3

SOCIAL CHOICE IN MACHINE DESIGN

D.F. NOBLE

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Introduction

Almost everyone would agree that the technology of production and the social relations of production are somehow related. The explanation of this relationship often takes the form of a more or less "hard" technological determinism: Technology is the independent variable which effects changes in social relations; it has its own immanent dynamic and unilinear path of development. Further, it is an irreducible first cause from which social effects automatically follow. These effects are commonly called its "social impact."

Social analysts have recently begun to acknowledge that the technology and the social changes it seems to bring about are in reality interdependent, and it has become fashionable to talk about the dialectic between the forces of production and social relations. Nevertheless, most studies of production continue to focus primarily on the ways in which technology affects social relations and there is precious little effort made to show precisely how technology reflects them. That is, although grantsmanship now demands that people refer to the mutual dependence of technology and society, and although socialists and other radicals now take it for granted that technological development is socially determined, there remains very little concrete, historical analysis that demonstrates the validity of the position. The present essay, a case history of the design, deployment, and actual use of automatically controlled machine tools, is meant to be a step in that direction.

Elsewhere I have tried to show that technology is not an autonomous force impinging upon human affairs from the "outside," but is the product of a social process, a historically specific activity carried on by some people, and not others, for particular purposes (Noble 1977). Technology thus does not develop in a unilinear fashion; there is always a range of possibilities or alternatives that are delimited over time—as some are selected and others denied—by the social choices of those with the power to choose, choices which reflect their intentions, ideology, social position, and relations with other people in society. In short, technology bears the social "imprint" of its authors. It follows that "social impacts" issue not so much from the technology of production as from the social choices that technology embodies. Technology, then, is not an irreducible first cause; its social effects follow from the social causes that brought it into being: behind the technology that affects social relations lie the very same social relations. Little wonder, then, that the technology usually tends to reinforce rather than subvert those relations.

Here I want to render this abstract argument concrete by examining a particular technology. Moreover, I want to go a step further and show that the relationship between cause and effect is never automatic—whether the cause is the technology or the social choices that lie behind it—but is always mediated by a complex process whose outcome depends, in the last analysis, upon the relative strengths of the parties involved. As a result, actual effects are often not consonant with the expectations implicit in the original designs. The technology of production is thus twice determined by the social relations of production: first, it is designed and deployed according to the ideology and social power of those who make such decisions; and second, its actual use in production is determined by the realities of the shop-floor struggles between classes.

This essay is divided into six parts. A description and brief history of the technology involved is followed by a two-part section on social choice in design that discusses both the horizontal relations of production (between firms) and the vertical relations of production (between capital and labor). The fourth part examines social choice in the deployment of technology and the fifth looks at shop-floor realities where this technology is being used in the United States today. In the last part some alternative realities, with different social relations, are described.

The Technology: Automatically Controlled Machine Tools

The focus here is numerically controlled machine tools, a particular production technology of relatively recent vintage.

According to many observers, the advent of this new technology has produced something of a revolution in manufacturing, a revolution which, among other things, is leading to increased concentration in the metalworking industry and to a reorganization of the production process in the direction of greater managerial control. These changes in the horizontal and vertical relations of production are seen to follow logically and inevitably from the introduction of the new technology. "We will see some companies die, but I think we will see other companies grow very rapidly," a sanguine president of Data Systems Corporation opined (Stephanz 1971). Less sanguine are the owners of the vast majority of the smaller metalworking firms which, in 1971, constituted 83 percent of the industry; they have been less able to adopt the new technology because of the very high initial expense of the hardware, and the overhead and difficulties associated with the software (ibid). In addition, within the larger, better endowed shops, where the technology has been introduced, another change in social relations has been taking place. Earl Lundgren, a sociologist who surveyed these shops in the late 1960s, observed a dramatic transfer of planning and control from the shop floor to the office (1969).

For the technological determinist, the story is pretty much told: numerical control leads to industrial concentration and greater managerial control over the production process. The social analyst, having identified the cause, has only to describe the inevitable effects. For the critical observer, however, the problem has merely been defined. This new technology was developed under the auspices of management within the large metalworking firms. Is it just a coincidence that the technology tends to strengthen the market position of these firms and enhance managerial authority in the shop? Why did this new technology take the form that it did, a form which seems to have rendered it accessible only to some firms, and why only this technology? Is there any other way to automate machine tools, a technology, for example, which would lend itself less to managerial control? To answer these questions, let us take a closer look at the technology.

A machine tool (for instance, a lathe or milling machine) is a machine used to cut away surplus material from a piece of metal in order to produce a part with the desired shape, size, and finish. Machine tools are really the guts of machine-based industry because they are the means whereby all machinery, including the machine tools themselves, are made. The machine tool has traditionally been operated by a machinist who transmits his skill and purpose to the machine by means of cranks, levers, and handles. Feedback is achieved through hands, ears, and eyes. Throughout the nineteenth century, technical advances in machining developed by innovative machinists built some intelligence into the machine tools themselves—automatic feeds, stops, throw-out dogs, mechanical cams—making them partially "self-acting." These mechanical devices relieved the machinist of certain manual tasks, but he retained control over the operation of the machine. Together with elaborate tooling—fixtures for holding the workpiece in the proper cutting position and jigs for guiding the path of the cutting tool—these design innovations made it possible for less skilled operators to use the machines to cut parts after they had been properly "set up" by more skilled men;* but the source of the intelligence was still the skilled machinist on the floor.

The 1930s and 1940s saw the development of tracer technology. Here patterns, or templates, were traced by a hydraulic or electronic sensing device which then conveyed the information to a cutting tool which reproduced the pattern in the workpiece. Tracer technology made possible elaborate contour cutting, but

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* The use of jigs and fixtures in metalworking dates back to the early nineteenth century and was the heart of interchangeable parts manufacture, as Merritt Roe Smith has shown (1976). Eventually, in the closing decades of the century, the "toolmaker" as such became a specialized trade, distinguished from the machinist. The new function was a product of modern management, which aimed to shift the locus of skill and control from the production floor, and the operators, to the toolroom. But however much the new tools allowed management to employ less skilled, and thus cheaper, machine operators, they were nevertheless very expensive to manufacture and store and they lent to manufacture a heavy burden of inflexibility, shortcomings which one Taylorite, Sterling Bunnell, warned about as early as 1914 (cited in David Montgomery, unpublished ms.). The cost-savings that resulted from the use of cheaper labor were thus partially offset by the expense of tooling. Numerical control, as we will see, was developed in part to eliminate the cost and inflexibility of jigs and fixtures and, equally important, to take skill, and the control of it, off the floor altogether. Here again, however, the expense of the solution was equal to or greater than the problem. It is interesting to note that in both cases expensive new technologies were introduced to make it possible to hire cheaper labor, and the tab for the conversion was picked up by the state—the Ordnance Department in the early nineteenth century, the departments of the army and navy in World War I, and the air force in the second half of the twentieth century.

it was only a partial form of automation: for instance, different templates were needed for different surfaces on the same workpiece. With the war-spurred development of a whole host of new sensing and measuring devices, as well as precision servomotors which made possible the accurate control of mechanical motion, people began to think about the possibility of completely automating contour machining.

Automating a machine tool is different from automating, say, automotive manufacturing equipment, which is single-purpose, fixed automation, and cost-effective only if high demand makes possible a high product volume. Machine tools are general purpose, versatile machines, used primarily for small batch, low volume production of parts. The challenge of automating machine tools, then, was to render them self-acting while retaining their versatility. The solution was to develop a mechanism that translated electrical signals into machine motion and a medium (film, lines on paper, magnetic or punched paper tape, punched cards) on which the information could be stored and from which the signals could be reproduced.

