I am delighted to be here this morning to speak on the social implications of automation. Although automation is one of the central issues we face today as a society, there has been remarkably little analysis or discussion of the human consequences of technological change. Without this analysis and debate, it is difficult, if not impossible, to identify and address the potential effects of change. Some of these effects are positive and should be encouraged. But others are clearly negative. Without focusing on the human dimension, we inevitably leave these negative consequences to fester and become worse, rather than addressing them in a way that could minimize or perhaps eliminate them.

This morning, I would like to address two broad areas concerning the human consequences of automation. The first concerns engineers as engineers: the impact of computer technology on the workplace. I want to explore how the change in technology affects jobs, skills, and the structure of work. The second area concerns engineers as citizens: the impact of automation on employment and its human consequences. I will discuss this second theme more briefly, not because of its importance, but to concentrate on automation and work.

Impact on the Workplace

In looking at the impact of computer technology on the workplace, a central question underlies my remarks this morning. Is there a contradiction between the potential of computer technology to enrich work and the reality of its use? And if so, what are the sources and consequences of this contradiction? Before addressing this question, I would like to explore some general themes surrounding whether or not a contradiction exists and then to anchor the discussion in the specific realities of the shop floor, the interaction of managers, workers, engineers, and automation at the point of production.

The potential of computer technology in the workplace—and I am using computer technology and automation synonymously, because automation today is overwhelmingly computer-related—is extraordinary. It is characterized by flexibility to automate a variety of work, flexibility to quickly revamp production, and flexibility to organize work in alternative ways. Computer technology in the industrial workplace certainly makes possible greater skill, more creative work, and a more autonomous work environment. It makes possible a qualitative enhancement of what people do on the job. But this potential is not necessarily the reality most workers and first-line managers face in production today.

Authority vs. Autonomy

Technology provides us with a choice, and that choice has two faces. One face is the use of technology to enhance authority and to more closely monitor and often discipline workers. The other face is the use of technology to increase autonomy by facilitating coordination and the interrelation of people in production. Thus, the basic choice is one of authority on the one hand and autonomy on the other. The alternative chosen, I will argue, has less to do with the capabilities of the technology involved and more to do with the underlying goals that influence the design, development, and deployment of technology.

Rather than realizing the exceptional potential of computer technology today, the reality is moving in a direction of increased authority in industrial production. A direction that frequently degrades the quality of life on the job and, ironically, in certain instances, throttles, rather than increases, worker productivity. This is ironic, since automation is almost always justified by its ability to increase productivity. It would be a mistake, however, to pose the choices as computer automation on one hand and conventional systems on the other. The real choices are how computer technology will be developed and integrated into the workplace and the role people will play in the operation and deployment of new systems.

Social Paradox

Paradoxically, while the technology itself provides unprecedented choice, socially we associate the development and deployment of computers with one path of development, the existing path. There is remarkably little social experimentation as to how computer technology could be used and what consequences stem from one path of development versus the other. Part of the lack of experimentation stems from a lack of a feedback mechanism for engineers in general and for design engineers in particular. It has been my experience that engineers, particularly in academia, who deal with control or automation issues relating to the workplace, have remarkably little contact with those directly affected by design decisions—that is, workers and first-line supervisors in production. In fact, this problem of a lack of a feedback mechanism begins when engineers are educated.

At the Massachusetts Institute of Technology, for example, I have spoken with students majoring in areas closely related to manufacturing who have about as much interest in speaking to workers as Frank Perdue has in speaking to chickens. You know it is somehow related to what you are doing, but you do not see the direct relevance. And it is not that the students are morally unconcerned, or even technically unconcerned; it is that there is little incentive in the education of engineers to have that broader perspective. Yet, as I will argue later in my talk, it is not simply an issue of social consequences in a moral sense; it is something of direct relevance to the effectiveness of design in actual production, in an actual working environment versus the artificial environment of the laboratory.

The second part of the problem, in addition to the lack of a feedback mechanism, is that the values underlying the design of new systems are seldom made explicit. Science and engineering, particularly when it comes to the design of automation, are hardly value-free. Unfortunately, these underlying values

and assumptions governing the way engineers and managers design and deploy new systems are not directly stated.

Production Reality

I would like to relate these general themes to the realities of production by focusing on two areas. The first is the use of technology as a universal solution to the problems of manufacturing rather than as a tool to solve specifically defined problems. Technology as a panacea results in systems of unusual complexity that are prone to breakdown. The alternative is an approach that seeks to use computers in conjunction with human experience, creativity, knowledge, and special skills to solve problems in manufacturing. I would like to illustrate this theme with an anecdote, which I offer as characteristic of a prevalent approach to the use of automation.

