The Robots are Coming

H. Allan Hunt
W.E. Upjohn Institute

Timothy L. Hunt
W.E. Upjohn Institute

Chapter 1 (pp. 1-17) in:
**Human Resource Implications of Robotics**
H. Allan Hunt and Timothy L. Hunt
Kalamazoo, MI: W.E. Upjohn Institute for Employment Research, 1983

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1

"The Robots are Coming"

Introduction

In the past year or so there have been cover stories or special reports about robots in *Time*, *Newsweek*, *Fortune*, *Business Week*, and *The Wall Street Journal*, among others. Indeed, the existence of a robot "revolution" in our factories appears to be treated as a fact in the popular media. Yet there is surprisingly little information available about the possible social and economic implications of robots. How many robots are toiling in our factories today? Which jobs and how many will be done by robots that were once done by human workers? What new jobs and how many will be created by robots? In such an information vacuum it is easy to exaggerate or to misunderstand the few facts that are available; possible even to inadvertently mislead policymakers and the general public as to the impact of robots.

A recent study by Pat Choate warns of the imminent robotization of American factories. He says "the speed and force of this change will be awesome." (Choate, p. 13) He concludes, "As the economy robotizes and domestic jobs are lost to foreign production, 10 million to 15 million manufacturing workers and a similar number of service workers likely will be displaced from their existing jobs. Much of this
displacement will occur in the mid- to late 1980s.” (Choate, p. 2) Yet nowhere in the study does Choate really say how many jobs will be specifically lost to robots.

On the other hand, Cetron and O’Toole, in their publications on the jobs of tomorrow, predict that millions of new jobs will be created by these same robots. According to them, “there will be as many as 1.5 million robotics technicians on the job in the U.S. alone by 1990. . . .” (Cetron and O’Toole, 1982a, p. 12 and 1982b, p. 259) These technicians will be needed for maintenance of robots for the most part. In a recent issue of Newsweek, which highlighted the growth industries and jobs of the future, the work of Cetron and O’Toole and others was referenced. That article included an estimate of total employment in industrial robot production in 1990 of 800,000. (“Growth Industries of the Future,” p. 83) If these numbers are believable, then over 2 million U.S. workers will be building or maintaining robots by 1990. At the same time, millions of other workers could be displaced by those robots.

Policymakers, lacking adequate information, must make do with whatever is available. Under these circumstances, even the Secretary of Labor can be misled. In a speech to the Productivity Advisory Committee, Secretary Donovan said, “. . .there will be a major shift from production-line workers to versatile workers able to program, repair, and service the array of robots on the factory floor. In fact, by 1990, half of the workers in any factory may well be engineers and technicians and other white collar specialists, rather than the current blue collar workers.” (emphasis added)

This small sampling of currently available hyperbole about industrial robots contrasts sharply with the facts, in our judgment. The Robot Institute of America, the industry trade association of robot manufacturers and users of
robots, predicts that there will be 75,000 to 100,000 robots in U.S. factories by 1990. (Robot Institute of America, p. 30) Indeed, even the most optimistic robot industry experts foresee no more than 150,000 robots by 1990. In interviews that we conducted, robot manufacturers were certainly enthusiastic about the growth prospects for their industry, but they deplored the "off-the-wall" predictions appearing in the popular media.

In any case, the application of as many as 150,000 industrial robots will not support cataclysmic employment impacts, either in terms of job creation or job displacement. It is not reasonable to think that 1.5 million technicians are needed to maintain 150,000 robots, nor is it reasonable to suppose that 150,000 robots will displace millions of workers. Perhaps it makes interesting reading to claim that by 1990 employment in robot manufacturing will approximate 800,000 people. But such a figure would surpass current U.S. employment in the motor vehicle industry. Even more startling, a figure of 1.5 million robotics technicians by 1990 would surpass current U.S. employment of all engineering and science technicians. While these and other wild claims about the impacts of robots may attract considerable media attention, they do not square with the facts, as we shall demonstrate in this monograph.

We agree that the robots are coming, but the near term employment impacts will not be overwhelming by any means. The impact of robots will be felt gradually and cumulatively through the years, an evolutionary rather than a revolutionary process. While these statements may not make headlines, we believe they can be shown to be accurate. In our opinion, the recent intense media attention on robotics may have seriously confused the issues and the policymakers.
Scope and Purpose of the Study

This monograph will explore one aspect of the evolution of technology, the application of industrial robots to the manufacturing process. We focus on the human resource implications of the industrial utilization of robotics technology rather than on the technology itself. More specifically, we estimate the job creation and job displacement potential of industrial robots in the U.S. by 1990. We also derive estimates of the impacts of robotics on one state in the nation, the State of Michigan.