The automating of machine tools, then, involves two separate processes. You need tape-reading and machine controls, a means of transmitting information from the medium to the machine to make the tables and cutting tool move as desired, and you need a means of getting the information on the medium, the tape, in the first place. The real challenge was the latter. Machine controls were just another step in a known direction, an extension of gunfire control technology developed during the war. The tape preparation was something new. The first viable solution was "record-playback," a system developed in 1946–1947 by General Electric, Gisholt, and a few smaller firms.* It involved having a machinist make a part while the motions of the machine under his command were recorded on magnetic tape. After the first piece was made, identical parts could be made automatically by playing back the tape and reproducing the machine motions. John Diebold, a management

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* The discussion of the record-playback technology is based upon extensive interviews and correspondence with the engineers who participated in the projects at General Electric (Schenectady) and Gisholt (Madison, Wisconsin), and the trade journal and technical literature.

consultant and one of the first people to write about "flexible automation," heralded record-playback as "no small achievement . . . it means that automatic operation of machine tools is possible for the job shop—normally the last place in which anyone would expect even partial automation" (1952:88). But record-playback enjoyed only a brief existence, for reasons we shall explore. (It was nevertheless immortalized as the inspiration for Kurt Vonnegut's *Player Piano*. Vonnegut was a publicist at GE at the time and saw the record-playback lathe which he describes in the novel.)

The second solution to the medium-preparation problem was "numerical control" (N/C), a name coined by MIT engineers William Pease and James McDonough. Although some trace its history back to the Jacquard loom of 1804, N/C was in fact of more recent vintage; the brainchild of John Parsons, an air force subcontractor in Michigan who manufactured rotor blades for Sikorski and Bell helicopters. In 1949 Parsons successfully sold the air force on his ideas, and then contracted out most of the research work to the Servomechanisms Laboratory at MIT; three years later the first numerically controlled machine tool, a vertical milling machine, was demonstrated and widely publicized.

Record-playback was, in reality, a multiplier of skill, simply a means of obtaining repeatability. The intelligence of production still came from the machinist who made the tape by producing the first part. Numerical control, however, was based upon an entirely different philosophy of manufacturing. The specifications for a part—the information contained in an engineering blueprint—are first broken down into a mathematical representation of the part, then into a mathematical description of the desired path of the cutting tool along up to five axes, and finally into hundreds or thousands of discrete instructions, translated for economy into a numerical code, which is read and translated into electrical signals for the machine controls. The N/C tape, in short, is a means of formally circumventing the role of the machinist as the source of the intelligence of production. This new approach to machining was heralded by the National Commission on Technology, Automation, and Economic Progress as "probably the most significant development in manufacturing since the introduction of the moving assembly line" (Lynn et al. 1966:89).

Choice in Design: Horizontal Relations of Production

This short history of the automation of machine tools describes the evolution of new technology as if it were simply a technical, and thus logical, development. Hence it tells us very little about why the technology took the form that it did, why N/C was developed while record-playback was not, or why N/C as it was designed proved difficult for the metalworking industry as a whole to absorb. Answers to questions such as these require a closer look at the social context in which the N/C technology was developed. In this section we will look at the ways in which the design of the N/C technology reflected the horizontal relations of production, those between firms. In the following section. we will explore why N/C was chosen over record-playback by looking at the vertical relations of production, those between labor and management.

To begin with, we must examine the nature of the machine-tool industry itself. This tiny industry which produces capital goods for the nation's manufacturers is a boom or bust industry that is very sensitive to fluctuations in the business cycle, experiencing an exaggerated impact of good times—when everybody buys new equipment—and bad times—when nobody buys. Moreover, there is an emphasis on the production of "special" machines, essentially custom-made for users. These two factors explain much of the cost of machine tools: manufacturers devote their attention to the requirements of the larger users so that they can cash in on the demand for high-performance specialized machinery, which is very expensive due to high labor costs and the relatively inefficient low-volume production methods (see Rosenberg 1963; Wagoner 1968; Brown and Rosenberg 1961; Melman 1959). The development of N/C exaggerated these tendencies. John Parsons conceived of the new technology while trying to figure out a way of cutting the difficult contours of helicopter rotor blade templates to close tolerances; since he was using a computer to calculate the points for drilling holes (which were then filed together to make the contour) he began to think of having the computer control the actual positioning of the drill itself. He extended this idea to three-axis milling when he examined the specification for a wing panel for a new combat fighter. The new high-performance, high-speed aircraft demanded a great deal of difficult and expensive machining to produce airfoils (wing surfaces, jet engine blades), integrally stiffened wing sections for greater tensile strength and less weight, and variable thickness skins. Parsons took his idea, christened "Cardomatic" after the IBM cards he used, to Wright Patterson Air Force Base and convinced people at the Air Material Command that the air force should underwrite the development of this potent new technology. When Parsons got the contract, he subcontracted with MIT's Servomechanism Laboratory, which had experience in gunfire control systems.* Between the signing of the initial contract in 1949 and 1959, when the air force ceased its formal support for the development of software, the military spent at least $62 million on the research, development, and transfer of N/C. Up until 1953, the air force and MIT mounted a large campaign to interest machine-tool builders and the aircraft industry in the new technology, but only one company, Giddings and Lewis, was sufficiently interested to put their own money into it. Then, in 1955, N/C promoters succeeded in having the specifications in the Air Material Command budget allocation for the stockpiling of machine tools changed from tracer-controlled machines to N/C machines. At that time, the only fully N/C machine in existence was in the Servomechanism Lab. The air force undertook to pay for the purchase, installation, and maintenance of over 100 N/C machines in factories of prime subcontractors; the contractors, aircraft manufacturers, and their suppliers would also be paid to learn to use the new technology. In short, the air force created a market for N/C. Not surprisingly, machine-tool builders got into action, and research and development expenditure in the industry multiplied eightfold between 1951 and 1957.

The point is that what made N/C possible—massive air force support—also helped determine the shape the technology would take. While criteria for the design of machinery normally includes cost to the user, here this was not a major consideration; machine-tool builders were simply competing to meet performance and "competence" specifications for government-funded

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* This brief history of the origins of N/C is based upon interviews with Parsons and MIT personnel, as well as the use of Parsons' personal files and the project records of the Servomechanism Laboratory.

users in the aircraft industry. They had little concern with cost effectiveness and absolutely no incentive to produce less expensive machinery for the commercial market.

But the development of the machinery itself is only part of the story; there was also the separate evolution of the software. Here, too, air force requirements dictated the shape of the technology. At the outset, no one fully appreciated the difficulty of getting the intelligence of production on tape, least of all the MIT engineers on the N/C project, few of whom had had any machining experience before becoming involved in the project. Although they were primarily control engineers and mathematicians, they had sufficient hubris to believe that they could readily synthesize the skill of a machinist. It did not take them long to discover their error. Once it was clear that tape preparation was the stumbling block to N/C's economic viability, programming became the major focus of the project. The first programs were prepared manually, a tedious, time-consuming operation performed by graduate students, but thereafter efforts were made to enlist the aid of Whirlwind, MIT's first digital computer. The earliest programs were essentially subroutines for particular geometric surfaces which were compiled by an executive program. In 1956, after MIT had received another air force contract for software development, a young engineer and mathematician named Douglas Ross came up with a new approach to programming. Rather than treating each separate problem with a separate subroutine, the new system, called APT (Automatically Programmed Tools), was essentially a skeleton program—a "systematized solution," as it was called—for moving a cutting tool through space; this skeleton was to be "fleshed out" for every particular application. The APT system was flexible and fundamental; equally important it met air force specifications that the language must have a capacity for up to five-axis control. The air force loved APT because of its flexibility; it seemed to allow for rapid mobilization, for rapid design change, and for interchangeability between machines within a plant, between users and vendors, and between contractors and subcontractors throughout the country (presumably of "strategic importance" in case of enemy attack). With these ends in mind, the air force pushed for standardization of the APT system and the Air Material Command cooperated with the Aircraft Industries Association Committee on Numerical Control to make APT the industry standard, the machine tool and control manufacturers followed suit, developing "postprocessors" to adapt each particular system for use with APT.