Automatic Tool Changer

At the 1984 International Machine Tool Show in Chicago, where machine tool vendors from throughout the world bring their wares for display, one of the most impressive single displays was by a Japanese machine tool company, one of the largest producers of automated machine tools in the world. I was particularly impressed by an automatic tool changer on one of the company's machining centers, which is an automated milling machine that is at the core of small-batch production. This tool changer was a modular system capable of changing up to 700 tools. The design approach was elegant and impressive. The company, unlike many U.S. machine tool builders, has a reputation for using the most advanced of its own machines in the production of new machine tools. At the show, I had an opportunity to speak with one of the company's vice presidents, and I asked if this new tool changer was already used in the company's own factories. He replied "Oh no, we don't use this, because two years ago, we reduced the total number of tools used for the production of all our machine tools from 600 to 70." So we have no need for a system that can change 700 tools. We export this to the U.S."

The notion of using technology to automate an ill-considered organizational approach is a theme running through more than this anecdote. I visited an agricultural implement factory in the Midwest that had recently won an award for its use of computerized technology. One of its more impressive systems was an automated inventory and material handling system. This system, impressive though it was, automated a process other companies are seeking to minimize—high inventory levels.

Human Input

The second broad area I would like to explore is technology as a vehicle to minimize human input in production. There are two subthemes here. The first is often an unstated engineering assumption that humans introduce variability into controlled systems: variability is inherently bad; therefore, human intervention is inherently to be avoided. This assumption, however, is unproven. In an actual manufacturing environment, the variabilities are so great that workers, rather than an additional source of variability, are often a critical factor to limit production unpredictability.

The second, and related theme, is a managerial assumption that computer technology can be a solution to labor-relations problems. If you have a worker who does not want to come in on Monday, a robot will certainly be there. Iron Age Magazine, a respected trade journal in metalworking, elaborates: "Workers in union have too much say in manufacturing's destiny, many metal-working executives feel, and large, sophisticated, computerized systems can help wrest some of that control away from labor and put it back in the hands of management, where it belongs." Are we to assume that statements such as this have no influence on the design and development of new systems? Put another way, it would be hard to visualize a computerized system that stresses autonomy if goals such as this were involved in its design.

Machinist Intervention

Let us focus on computerized machine tools, or computer numerical control. Computerized machine tools are the backbone of batch production, volumes of several hundred to several thousand in manufacturing. In the operation of these machines, a preprogrammed source, rather than a machinist, guides the machine through its paces. An advantage managers often cite when contrasting computerized machining to conventional machining is the ability to completely eliminate the active input of machinists. A preprogrammed source governs the speed of the machine, the feed of the machine, the path of the cutter, and other variables. In theory, the machinist becomes a monitor to observe what takes place. In practice, this is rarely the case. After 30 years of development, machinists exercise considerable input into the manufacturing process. Ironically, the machines are often deployed on the assumption that little actual worker intervention will be required.

Alternative Choices

In reality, there are two opposed alternatives in designing and using computerized manufacturing systems. Choice A is the face of greater authority. All programming for the machine tool is done at a remote site by programmers who also enter all improvements.
on the program. An important element of machine control therefore resides with the programmer, and the machinist is relegated to the role of a monitor. This choice is the clear favorite for most U.S. manufacturing. In choice B, which is more rarely utilized, machinists play an active role in programming and editing. Although a programming department performs unusually complex jobs and coordinates the programming function, a considerable amount of authority is transferred to the shop floor. This approach is based on the assumption that, because the machinist is close to the machine, the worker's intervention can improve the programming process.

For a study I conducted for the congressional Office of Technology Assessment, I visited nine companies that did extensive amounts of computerized machining, from small shops to large aerospace firms. In eight cases, managers maintained that choice A was being followed on the shop floor; that is, most programming was performed by programmers. In fact, a large contradiction existed between the choice managers may have desired and what actually took place. This contradiction is important because following the remote programming option can make worker intervention difficult, even when that intervention is necessary.

**Documenting Efficiency**

While over 100,000 computerized machine tools are in use in the United States, there is remarkably little data documenting the efficiency of choice A versus choice B. One of the few public studies I am aware of was done by a medium-sized machine shop in Ohio and was published in *American Machinist* in 1983. The shop did 1848 new programs for its 18 NC machine tools in 1983. The company undertook the study to disprove its machinists' complaints. The machinists, paid on incentive according to their production, argued that inefficient programming was hampering their earnings.

The company concluded that, of the almost 2000 programs, 76.5 percent of its programs were error-free. (The company defined programs with an error as one that would require unprogrammed operator intervention.) Drill presses, a very simple, point-to-point type of programming, had a 91 percent error-free rating. But, on the complex five-axis machine centers, the core of the shop where most of the value was added, only 26 percent of the programs were error-free. Without data such as this, managers deploy machine tools based on unstated assumptions rather than analysis of the consequences of one path versus the other, even in narrowly construed productivity terms.

