). Braverman gives too much credit to management and too little to the evolving forces of production by posing technological advance as chiefly a matter of 'conception' passing over to the side of capital.

It is easy to fall prey to the illusions created by a ceaselessly moving division of labour. But one cannot simply read skill off from the state of technology. At the micro-level, jobs are constructed in such a way as to concentrate better and worse tasks, then allocated according to gender, race and other 'background' factors (Edwards *et al.*, 1975). More broadly, the skill content of work is raised or demoted ideologically according to the bearer of the job, so that many of the jobs typically held by women branded unskilled may have a considerable skill content (Jenson, Chapter 7, below; Phillips and Taylor, 1980). In making the case for a revival of craft skills with the coming of flexible specialization, Piore and Sabel (1984) extract only the better aspects of the overall situation of workers. Despite the admirable strength of the craft workers in today's Emilia Romagna or the Paris of Proudhon's time, the best jobs have been reserved for a select group of men (Harvey, 1985; Vinay, 1987). In fact, production 'flexibility' in such contexts may depend less on new machinery and upgraded skills than on flexible methods of exploiting labour such as the use of temporaries, external subcontracting, and abuse of illegal immigrants (Storper and Christopherson, 1987; Jenson, Chapter 7 and Walby, Chapter 6, below).

Human labour is then still the central force of production, not an afterthought to machines – or science and engineering in general. Mechanical advance can proceed in certain ways without immediate reference to the way human labour functions, as in advances in catalytic cracking. But social production as a whole cannot. The dialectic of labour and machines in the development of the forces of production is an ongoing one. Again and again, living labour reasserts itself as necessary. Not only is the fully automated factory an unattainable pipe dream of some capitalists (cf. Jones, Chapter 2, above), but the notion of full automation is itself an illusion. Industrial production is something that only humans do. While it may change form over time, human labour can never be eliminated. Braverman's model effectively annihilates the subject of labour – and not just the workers' will to resist. Yet production remains entirely humanly conceived, directed and undertaken, no matter how capital may distort that effort or how many machines participate.

To sum up, on the one hand, Braverman exaggerates the purely technical degradation of labour under capitalism, and it is this that leads him to underestimate worker resistance to capitalist offensives. The nature of human action, materials and machinery involved in particular labour processes, as well as the dynamics of product and process development, make work less susceptible to the logic of Taylorism or other existing strategies of capital than he suggests. Some solid foundations of resistance are granted workers by the technical realities of production (Storper and Walker, 1983) – although we know little about the exact relations between technology and politics; for example, the degree of work integration may be significant to worker solidarity (Mills, 1979). On the other hand, the manifest degradation of so much work under capitalism belies the views of technological optimists. The reason is that it has less to do with the division of labour and mechanization than with the relations of production, as Marx, I believe, came to realize by the time he wrote *Capital*. To blame technology for the conditions of work is to fall captive to a certain fetishism of that most impressive of commodities, the machine. While mechanization engenders real dangers and deprivations – nuclear power is not magically rendered safe by socialism, for instance – it still pales by comparison as a source of labour's degradation with the central social fact of having to work for someone else by virtue of the latter's ownership of property, with all that follows from that: demeaning treatment, inequitable assignment of tasks, lack of protection from hazards.

The geography of industrialization

We can now turn to the implications of the approach to mechanization

outlined here for understanding the geographical tendencies of capitalist industrialization. The transformation of work is, more often than not, also the transformation of the *place* of work, as well. The geography of industrialization is not just the outcome of changes in production, however, but part and parcel of those changes and how they are brought into being (see also Chapter 13).

The prevailing models linking mechanization to industrial location are of two broad types. The first group includes the product cycle and two variants, the new international division of labour and corporate spatial hierarchy. Under the simple product cycle theory new industries arise in old industrial centres, or seedbeds, where a good supply of skilled labour and specialized markets and suppliers can be found. As they grow up – in this organic metaphor – the product and its production methods become increasingly standardized and mechanized, with consequent expansion of market area and deskilling of labour. These two conditions sever the link to the old industrial cores and make locations in peripheral, cheap labour areas more attractive (Scott, 1983; Vernon, 1960). Mechanization, therefore, leads to deskilling which leads in turn to dispersal of large plants, in a geographic extension of the deskilling thesis.

The new division of labour theory expands the model to allow for a spatial division of labour within industries such that more skilled, less mechanized units such as research or factories specializing in new products remain within the compass of old industrial centres while only standardized factory production disperses to the periphery (Froebel, *et al.*, 1980). The corporate hierarchy model adds that this is all possible due chiefly to the modern multilocal firm, whose headquarters move to the largest metropolitan centres, mid-level functions, such as research and divisional management, reside in medium-size cities or suburbs, and 'branch plants' are banished to the hinterlands in search of cheap and docile labour supplies (R. Cohen, 1981; Hymer, 1972). The two principal implications of these models for industrial geography are the growing separation of specialized bits of production across wider national and international arenas and the long-term stability of the urban, regional and national hierarchy of capitalist development.