Before long the APT computer language had become the industry standard, despite initial resistance within aircraft company plants. Many of these companies had developed their own languages to program their N/C equipment, and these in-house languages, while less flexible than APT, were nevertheless proven, relatively simple to use, and suited to the needs of the company. APT was something else entirely. For all its advantages—indeed, because of them—the APT system had decided disadvantages. The more fundamental a system is, the more cumbersome it is, and the more complex it is, the more skilled a programmer must be, and the bigger a computer must be to handle the larger amount of information. In addition, the greater the amount of information, the greater the chance for error. But initial resistance was overcome by higher level management, who had come to believe it necessary to learn how to use the new system "for business reasons" (cost-plus contracts with the air force). The exclusive use of APT was enforced. Thus began what Douglas Ross himself has described as "the tremendous turmoil of practicalities of the APT system development"; the system remained "erratic and unreliable," and a major headache for the aircraft industry for a long time.

The standardization of APT, at the behest of the air force, had two other interrelated consequences. First, it inhibited for a decade the development of alternative, simpler languages, such as the strictly numerical language NUFORM (created by A. S. Thomas, Inc.), which might have rendered contour programming more accessible to smaller shops. Second, it forced those who ventured into N/C into a dependence on those who controlled the development of APT,* on large computers and

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* The air force funded development of APT was centered initially at MIT. In 1961 the effort was shifted to the Illinois Institute of Technology Research Institute (IITRI) where it has been carried on under the direction of a consortium composed of the air force, the Aircraft Industries Association (AIA), and major manufacturers of machine tools and electronic controls. Membership in the consortium has always been expensive, beyond the financial means of the vast majority of firms in the metalworking industry. APT system use, therefore, has tended to be restricted to those who enjoyed privileged access to information about the system's development. Moreover, the APT system has been treated as proprietary information within user plants; programmers have had to sign out

mathematically sophisticated programmers. The aircraft companies, for all their headaches, could afford to grapple with APT because of the air force subsidy, but commercial users were not so lucky. Companies that wanted military contracts were compelled to adopt the APT system, and those who could not afford the system, with its training requirements, its computer demands, and its headaches, were thus deprived of government jobs. The point here is that the software system which became the de facto standard in industry had been designed with a user, the air force, in mind. As Ross explained, "the universal factor throughout the design process is the economics involved. The advantage to be derived from a given aspect of the language must be balanced against the difficulties in incorporating that aspect into a complete and working system" (Ross 1978:13). APT served the air force and the aircraft industry well, but at the expense of less endowed competitors.

Choice in Design: Vertical Relations of Production

Thus far we have talked only about the form of N/C, its hardware and software, and how these reflected the horizontal relations of production. But what about the precursor to N/C, record-playback? Here was a technology that was apparently perfectly suited to the small shop: tapes could be prepared by recording the motions of a machine tool, guided by a machinist or a tracer template, without programmers, mathematics, languages, or computers.* Yet this technology was abandoned in favor of N/C by the aircraft industry and by the control man-

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for manuals and have been forbidden from taking them home or talking about their contents with people outside the company.

* Technically, record-playback was as reliable as N/C, if not more so—since all the programming was done at the machine, errors could be eliminated during the programming process, before production began. Moreover, it could be used to reproduce parts to within a tolerance of a thousandth of an inch, just like N/C. (It is a common mistake to assume that if an N/C control system generates discrete pulses corresponding to increments of half a thousandth, the machine can produce parts to within the same tolerances. In reality, the limits of accuracy are set by the machine itself—not to mention the weather—rather than by the electrical signals.)

ufacturers. Small firms never saw it. The Gisholt system, designed by Hans Trechsel to be fully accessible to machinists on the floor, was shelved once that company was bought by Giddings and Lewis, one of the major N/C manufacturers. The GE record-playback system was never really marketed since demonstrations of the system for potential customers in the machine-tool and aircraft companies elicited little enthusiasm. Giddings and Lewis did in fact purchase a record-playback control for a large profile "skin mill" at Lockheed but switched over to a modified N/C System before regular production got underway. GE's magnetic tape control system, the most popular system in the 1950s and 1960s, was initially described in sales literature as having a "record-playback option," but mention of this feature soon disappeared from the manuals, even though the system retained the record-playback capacity.*

Why was there so little interest in this technology? The answer to this question is complicated. First, air force performance specifications for four- and five-axis machining of complex parts, often out of difficult materials, were simply beyond the capacity of either record-playback or manual methods. In terms of expected cost reductions, moreover, neither of these methods appeared to make possible as much of a reduction in the manufacturing and storage costs of jigs, fixtures, and templates as did N/C. Along the same lines, N/C also promised to reduce more significantly the labor costs for toolmakers, machinists, and patternmakers. And, of course, the very large air force subsidization of N/C technology lured most manufacturers and users to where the action was. Yet there were still other, less practical, reasons for the adoption of N/C and the abandonment of record-playback, reasons that have more to do with the ideology of engineering than with economic calculations. However useful as a production technology, record-playback was considered quaint from the start, especially with the advent of N/C. N/C was always more than a technology for cutting metals, especially in the eyes of its MIT designers, who knew little about metalcutting: it was a symbol of the computer age, of mathematical elegance, of power, order, and predictability, of continuous

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* This history is based upon interviews with Hans Trechsel, designer of Gisholt's "Factrol" system, and interviews and correspondence with participating engineering and sales personnel at GE (Schenectady), as well as articles in various engineering and trade journals.

flow, of remote control, of the automatic factory. Record-playback, on the other hand, however much it represented a significant advance on manual methods, retained a vestige of traditional human skills; as such, in the eyes of the future (and engineers always confuse the present and the future) it was obsolete.

The drive for total automation which N/C represented, like the drive to substitute capital for labor, is not always altogether rational. This is not to say that the profit motive is insignificant—hardly. But economic explanations are not the whole story, especially in cases where ample government financing renders cost-minimization less of an imperative. Here the ideology of control emerges most clearly as a motivating force, an ideology in which the distrust of the human agency is paramount, in which human judgment is construed as "human error." But this ideology is itself a reflection of something else: the reality of the capitalist mode of production. The distrust of human beings by engineers is a manifestation of capital's distrust of labor. The elimination of human error and uncertainty is the engineering expression of capital's attempt to minimize its dependence upon labor by increasing its control over production. The ideology of engineering, in short, mirrors the antagonistic social relations of capitalist production. Insofar as the design of machinery, like machine tools, is informed by this ideology, it reflects the social relations of production.* Here we will emphasize this aspect of the explanation—why N/C was developed and record-playback was not—primarily because it is the aspect most often left out of such stories.