Robotics technology is important to Michigan for at least two major reasons. First, Michigan has traditionally relied on the "metalbending" business for a large share of its manufacturing exports. In particular, the dependence of the Michigan economy on auto and auto-related manufacturing is well-documented. This focus has led to a major concentration on manufacturing process technology as well. Thus Michigan already has a very substantial commitment to manufacturing and to manufacturing process technology.

Second, in 1981, Governor Milliken designated robotics technology as the highest priority in the drive to rebuild the Michigan economy with a high technology base. (Milliken, 1981a, pp. 14-15; Milliken, 1981b, p. 13) Of course, the established stake in manufacturing process technology had a role in the selection. So did the circumstance that the auto industry, upon which Michigan has depended for so long, is the leader in the application of industrial robots to the manufacturing process. It was fairly obvious that industrial robots constituted a threat to the Michigan employment base. It was also obvious that the domestic auto industry had been facing intense competitive pressure from the Japanese, and that part of the Japanese cost advantage was emanating from their superior productivity. This in turn could be attributed to the Japanese use of industrial robots, among other factors.
In the face of this situation, the Governor's High Technology Task Force elected to try to make Michigan a world class center of excellence in manufacturing process technology, including but not limited to robotics technology. The centerpiece of this effort has become the development of the Industrial Technology Institute as an independent non-profit corporation designed (1) to foster basic and applied research in manufacturing process technology, including the social and economic implications thereof, and (2) to provide practical assistance to Michigan manufacturers in both adopting and producing new manufacturing process technology. (Industrial Technology Institute, p. ii)

Because of the various initiatives of the State of Michigan and the belief that robotics technology might significantly affect the state's economy, the Michigan Occupational Information Coordinating Committee (MOICC) asked the W. E. Upjohn Institute to look at the labor market implications of robotics in order to provide a base upon which human resource planning could proceed. The present monograph contains much of the information reported to MOICC in the Michigan study, but the major focus is on the national estimates. Thus, we regard the present volume as an extension of the earlier work.

This study is specifically targeted for policymakers and social researchers, particularly those involved in employment and training questions associated with robotics. No prior knowledge of industrial robots is assumed or needed. Technical questions about industrial robots are discussed only to the extent necessary.

There are precious little hard data about industrial robots today. Our data were gathered through published sources and through interviews with robot manufacturers, corporate users of robots, and other experts. While some judgment was undeniably necessary, we attempted to maintain objectivity
throughout our efforts. Our methodology and judgments are explicitly stated in the study. This reflects our hope that this study will lead to other efforts to improve the understanding of the social and economic impacts of industrial robots.

A consistent framework is utilized in the study to evaluate the social and economic implications of industrial robots, particularly the job creation and job displacement caused by industrial robots. That means, for instance, that our projections of the population of robots in 1990 are consistent with our estimates of job displacement and job creation in that same year. Actually, we provide a range for the estimates because of the uncertainties involved, but the point is that the projections are consistent and comparable. This is very helpful in avoiding unrealistic or exaggerated conclusions.

The outline of the study is as follows. In chapter 2 we present a selective review of other forecasts and then our forecast of the U.S. robot population in 1990. The chapter concludes with the derivation of the 1990 projected Michigan robot population. In chapter 3 we discuss the jobs to be eliminated by the robot population projected in chapter 2. That includes not only the number of jobs involved but also the specific occupations. In addition to this examination of job displacement, there is also a discussion of the possible unemployment impacts of robots. Chapter 4 is organized similarly but discusses the jobs that will be created as a result of industrial robots. In both chapters, the focus is on the United States and the State of Michigan. The conclusions of the study are presented in chapter 5.

Given the current lack of information about industrial robots, an annotated bibliography is also provided as part of the study. It is not necessarily complete, nor does it include the popular news magazines or many of the technical journals. However, it is, to the best of our knowledge, the first compilation of an annotated research bibliography on the
social and economic impacts of industrial robots. We hope
the interested reader can use the annotations to identify
items of interest; they cover a broad range, from the highly
technical and mathematical economic literature of
 technological change to simple descriptions of robot
characteristics.