These formerly dominant explanations for the spatial order of capitalist industrialization are yielding to two theses drawn from recent inquiries into machine technologies, employment practices and business organization. One involves the 'flexible production complex', defined at a regional or large metropolitan scale, and the other focuses on Japan and the newly industrializing East Asian countries, at an international scale. Within the former, the flexible specialization school has been captivated by the example of the Third Italy. In the approach taken by Sabel (1982; Brusco and Sabel, 1983; Piore and Sabel, 1984) it is the skill base of the new high-tech workshops that is making rapid

industrial growth possible and attracting subcontracts from Fiat in Turin and elsewhere (Murray, 1983). A similar argument has been made for Silicon Valley, where engineering skills and technical innovation in microelectronics are said to create a unique centre of growth (Hall and Markusen, 1985). Storper and Scott (1988) have tried to generalize the principle of 'flexible production complexes', but on a broader basis than flexible automation. They argue that the flexible organization (integration) of production possible in such agglomerations of activity is central to their expansion at the expense of more isolated production sites (see also Scott, 1983).

Another group sees the focal point of advances in production and mechanization as Japan, and the competitive advantage it has gained in many industries by means of just-in-time, *kanban*, work teams, product quality and robotics. The background to Japan's breakthrough into world industrial leadership in innovation is explained in various ways, such as a long process of development from older, less sophisticated industries to newer high-tech ones (Cummings, 1984), highly organized state planning (Johnson, 1982), or protectionism and low interest rates (Okimoto *et al.*, 1984). Whatever the causes, however, it is agreed that the Japanese have pushed ahead of the pack in many critical areas of production organization and automation, especially in contrast to American Fordism (Abernathy *et al.*, 1983; Cusumano, 1985).

Common to both the Japanese and 'flexible cluster' models is a view that emerging centres of industry can eclipse the old on the basis of innovations in products and production methods. This is a dramatic reversal from the product cycle and new international division of labour models, in which established urban-industrial core areas remain the centres of innovation and accumulation. The view of hierarchical stability has been shattered by the wholesale geographic restructuring of industry in all advanced capitalist nations, as in the collapse of northern Britain, the rapid growth of the US sunbelt, and the shift of the entire world capitalist economy toward the Pacific. In fact, capitalist industrialization has repeatedly ignited the rapid growth of formerly outlying areas, from eighteenth-century Coalbrookdale to twentieth-century Los Angeles. Once the rapid growth potential of a new product or process is unleashed, a new locus of industry can mushroom, attracting suppliers investors and workers to it and forging them into the new configurations needed to master a new technology. The dynamics of industrialization allow firms to overcome the limitations of outlying areas, which may at first appear unattractive. Yet the very freedom of operation which capitalists find away from the centres of activity can be highly desirable in terms of moulding labour, management and local politics to new ways of producing – which are likely to include new product and process technologies, new ways of working and forms of labour control, and

new forms of business organization. Conversely, older core areas can be paralysed by their traditional specializations in the face of continuously altered circumstances: new industries, new production methods, new labour relations, new business practices. This is not to say that it is easy for all peripheral places to forge ahead – as dependency theorists stress, there are many ways in which backwardness is reproduced in the international capitalist world – but at least it is possible in this manner to explain what was impossible in the top-down models of spatial hierarchy (Storper and Walker, 1989).

These revised views of spatial clustering and changing locus of industry fit with the model of the labour process and mechanization presented here. First, mechanization does not proceed uniformly across industries, as depicted by the product cycle; instead it follows diverse and irregular paths of automation among different industries. Industries thus find their own particular locales and do not, as they expand over time, necessarily conform to one overarching spatial division of labour, or place hierarchy.

Second, spatial decentralization does not follow from the product cycle of mechanical maturation, deskilling and the search for outlying cheap labour sites. The kind of dispersal of branch plants captured by the product cycle model is only significant in selected industries utilizing Fordist methods and faced with increasing competition, as in General Motors' unsuccessful strategy in the 1970s of moving plants to the southern US to evade the United Auto Workers union. The auto assembly factories involved were not significantly more mechanized or deskilled than their predecessors. Historically, US (and world) car production had earlier become more concentrated in and around Detroit precisely because of Ford's breakthrough into mass production with the assembly line – quite the reverse of the product cycle model. The spread of Ford plants around the country and abroad followed very quickly, as competitors were laid to rest and new markets captured by the Model T.