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* It could be argued that control in the capitalist mode of production is not an independent factor (a manifestation of class conflict), but merely a means to an economic end (the accumulation of capital). Technology introduced to increase managerial control over the work force and eliminate pacing is, in this view, introduced simply to increase profits. Such reductionism, which collapses control and class questions into economistic ones, renders impossible any explanation of technological development in terms of social relations or any careful distinction between productive technology which directly increases output per person-hour and technology which does so only indirectly by reducing worker resistance or restriction of output. Finally, it makes it hard to distinguish a technology that reduces pacing from a gun in the service of union-busting company agents; both investments ultimately have the same effect and the economic results look the same on the balance sheet. As Jeremy Brecher reminds us, "The critical historian must go behind the economic category of cost-minimization to discover the social relations that it embodies (and conceals)" (1978).

Ever since the nineteenth century, labor-intensive machine shops have been a bastion of skilled labor and the locus of considerable shop-floor struggle. Frederick Taylor introduced his system of scientific management in part to try to put a stop to what he called "systematic soldiering" (now called "pacing"). Workers practiced pacing for many reasons: to keep some time for themselves, to exercise authority over their own work, to avoid killing "gravy" piece-rate jobs by overproducing and risking a rate cut, to stretch out available work for fear of layoffs, to exercise their creativity and ingenuity in order to "make out" on "stinkers" (poorly rated jobs), and, of course, to express hostility to management (see articles by Roy; Mathewson 1969). Aside from collective cooperation and labor-prescribed norms of behavior, the chief vehicle available to machinists for achieving shop-floor control over production was their control over the machines. Machining is not a handicraft skill but a machine-based skill; the possession of this skill, together with control over the speeds, feeds, and motions of the machines, enables machinists alone to produce finished parts to tolerance (Montgomery 1976b). But the very same skills and shop-floor control that made production possible also make pacing possible. Taylor therefore tried to eliminate soldiering by changing the process of production itself, transferring skills from the hands of machinists to the handbooks of management; this, he thought, would enable management, not labor, to prescribe the details of production tasks. He was not altogether successful. For one thing, there is still no absolute science of metalcutting and methods engineers, time-study people, and Method Time Measurement (MTM) specialists—however much they may have changed the formal processes of machine-shop practice—have not succeeded in putting a stop to shop-floor control over production.*

Thus, when sociologist Donald Roy went to work in a machine shop in the 1940s, he found pacing alive and well. He recounts an incident that demonstrates how traditional patterns of authority rather than scientific management still reigned supreme:

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* The setting of rates on jobs in machine shops is still more of a guess than a scientific determination. This fact is not lost on machinists, as their typical descriptions of the methods-men suggests: "They ask their wives, they don't know; they ask their children, they don't know; so they ask their friends." Of course, this apparent and acknowledged lack of scientific certainty comes into play during bargaining sessions over rates, when "fairness" and power, not science, determine the outcome.

> "I want 25 or 30 of those by 11 o'clock," Steve the superintendent said sharply, a couple of minutes after the 7:15 whistle blew. I [Roy] smiled at him agreeably. "I mean it," said Steve, half smiling himself, as McCann and Smith, who were standing near us, laughed aloud. Steve had to grin in spite of himself and walked away. "What he wants and what he is going to get are two different things," said McCann. (1953:513)

Thirty years later, sociologist Michael Burawoy returned to the same shop and concluded, in his own study of shop-floor relations, that "in a machine shop, the nature of the relationship of workers to their machines rules out coercion as a means of extracting surplus" (1976).

This was the larger context in which the automation of machine tools took place; it should be seen, therefore, as a further managerial attempt to wrest control over production from the shop-floor work force. As Peter Drucker once observed, "What is today called automation is conceptually a logical extension of Taylor's scientific management" (1967:26). Thus it is not surprising that when Parsons began to develop his N/C "Cardomatic" system, he took care not to tell the union (the UAW) in his shop in Traverse City about his exciting new venture. At GE (Schenectady), a decade of work-stoppages over layoffs, rate cuts, speed-ups, and the replacement of machinists with less skilled apprentices and women during the war, culminated in 1946 in the biggest strike in the company's history, led by machinists in the United Electrical Workers (UE) and bitterly opposed by the GE Engineers' Association. GE's machine-tool automation project, launched by these engineers soon afterward, was secret, and although the project had strong management support, publicist Vonnegut recalled, with characteristic understatement, that "they wanted no publicity this time."*

During the first decade of machine-tool automation development, the aircraft industry—the major user of automatic machine tools—also experienced serious labor trouble as the machinists and auto workers competed to organize the plants. The postwar depression had created discontent among workers faced with layoffs, company claims of inability to pay, and massive downward reclassifications (Allen and Schneider 1956). Major strikes took place at Boeing, Bell Aircraft (Parsons' prime contractor), McDonnell Douglas, Wright Aeronautical, GE (Evandale) (jet engines), North American Aviation, and Republic Air-

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* Kurt Vonnegut, letter to author, February 1977.

craft. It is not difficult, then, to explain the popularity among management and technical men of a November 1946 *Fortune* article entitled "Machines Without Men." Surveying the technological fruits of the war (sensing and measuring devices, servomechanisms, computers, etc.), two Canadian physicists promised that "these devices are not subject to any human limitations. They do not mind working around the clock. They never feel hunger or fatigue. They are always satisfied with working conditions, and never demand higher wages based on the company's ability to pay." In short, "they cause much less trouble than humans doing comparable work" (Leaver and Brown 1946:203).

One of the people who was inspired by this article was Lowell Holmes, the young electrical engineer who directed the GE automation project. However, in record-playback, he developed a system for replacing machinists that ultimately retained machinist and shop-floor control over production because of the method of tape preparation.* This "defect" was recognized immediately by those who attended the demonstration of the system; they showed little interest in the technology. "Give us something that will do what we say, not what we do," one of them said. The defects of record-playback were conceptual, not technical; the system simply did not meet the needs of the larger firms for managerial control over production. N/C did. "Managers like N/C because it means they can sit in their offices, write down what they want, and give it to someone and say, 'do it,' " the chief GE consulting engineer on both the record-playback and N/C projects explained. "With N/C there is no need to get your hands dirty, or argue" (personal interview). Another consulting engineer, head of the Industrial Applications Group which served as intermediary between the research department and sales department at GE (Schenectady) and a key figure in the development of both technologies, explained the shift from record-

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* The fact that record-playback lends itself to shop-floor control of production more readily than N/C is borne out by a study of N/C in the United Kingdom done by Erik Christiansen in 1968. Only in those cases where record-playback or plugboard controls were in use (he found six British-made record-playback jig borers) did the machinist keep the same pay scale as with conventional equipment and retain control over the entire machining process. In Christiansen's words, record-playback (and plugboard programming) "mean that the shop floor retains control of the work cycle through the skill of the man who first programmed the machine" (1968:27, 31).

playback to N/C: "Look, with record-playback the control of the machine remains with the machinist—control of feeds, speeds, number of cuts, output; with N/C there is a shift of control to management. Management is no longer dependent upon the operator and can thus optimize the use of their machines. With N/C, control over the process is placed firmly in the hands of management—and why shouldn't we have it?" (personal interview). It is no wonder that at GE, N/C was often referred to as a management system, not as a technology of cutting metals.*

Numerical control dovetailed nicely with larger efforts to computerize company operations, which also entailed concentrating the intelligence of manufacturing in a centralized office. In the intensely anti-Communist 1950s, moreover, as one former machine-tool design engineer has suggested, N/C looked like a solution to security problems, enabling management to remove blueprints from the floor so that subversives and spies couldn't get their hands on them. N/C also appeared to minimize the need for costly tooling and it made possible the cutting of complex shapes that defied manual and tracer methods, and reduced actual chip-cutting time. Equally important, however, N/C replaced problematic time-study methods with "tape time"—using the time it takes to run a cycle as the base for calculating rates—replaced troublesome skilled machinists with more tractable "button-pushers," and eliminated once and for all the problem of pacing. If, with hindsight, N/C seems to have led to organizational changes in the factory, changes which enhanced managerial control over production, it is because the technology was chosen, in part, for just that purpose. This becomes even clearer when we look at how the chosen technology was deployed.