**Hidden Cost**

There is an additional hidden cost of utilizing technology to increase authority in the workplace, and that cost is systems of great complexity that are prone to breakdown. Some of the more sophisticated managers in industry are coming to realize just that. During a recent panel discussion, a vice president of manufacturing from a large manufacturing firm stated that "Our biggest problem is probably too much technology too soon, and by that I mean we do things so complex, so early, many times it turns out to not prove out as well as we had hoped.

Transfer lines are the backbone of mass production, where volumes are in the hundred-thousandths, in the same way that computer numerical control is central to batch production. Transfer lines are a technology first introduced by the automobile industry in the early 1950s. The idea was that operators would load a cylinder block at one end, and that 40 or 50 machine tools later, with no human intervention, operators would pull out a machined block at the other end.

**Line Downtime**

In the last 30 years, transfer lines have become increasingly sophisticated, but they have also been plagued with significant downtime. The Ford Motor Company did a study of 154 of its own transfer lines and their operation between 1974 and 1980. The study concluded that the systems were experiencing between 40 and 60 percent downtime; 40-60 percent of the time when these machines were supposed to operate, they were not. There are various causes for this downtime: broken tools, lack of parts, operators absent, waiting for repairmen. However, I think there is a fundamental issue here about the relationship of workers and automation and of more effectively designing human input into the system. This is critical because of the consequences of authoritarian approaches on the quality of life on the job. It is also important because human skill, experience, creativity, and knowledge
remain vital in effectively utilizing the most sophisticated technologies. While it is possible to design systems that minimize direct human input, often the result is a greater reliance on indirect input. To keep the equipment operating, workers must struggle against designs that seek to avoid their intervention as well as the actual problems of production. The result can be long periods of boredom when the operator’s intervention is not needed, alternating with bursts of extreme stress when it is needed. At the time the intervention is critical, it is often difficult to exercise effectively. The result is high levels of downtime.

**Impact on Employment**

The second area I would like to discuss is the issue of automation and employment. This issue affects engineers and the engineering community as citizens rather than specifically as engineers. The relation between automation and employment is complex. There are issues of competitiveness, international trade, the state of the economy, the health of given industries, and demographics, among others. Against a background of modest economic growth, rapid automation raises key issues for employment.

Kenneth Olson, President of Digital Equipment, summed up a central concern when he said, “We have no foreseeable plans for additional domestic plant capacity. All the things we promised with computers, to make manufacturing much more efficient, have really happened. We doubled our size in dollar volume in the last three years, with a decrease in manufacturing people.” And that capability is hardly isolated.

Just as important as the long-term consequences of automation are the short-term impacts. The unevenness of the current economic expansion, for example, is, in part, due to a combination of rapid automation in some industries and global decentralization of manufacturing firms. So, while the state of Massachusetts has an employment shortage—unemployment in the 3–4 percent range—the state of Michigan has unemployment that approaches double-digit ranges.

Consider the traditional unemployment numbers as an indicator of economic well-being. Unemployment in late 1984 and the first half of 1985 has hovered somewhere around 7 percent. However, this includes only those people actively looking for work. Once a worker has ceased actively looking for work, even if that worker has not found a job, he or she is no longer counted as unemployed. There are over 1-million workers in this category who are, instead, numbered as “discouraged workers.” Moreover, the spectacular rise of involuntary part-time work underscores the structural change in the economy.

In the last decade, the number of workers seeking full-time jobs who only have part-time jobs has risen by 170 percent. There are now 5.5-million workers working part-time on an involuntary basis. A steel worker or an auto worker who, working 40 hours a week, loses his or her job and winds up as a security guard working 18 hours a week is counted as “employed,” although as a part-time worker. This category of involuntary part-time work is further supplemented by workers working short work weeks for economic or other circumstances beyond their control. If we add the approximately 7-million people unemployed in the official statistics, the over 1 million discouraged workers, and the 5.5-million involuntary part-time workers, the full scope of the unemployment problem in the U.S. today becomes clearer.

**Utilize Human Talents**

Is the solution, then, to halt automation? I do not think so. It is important, however, to break out of the false choices of computerization on the one hand or no computerization on the other. The real choice is developing computer technology such that within the workplace, the technology utilizes the extraordinary talents human beings can contribute. And, outside of the workplace, utilizing technology in a way that shares the gains in productivity so that unemployment is not the consequence of technological change. In both areas, there has been remarkably little exploration of the unstated assumptions underlying the utilization of technology or the alternatives. To use computer technology in a human way—to realize its extraordinary potential to enrich jobs and provide increased productivity for the society—requires a careful, thorough exploration of the alternatives, and the placing of human beings at the central point of the equation rather than as an afterthought.