Third, the formation of territorial production clusters continues to rest heavily on spatial concentration as a way of handling the innumerable problems of interfirm organization of production systems. While not directly tied to mechanization, it follows from what has been said here about the 'lost dimension' of the labour process, integration. Neither the factory nor automated machine systems can alone cope with the manner of co-ordinating work across complex divisions of labour, and in this sense there is no such thing as a self-contained branch plant. Therefore, a theory such as the product cycle that tries to read off location from the level of mechanization in one factory is bound to err.

Fourth, industries periodically lurch in new directions owing to fundamental shifts in product technology or production methods (which usually involve important changes in emphasis among the five

dimensions of labour and mechanization). Such restructurings can rejuvenate an industry or create entirely new industries at an experimental, labour-intensive stage of development, thereby rupturing any simple temporal relation between industrial evolution, mechanization and location. For example, gains in standardization or machine assembly of random memory semiconductor chips are overturned with each new generation of very large-scale integration. More dramatically, when electronics broke off from the electrical equipment industry, with the invention of the semiconductor, it also jumped from the northeastern USA to Silicon Valley in California. When Japanese automakers came up with just-in-time and other advances, the world centre of auto production began to shift from Detroit to Nagoya. Mechanization and technological change are inherently revolutionary processes, and so is geographical industrialization.

Fifth, when new centres of industry, such as Hollywood in the 1920s, begin to develop, they do so by creating new skills and new machines (Christopherson and Storper, 1989). Many of the requisite skills have never existed before, owing to the new products, new materials and new machinery needed to explore an uncharted technological terrain. This is what industrialization has always entailed: the creation of a productive power which did not exist before (Walker, 1988). And it does so in particular places, from the earliest experiments in Shropshire and Derbyshire through the miraculous growth of Manchester or Lowell to the explosive expansion of Paris and New York.

In short, the growth of capitalism, and the renewal of its prodigious powers of expansion, is intimately connected to industry localization, territorial clustering and the periodic opening up of new industrial centres. Alas, most social scientists, trained in aspatial ways of thinking, have been blind to the geographic dimension of industrialization. The transformation of work must be taken up in the broadest possible terms, in which changes in the labour process, technology, organization and industry location are seen as so many facets of the same immense process: capitalism's never-ending revolution of the forces of production and of the conditions of life for working people around the world. The transformations of work capitalism brought on by the rationalization, division and automation of labour processes are quite diverse, as we have seen, and can move in unexpected directions. This creates an uneven and unstable terrain on which capital and labour contest the content, performance and rewards of work. It is ~~not~~ ^{less} a literal terrain, moreover, a place of cities and regions as well as shop-floors. The global transformation of work rests on the ability of capital to command that larger field of battle by dividing and conquering scattered labour forces, by tactical expansion, retreat and reposition of its industries, and by the build-up of whole new territorial bases of operation (Storper and Walker, 1989). It is,

ultimately, this ability that checks the social forces – especially an organized working class – that can bring about a widespread transformation to more humane conditions of work.

4 *Multinational corporations and the new international division of labour: a critical appraisal*

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Introduction

The study of multinational corporations came of age during the period of US dominance of an expanding global economy. In this context, explanations of the determinants of foreign direct investment – why firms invest abroad – focused to a great extent on questions of market power.¹ Firms moved abroad to exploit (or defend) their oligopolistic or 'ownership' advantages in foreign markets, including proprietary technology, greater capital resources and product differentiation (Caves, 1971, 1974, 1982; Dunning, 1971, 1974, 1981; Hymner, 1976; Kindleberger, 1970; Kindleberger and Audretsch, 1983; Vernon, 1966, 1974). Alternatively, it was argued that firms invest abroad to maximize efficiency by internalizing trade within the firm (Buckley and Casson, 1976; Teece, 1981). Both lines of analysis implicitly suggest that direct investment will be oriented principally to major market areas, hence, in all likelihood, other developed countries.

As the advanced industrial economies entered a period of stagnation, accompanied by large-scale rationalization and restructuring of industry, a new line of analysis emerged that viewed foreign investment primarily as a defensive reaction to problems of profitability and competitiveness in the core of the world economy arising from the pressures of high labour costs, union militancy and labour-market rigidities (Amin, 1979; Frobel *et al.*, 1980; Susman, 1984; Vuskovic, 1980). In this new international division of labour concept (NIDL), production moves offshore primarily in search of low-cost, relatively docile labour in the periphery.

The NIDL has become very much a part of the working vocabulary of those concerned with questions of industrial restructuring on a global scale. In contrast to the old, broadly sectoral and horizontal division of labour, where the periphery provided food and raw materials in exchange for manufactured goods from the core (Lipietz, 1985), the NIDL highlights the changing spatial distribution of functions in the global economy. In this process of intra-sectoral, vertical de-linking, the core retains high-level knowledge and skill-