Choice in Deployment: Managerial Intentions

There is no question but that management saw in N/C the potential to enhance their authority over production and seized upon it, despite questionable cost effectiveness.† Machine-tool

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* GE Company 1958. See also Forrester *et al.* 1955.

† The cost effectiveness of N/C depends upon many factors, including training costs, programming costs, computer costs, and the like, beyond mere time saved in actual chip-cutting or reduction in direct labor costs. The MIT staff who

conducted the early studies on the economics of N/C focused on the savings in cutting time and waxed eloquent about the new revolution. At the same time, however, they warned that the key to the economic viability of N/C was a reduction in programming (software) costs. Machine-tool company salesmen were not disposed to emphasize these potential drawbacks, though, and numerous users went bankrupt because they believed what they were told. In the early days, however, most users were buffered against such tragedy by state subsidy. Today, potential users are somewhat more cautious, and machine-tool builders are more restrained in their advertising, tempering their promise of economic success with qualifiers about proper use, the right lot and batch size, sufficient training, etc.

For the independent investigator, it is extremely difficult to assess the economic viability of such a technology. There are many reasons for this. First, the data is rarely available or accessible. Whatever the motivation—technical fascination, keeping up with competitors, etc.—the purchase of new capital equipment must be justified in economic terms. But justifications are not too difficult to come by if the item is desired enough by the right people. They are self-interested anticipations and thus usually optimistic ones. More important, firms rarely conduct postaudits on their purchases, to see if their justifications were warranted. Nobody wants to document his errors and if the machinery is fixed in its foundation, that is where it will stay, whatever a postaudit reveals; you learn to live with it. The point here is that the economics of capital equipment is not nearly so tidy as economists would sometimes have us believe. The invisible hand has to do quite a bit of sweeping up after the fact.

If the data does exist, it is very difficult to get a hold of. Companies have a proprietary interest in the information and are wary about disclosing it for fear of revealing (and thus jeopardizing) their position vis à vis labor unions (wages), competitors (prices), and government (regulations and taxes). Moreover, the data, if it were accessible, is not all tabulated and in a drawer somewhere. It is distributed among departments, with separate budgets, and the costs to one are the hidden costs to the others. Also, there is every reason to believe that the data that does exist is self-serving information provided by each operating unit to enhance its position in the firm. And, finally, there is the tricky question of how "viability" is defined in the first place. Sometimes, machines make money for a company whether they were used productively or not.

The purpose of this aside is to emphasize the fact that "bottom-line" explanations for complex historical developments, like the introduction of new capital equipment, are never in themselves sufficient, nor necessarily to be trusted. If a company wants to introduce something new, it must justify it in terms of making a profit. This is not to say, however, that profit making was its real (or, if so, its only) motive or that a profit was ever made. In the case of automation, steps are taken less out of careful calculation than on the faith that it is always good to replace capital with labor, a faith kindled deep in the soul of manufacturing engineers and managers (as economist Michael Piore, among others, has shown. See, for example, Piore 1968). Thus, automation is driven forward, not simply by the profit motive, but by the ideology of automation itself, which reflects the social relations of production builders and control manufacturers, of course, also promoted their wares along these lines; well attuned to the needs of their customers, they promised an end to traditional managerial problems. Thus the president of the Landis Machine Company, in a trade journal article entitled "How Can New Machines Cut Costs?" stressed the fact that "with modern automatic controls, the production pace is set by the machine, not by the operator" (Stickell 1960:61). The advertising copy of the MOOG Machine Company of Buffalo, New York, similarly described how their new machining center "has allowed management to plan and schedule jobs more effectively," while pointing out, benevolently, that "operators are no longer faced with making critical production decisions" (MOOG Hydra-Point News 1975).

Machine-tool and control system manufacturers peddled their wares and the trade journals, forever in search of advertisements, echoed their pitch. Initially, potential customers believed the hype; they very much wanted to. Earl Lundgren, the sociologist who surveyed N/C user plants in the 1960s concluded that the "prime interest in each subject company was the transfer of as much planning and control from the shop to the office as possible" and that management believed that "under numerical control the operator is no longer required to take part in planning activities" (Lundgren 1969).

In my own survey (1977–1978) of twenty-five plants in the Midwest and New England—including manufacturers of machine tools, farm implements, heavy construction equipment, jet engines and aircraft parts, and specialized industrial machinery—I observed the same phenomenon. Everywhere, management initially believed in the promises of N/C promoters and attempted to remove all decision making from the floor and assign unskilled people to N/C machines; to substitute "tape time" for problematic time studies to set base rates for piecework and measure output quotas; and to tighten up authority by concentrating all mental activity in the office and otherwise to extend detail control over all aspects of the production process.

This is not to say, however, that I drew the same conclusions that Lundgren did in his earlier survey. Characteristically, for an industrial sociologist, he viewed such changes as requirements of the new technology whereas, in reality, they reflected simply the possibilities of the technology which were "seized upon" (to use Harry Braverman's phrase) by management to realize particular objectives, social as well as technical. There is nothing inherent in N/C technology, however, that makes it necessary to assign programming and machine tending to different people (that is, to management and workers, respectively); the technology merely makes it possible (Braverman 1974:199). Management philosophy and motives—reflecting the social relations of the capitalist mode of production in general and a historically specific economic and political context in particular—make it necessary that the technology be deployed in this way.

One illustration of managerial choice in machine deployment is provided by the experience of a large manufacturing firm near Boston. In 1968, owing to low worker morale, turnover, absenteeism, and the general unreliability of programming and machinery, the company faced what it termed a "bottleneck" in its N/C lathe section. Plant managers were frantic to figure out a way to achieve the expected output from this expensive equipment. In that prosperous and reform-minded period, they decided upon a job enlargement/enrichment experiment wherein machine operators would be organized into groups and their individual tasks extended. Although it was the hope of the company that such a reorganization would boost the morale of the men on the floor and motivate them to "optimize the utilization" of the machinery, the union was at first reluctant to cooperate, fearing a speed-up. The company was thus hard pressed to secure union support for their program and instituted a bonus for all participants. At one of the earliest management-union meetings on the new program, the company spokesman began his discussion of the job-enlargement issue with the question (and thinly/veiled threat), "Should we make the hourly people button-pushers or responsible people?" Given the new technology, management believed they now had the choice, and, given the pressure of unusual circumstances, they were prepared to exercise it in what they understood to be an atypical way.*

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* This experiment was relatively successful, but short-lived. Attracted to the program by the bonus, the reorganized work groups soon grew accustomed to the new conditions: no foremen or punch clock, their own tool crib, their own scheduling of parts through the shop, and even some training in programming. Morale improved and turnover, absenteeism, and the scrap-rate declined accordingly. However, managerial enthusiasm for the experiment soon waned, and, after only a few half-hearted years, it was unilaterally called off. The company claimed that the union's desire to extend the experiment to other areas of the shop and to othe plants within the same corporation threatened to make

A second illustration of the managerial imperative behind technological determinism is provided in an interview I had with two shop managers in a plant in Connecticut. Here, as elsewhere, much of the N/C programming is relatively simple, and I asked the men why the operators couldn't do their own programming. At first they dismissed the suggestion as ridiculous, arguing that the operators would have to know how to set feeds and speeds, that is, be industrial engineers. I pointed out that the same people probably set the feeds and speeds on conventional machinery, routinely making adjustments on the process sheet provided by the methods engineers in order to make out. They nodded. They then said that the operators couldn't understand the programming language. This time I pointed out that the operators could often be seen reading the mylar tape—twice-removed information describing the machining being done—in order to know what was coming (for instance, to anticipate programming errors that could mess things up). Again, they nodded. Finally they looked at each other, smiled, and one of them leaned over and confided, "We don't want them to." Here is the reality behind technological determinism in deployment.

Reality on the Shop Floor

Although the evolution of a technology follows from the social choices that inform it, choices which mirror the social relations of production, it would be an error to assume that in having exposed the choices, we can simply deduce the rest of reality from them. Reality cannot be extrapolated from the intentions that underlie the technology any more than from the technology itself.* Desire is not identical to satisfaction.

"In the conflict between the employer and employed," John G. Brooks observed in 1903, "the 'storm centre' is largely at this point where science and invention are applied to industry."† It is

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the program too expensive since an extension of the experiment meant also an extension of the bonus. The union business agent, formerly a shop steward in the experimental program and one of its stauchest supporters, explained the termination in another way: the company was losing control over the work force.

* This is an error that Braverman tended to make in discussing N/C.

† Cited in D. Montgomery (unpublished: Ch. 4, p. 1).

here that the reality of N/C was hammered out, where those who chose the technology finally came face-to-face with those who did not.

The introduction of N/C was not uneventful, especially in plants where the machinists' unions had a long history. Work stoppages and strikes over rates for the new machines were common in the 1960s, as they still are today. At GE, for example, there were strikes at several large plants and the entire Lynn, Massachusetts plant was shut down for a month during the winter of 1965. There are also less overt indications that management dreams of automatic machinery and a docile, disciplined work force but they have tended to remain just that.†

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† Perhaps the single most important, and difficult, task confronting the critical student of such rapidly evolving technologies as N/C is to try to disentangle dreams from realities, a hoped-for future from an actual present. The two realms are probably nowhere more confused than in the work of technologists. Thus, criticism of existing, or past, realities are typically countered with allusions to a less problematic future; the present is always the "debugging phase," the transition, at the beginning of the "learning curve"—merely a prelude to the future. As such, it is immune from scrutiny and criticism. To argue, as we do here, that N/C machinery does not run by itself or that mere "button-pushers" cannot produce good parts consistently on N/C, invites the rebuffs of those in the know, who refer to the automatic loading of N/C machines by the Unimate robots, to Flexible Manufacturing Systems (FMS) that tie any number of machines together with an automatic transfer line, to adaptive controls with sensors that automatically correct for tool wear and rough castings and the like, or to Direct Numerical Control systems (DNC) which centralize control over a whole plant of N/C equipment through one computer. Three important things must be kept in mind when dealing with such counterarguments.

First, technical people, it must be remembered, always have their eyes on the future—it is their job; they live in the state-of-the-art world which often has very little connection with industrial reality. Thus, it is hardly surprising that technical forecasters of the late 1950s predicted that by now at least 75 percent of machine tools in this country would be N/C (it is less than 2 percent), and that we would be seeing fully automatic metalworking factories (there are none). There is no better reason to believe the engineering and trade journals today, much less the self-serving forecasts of manufacturing engineers. All too often, social analysts merely echo these prophets, extrapolating wonderful or woeful consequences of projected technological changes without paying the slightest attention to the mundane vicissitudes of historical experience, or industrial practice. To them, the critic must respond: look again.

Second, judging from past experience, there is little reason simply to assume that the new experimental or demonstration systems will actually function on the shop floor as intended, much less perform economically. This author has visited

Here we will examine briefly three of management's expectations: the use of "tape time" to set rates; the deskilling of machine operators; and the elimination of pacing.

Early dreams of using tape time to set base rates and measure performance and output proved fanciful. As one N/C operator observed, while rates on manual machines were sometimes too high, they were usually within a reasonable range, whereas the rates on N/C were "out of all relation to reality—ridiculously high; N/C's were supposed to be like magic but all you can do automatically on them is produce scrap." The machines, contrary to their advertisements, could not be used to produce parts

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four plants in the United States with FMS systems and found their economic justifications suspect, their down time excessive, and their reliability heavily dependent upon a highly skilled force of computer operators, system attendants, and maintenance men; there was also little sign of further development. Adaptive systems, under development at Cincinnati Milacron, are still in an experimental stage; when placed on the shop floor, these even more complex and sensitive pieces of machinery are bound to produce more maintenance problems than they solve. DNC is simply another name for the automatic factory, the supreme fantasy of the industrial technocrats, now heralded by self-serving computer jocks, supported by beleaguered corporate managers (whose farsightedness is more rhetorical than real), and, as usual, funded by the military (in this case, the air force ICAM program).

Third, the ultimate viability of these technologies under the present mode of production depends, in the final analysis, upon the political and economic conditions that prevail and upon the relative strengths of the classes in their struggle over the control of production. To assume simply that the future will be what the designers and/or promoters of these technologies think it will be, would be to beg all of the questions being raised here, to ratify, out-of-hand, a form of technological determinism. Further, it would be to deny the realm of freedom that is being described, a freedom which could result not only in the delaying or subverting of these technologies (and thus the purposes they embody)—allowing for more time to struggle for greater freedom—but also in the fundamental reshaping of their design and use to meet ends other than simple capital accumulation and the extension of managerial and corporate power. See, for example, the discussion of Computer Numerical Control (CNC) in the final section on "alternative realities."

In short, a facile reference to the future is the educated habit of technical people in our society, people who are quite often seriously (and sometimes dangerously) ignorant of the past and mistaken about the present. To adopt their habit would be to suspend judgment (or, rather, yield to their judgment), to forego the critical, concrete, historical examination and assessment of the present situation, which alone can guide us intelligently into the still clouded future.

to tolerance without the repeated manual intervention of the operator in order to make tool offset adjustments, correct for tool wear and rough castings, and correct programming errors (not to mention machine malfunctions, such as "random holes" in drills and "plunges" in milling machines, often attributable to overheating). As the N/C operator just quoted explained, in a response to a *New York Times* article on the wonders of computer-based metalworking:

> Cutting metals to critical tolerances means maintaining constant control of a continually changing set of stubborn, elusive details. Drills run. End mills walk. Machines creep. Seemingly rigid metal castings become elastic when clamped to be cut, and spring back when released so that a flat cut becomes curved, and holes bored precisely on location move somewhere else. Tungsten carbide cutters imperceptibly wear down, making the size of a critical slot half a thousandth too small. Any change in any one of many variables can turn the perfect part you're making into a candidate for a modern sculpture garden, in seconds. Out of generations of dealing with the persistent, ornery problems of metal cutting comes the First Law of Machining: "Don't mess with success." (Tulin 1978:16)

In reality, N/C machines do not run by themselves—as the United Electrical Workers argued in its 1960 *Guide to Automation*, the new equipment, like the old, requires a spectrum of manual intervention and careful attention to detail, depending upon the machine, the product, and so on. The fiction that the time necessary to do a job could be determined by simply adding a standard factor or two (for setup, breaks, etc.) to the tape (cycle) time, was exploded early on, and with it hope of using the tape to measure performance (although some methods people still try).

The deskilling of machine operators has also, on the whole, not taken place as expected, for two reasons. First, as mentioned earlier, the assigning of labor grades and thus rates to the new machinery was, and is, a hotly contested and unresolved issue in union shops. Second, in union and nonunion shops alike, the determination of skill requirements for N/C must take into account the actual degree of automation and reliability of the machinery. Management has thus had to have people on the machines who know what they are doing simply because the machines (and programming) are not totally reliable; they do not run by themselves and produce good finished parts. Also, the machinery is still very expensive (even without microprocessors) and thus so is a machine smash-up. Hence, while it is true that many manufacturers initially tried to put unskilled people on the new equipment, they rather quickly saw their error and upgraded the classification. (In some places the most skilled people were put on the N/C machines and given a premium but the lower formal classifications were retained, presumably in the hope that someday the skill requirements would actually drop to match the classification—and the union would be decertified.) The point is that the intelligence of production has neither been built entirely into the machinery nor been taken off the shop floor. It remains in the possession of the work force.*

This brings us, once again, to the question of shop-floor control. In theory, the programmer prepares the tape (and thus sets feeds and speeds, thereby determining the rate of production), proofs it out on the machine, and then turns the show over to the operator, who from then on simply presses start and stop buttons and loads and unloads the machine (using standard fixtures). This rarely happens in reality, as was pointed out above. Machining to tolerances generally requires close attention

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* The shortage of skilled manpower has always been cited by managers and technical people as a justification for the introduction of labor-saving technologies like N/C. Rarely, however, is the shortage actually demonstrated or explained in any compelling way; it remains a necessary and unquestioned ideological prop. For a manpower shortage is a relative thing; relative to new air force and aircraft industry requirements in the cold war, there was a perceived shortage. But, given that shortages are only perceived in relation to a present or future need, they are predictable; they are not natural phenomena but socially created ones, remediable through training programs and sufficient monetary and other incentives. (This author remembers, for example, that not so long ago he went to college on loan programs created to deal with a recognized shortage of college teachers, relative to a vastly expanding educational system.) Thus, when managers introduce N/C because of the impending retirement of the last generation of skilled machinists, we must ask, where are their replacements? Why have apprenticeship programs been eliminated or shortened? Why do vocational courses habituate young people to "semiskilled" work in the name of training for a craft? The answer is that the shortage is, in reality, created to complement the new technology, not the other way around. Fortunately for capital, however, the skill is not entirely eliminated, however "unskilled" the classification; passed on informally and on the job, it remains on the shop floor. If it wasn't there, finished parts would never make it out the door.

to the details of the operation and frequent manual intervention through manual feed and speed overrides. This aspect of the technology, of course, reintroduces the control problem for management. Just as in the conventional shop, where operators are able to modify the settings specified on the worksheet (prepared by the methods engineer) in order to restrict output or otherwise "make out" (by running the machine harder), so in the N/C shop the operators are able to adjust feeds and speeds for similar purposes.

Thus, if you walk into a shop you will often find feed-rate override dials set uniformly at, say, 70 or 80 percent of tape-determined feed rate. In some places this is called the "70 percent syndrome"; everywhere it is known as pacing. To combat it, management sometimes programs the machines at 130 percent, and sometimes actually locks the overrides altogether to keep the operators out of the "planning process." This in turn gets management into serious trouble since the interventions are required to get the parts out the front door.

It is difficult to assess to what extent the considerable amount of intervention is attributable to the inherent unreliability of the complex equipment itself, but it is certainly true that the technology develops shortcomings once it is placed on the shop floor, whether or not they were there in the original designs. Machines often do not do what they are supposed to do and down time is still excessive. Technical defects, human errors, and negligence are acknowledged problems, and so is sabotage. "I don't care how many computers you have, they'll still have a thousand ways to beat you," lamented one manager of N/C equipment in a Connecticut plant. "When you put a guy on an N/C machine, he gets temperamental," another manager in Rhode Island complained. "And then, through a process of osmosis, the machine gets temperamental."

On the shop floor, it is not only the choices of management that have an effect. The same antagonistic social relations that, in their reflection in the minds of designers, gave issue to the new technology, now subvert it This contradiction of capitalist production presents itself to management as a problem of "worker motivation," and management's acceptance of the challenge is its own tacit acknowledgment that it does not have shop-floor control over production, that it is still dependent upon the work force to turn a profit.

Thus, in evaluating the work of those whose intentions to wrest control over production from the work force informed the design and deployment of N/C, we must take into account an article written by two industrial engineers in 1971 entitled "A Case for Wage Incentives in the N.C. Age." It makes it quite clear that the contradiction of capitalist production has not been eclipsed—computers or no computers:

> Under automation, it is argued, the machine basically controls the manufacturing cycle, and therefore the worker's role diminishes in importance. The fallacy in this reasoning is that if the operator malingers or fails to service the machine for a variety of reasons, both utilization and subsequent return on investment suffer drastically.
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> Basic premises underlying the design and development of N.C. machines aim at providing the capability of machining configurations beyond the scope of conventional machines. Additionally, they "de-skill" the operator. Surprisingly, however, the human element continues to be a major factor in the realization of optimum utilization or yield of these machines. This poses a continuing problem for management, because a maximum level of utilization is necessary to assure a satisfactory return on investment. (Doring and Saling 1971:31)

The motivation problem boils down to this: What will a machine operator, "skilled" or "unskilled," do when he sees a $250,000 milling machine heading for a smash-up? He could rush to the machine and press the panic button, retracting the workpiece from the cutter or shutting the whole thing down, or he could remain seated and think to himself, "Oh, look, no work tomorrow." For management, the situation poses the dilemma faced by every capitalist, a contradiction succinctly, if inadvertently, expressed by another plant manager in Connecticut. With a colleague chiming in, he proudly described the elaborate procedure they had developed whereby every production change, even the most minor, had to be okayed by an industrial engineer. "We want absolutely no decision made on the floor," he insisted; no operator was to make any change from the process sheets without the written authorization of a supervisor. A moment later, however, looking out onto the floor from his glass-enclosed office, he reflected upon the reliability of the machinery, and the expense of parts and equipment, and emphasized, with equal conviction, that "We need guys out there who can think."

Alternative Realities

Shop-floor realities are determined by the social relations, as well as the technology, of production and, as we have seen, the latter is shaped by the former no less than the reverse. But thus far we have examined only the ways in which managerial intentions, introduced in the form of new technology, are subverted in practice; this is only part of the story, the part defined, in a restricted way, by social relations which assign to labor a "negative" role. Having had to adopt a defensive posture against a far more powerful adversary, the American trade union movement opted out of certain struggles (for instance, for the right to make production decisions, now an exclusive "management prerogative") in order to concentrate on and gain advantage in others (for example, job security, wages, benefits). Accordingly, when confronted with changing technology labor has generally limited its response to post-hoc resistance. This has meant, of course, that labor's choices have not been registered in the actual design and deployment stages and that, therefore, the technology does not reflect its interest. A more forward-looking and sophisticated labor movement, however, facing an intensified management drive toward rationalization and automation, could transcend this passive role and begin to act positively, demanding, and preparing itself for, a voice in design and deployment decisions. As one American N/C machine operator has argued:

> The introduction of automation means that our skills are being downgraded, and instead of having the prospect of moving up to a more interesting job, we now have the prospect of either unemployment or a dead-end job. [But] there are alternatives that the union can explore. We have to establish the position that the fruits of technological change can be divided up—some to the workers, not all to the management, as is the case today. We must demand that the machinist rise with the complexity of the machine. Thus, rather than dividing his job up, the machinist should be trained to program and repair his new equipment—a task well within the grasp of most people in the industry.
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> Demands such as these strike at the heart of most management prerogative clauses which are in many collective-bargaining contracts. Thus, to deal with automation effectively, one has to strike another prime ingredient of business unionism: the idea of "let the management run the business." The introduction of N.C. equipment makes it imperative that we fight such ideas. (Emspak, unpublished)

The real potential of this challenge can perhaps best be illustrated by the existing variations in deployment of the latest generation of N/C machines, called Computer Numerical Control (CNC) systems. CNC machines come equipped with a small minicomputer control unit. With this addition, made feasible by the advent of microprocessors, it becomes possible to store the information from a dozen or so tapes right on the machine itself and then simply retrieve the right program to make a part. More important, the information from the tape can be manipulated and edited: the sequence of operations can be changed, and operations can be added or subtracted. After the changes are made and the parts are run, the machine can produce a "corrected" tape for permanent storage in the company library. With this technology, it becomes possible not only to edit tapes on the shop floor but to create them from scratch; in some systems, programs for even rather complex contours can be made right at the machine by either punching in the required information at a keyboard on the console (so-called manual data input—MDI) or by moving the machine itself to make the first part and entering the information after each operation. (This feature, of course, reintroduces the record-playback concept in an updated digitized form.)

Made possible by the revolution in microelectronics and introduced by machine-tool manufacturers in order to penetrate the vast job market (because it eliminates the overhead requirements of software preparation—the major obstacle for the job shop) and by large metalworking plants in order to get around insurmountable software programming problems (because it allows for easy tape correcting and editing), the new CNC technology lends N/C as never before to total shop-floor control.

Although the large metalworking plants in the United States are steadily introducing CNC equipment, the potential for shop-floor control is far from being realized. The GE plant in Lynn, Massachusetts, is a typical example. Here machine operators are not permitted to edit programs—much less to make their own—on the new CNC machines; quite often the controls are locked. Only supervisory staff and programmers are allowed to edit the programs. Managers are afraid of losing shop-floor control or confusing their tidy labor classification and wage system; programmers are afraid that operators lack the training and experience required for programming—an argument that has convinced at least some operators that these functions are beyond their intellectual grasp. The shortcomings of this system for the operators are obvious. Less obvious are the shortcomings for management: lower quality production and excessive machine down time. If the programs are faulty and the operator cannot (or is not allowed to) make the necessary adjustments, the parts produced will be faulty. If a machine goes down because of programming problems on the second and third shifts, when the programmers are not around, it is likely to be down for the night, with a corresponding loss in productivity.

The situation is quite different in the state-owned weapons factory in Kongsberg, Norway, a plant with roughly the same number of employees, a similar line of products (aircraft parts and turbines), a similar mix of commercial and military customers, and, most important, the same types of CNC machinery (although here they tend to be European-made rather than Japanese) as at GE.* But in Norway the operators routinely do all of the editing, according to their own criteria of safety, efficiency, quality, and convenience; they change the sequence of operations, add or subtract operations, and sometimes alter the entire structure of the program to suit themselves. When they are satisfied with a program and have finished producing a batch of parts, they press a button to generate a corrected tape which, after being approved by a programmer, is put into the library for permanent storage.

All operators are trained in N/C programming and, as a consequence, their conflicts with the programmers are reduced. One programmer—who, like most of his colleagues, had received his training in programming while still a machine operator—justified having any programmers at all by the fact that the programmer was a specialist and was thus more proficient (he also dealt directly with customers and did most of the APT programming of highly complex aircraft parts). Yet when asked if it bothered him to have his well-worked programs tampered with by the operators, he replied, without hesitation, that "the operator knows best; he's the one who has to actually

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* The following discussion of the situation in Kongsberg, Norway, is based upon correspondence and personal contact with participants in the trade union participation project and a recent research visit to Scandinavia (October 1978).

make the part and is more intimately familiar with the particular safety and convenience factors; also, he usually best knows how to optimize the program for his machine."

This situation, it should be pointed out, is unusual even for Norway. It is the result of many factors. The Iron and Metalworkers' Union in Norway is the most powerful industrial union in the country and the local "club" in Kongsberg is a potent force in the industrial, political, and social life of Kongsberg, representing a cohesive and rather homogeneous working-class community. The factory is important in state policy, as a holding company in electronics, and is an important center of high technology engineering. Also, social democratic legislation in Norway has encouraged worker participation in matters pertaining to working conditions and has given unions the right to information. Most important, however, the local "club" has been involved for the last seven years in what has been called the "trade union participation project," an important development in workers' control which focuses upon the introduction of computer-based manufacturing technology.

In 1971, the Iron and Metalworkers' Union, faced with an unprecedented challenge of new computer-based information and control systems (for production, scheduling, inventory, etc., as well as machining), took steps to learn how to meet it. They succeeded in hiring, on a single-party basis (that is, without management collaboration), the government-run Norwegian Computing Center to research the new technology for them. As the direct result of this unprecedented effort, computer technology was demystified for the union, and the union—and labor in general—was demystified for the computer scientists at the Center; the union became more sophisticated about the technology and the technical people became more attuned to the needs and disciplines of trade unionists. In practical terms, the study resulted in the production of a number of textbooks on the new technology, written by and for shop stewards, the creation of a new union position, the "data shop steward," and, in time, the establishment of formal "data agreements" (between individual companies and their local "clubs" and between the national union and the employers' federation) which outlined the union's right to participate in decisions about technology.

The Kongsberg plant was the first site of such trade union participation. Here the data shop steward, a former assembly worker, is responsible for keeping abreast of and critically scrutinizing all new systems; another man is assigned the job of supervising the activity of the data shop steward to ensure that he doesn't become a "technical man," that is, captive either of the technology or of management and out of touch with the interests of the people on the shop floor. The responsibilities are enormous: this is not a situation in which union and management cooperate harmoniously, nor is it a management-devised job-enlargement scheme to motivate workers. The task of the data shop steward, and the union in general, is to engage, as effectively as possible, in a struggle over information and control, a struggle engaged in, with equal sophistication and earnestness, by the other side.

When management plans to introduce a new computer-based production system, for example, the union must assume as a matter of course (based upon long experience) that the proposed design reflects purposes that are not necessarily consonant with the interests of the workers. The data shop steward and his colleagues must learn about the system early enough, and investigate it thoroughly enough, to ensure that it contains no features that make possible, for example, the measurement of individual performance or any monitoring of shop-floor activities that would restrict worker freedom or control. As it turns out, all new systems invariably contain such features (since they are often camouflaged attempts to introduce control mechanisms that have been successfully resisted by the workers in other forms), and it is up to the union to identify them and demand that they be eliminated. It is the union's responsibility to its members, in short, to struggle to "recondition" the system so that it meets their own, as well as management's, specifications. At Kongsberg, for example, after a long battle, the union has succeeded in securing for all of the people on the shop floor complete access to the computer-based production and inventory systems. Just as CNC has made automatic machining more accessible to shop-floor control, so computer-integrated production systems have made it possible to eliminate certain managerial functions by simply extending the reach of the people on the shop floor. How this technology will actually be employed in a plant depends less upon any inherent nature of the technology than upon the particular manufacturing processes involved, the political and economic setting, and the relative power and sophistication of the parties engaged in the struggle over control of production.

The social relations of production shape the technology of production as much as the other way around. Given different social relations, one sees different designs, different deployment. Of course, these relations are themselves shaped by larger conditions—the political, economic, and cultural climate, the labor market, trade union traditions and strengths, international competition and the flow of investment capital. These factors always influence the conditions for struggle, define its constraints. But whatever the constraints, whatever the social conditions, the technological possibilities remain.