In this introduction, the basic facts of robots are discussed
first: What is a robot? What work can a robot do? Where are
they currently being used? Then the place of robots in pro-
duction technology is assessed. Since robots are new
technology, we discuss the development of two other related
technologies, digital computers and numerically controlled
machine tools. Next some historical antecedents, including
the automation scare of the early 1960s, are considered.
These suggested analogies will hopefully lead to some com-
mon ground upon which to develop a more dispassionate
view of today's new technology—industrial robots. Finally,
we conclude chapter 1 with a discussion of a major study
which has examined the job displacement effects of robots in
great detail: the Carnegie-Mellon study. We believe misinter-
pretation of that study is responsible for some of the
misunderstanding about industrial robots in the popular
media.

What is a Robot?

Complete data on current installations of robots in the
U.S. are not available. In part, that can be accounted for by
confusion in defining exactly what constitutes a robot. A
very broad definition originated with the Japan Industrial
Robot Association, while the narrower definition used
throughout this study originated with the Robot Institute of
America (RIA) in 1979. The RIA definition was adopted by
the 11th International Symposium of Industrial Robots held
in Tokyo, Japan in October 1981. However, it should be
understood that international comparisons are still
treacherous, and RIA and others have had to reevaluate the U.S. robot population. There is still not total agreement about U.S. installations of industrial robots and no one can be certain exactly how many robots there are in the U.S. today.

The official RIA definition, now accepted internationally, is as follows:

A robot is a reprogrammable multifunctional manipulator designed to move material, parts, tools, or other specialized devices through variable programmed motions for the performance of a variety of tasks. (Robot Institute of America, p. 1)

The key to this definition is that a robot is a reprogrammable, multifunctional manipulator. A robot can perform the same task on identical workpieces repetitively; it can perform different tasks on the same workpiece; or it can be reprogrammed to perform entirely new tasks.

Unlike R2D2 and C3PO of the movie Star Wars, however, robots of today are essentially "dumb machines." They are generally immobile, they usually lack any visual or tactile sensory perception, and they cannot adapt to their environment in any way whatsoever. Generally they are no faster than human workers, but they are tireless. In layman's terms, that means a robot can reproduce a specific range of motions for which it has been programmed, but it does not know if it is really holding the part it is supposed to be or if the work was done correctly. Because of the robot's limitations, it must be carefully interfaced with other equipment using mechanical and/or electrical switches to prevent disasters, and procedures must be established to verify the performance of the robot.

Essentially, then, robots are stationary machines with a manipulator arm that can perform motions repetitively and
tirelessly. Unless the workpiece arrives at the exact location for which the arm is programmed, however, the robot will fail. If the workpiece is not of the size expected, or is oriented in the wrong position, the robot will fail. The bottom line is that today's robot can only operate in a carefully structured and oriented world. Furthermore, although the literature makes much of the reprogrammability of robots, relatively few robots today are truly reprogrammed. Minor alterations may be made in the path of the manipulator of a welding robot, but most of today's robots perform the same program over and over and over again.

RIA's 1981 survey reports 4,700 robots in the U.S. by functional application area. (Robot Institute of America, p. 3) By the end of 1982 we estimate that 6,800 to 7,000 robots were operating in U.S. factories. This should make it clear that most of the employment impacts to be discussed are in the future. The growth in application of industrial robots and the implications of that growth both have to be projected because of the very limited empirical base to date.

Robots perform a great variety of tasks today, but most are simple pick-and-place maneuvers such as loading or unloading machines, palletizing, etc. A common sequence might be as follows: the robot picks up the workpiece at a predetermined location, reorients it, places it in a machine tool for processing, removes it after processing, reorients it once again, places the item at a second predetermined location and returns to the beginning. There are also sophisticated welding robots in which the manipulator (arm) can be programmed to follow a continuous path through space instead of simply going to various predetermined points. Control of the entire path of the arm also facilitates spray painting or application of other finishes.

In the auto industry, welding applications of robotics dominate today because auto production is particularly
amenable to spot welding robots. There are only a limited variety of auto bodies, the assembly line can pre-position the parts precisely, and the environment can be perfectly organized because the nature of the work does not change. In short, it is a dull, repetitive, hazardous task that is ideally suited to today's robots. For these reasons, automakers are robotizing assembly line welding operations as normal retooling is done.

There are also pilot applications of robots for assembly tasks. However, assembly is generally a very complex task for today's "dumb" robots that cannot tell when the task is done correctly and must operate in a perfectly oriented and organized environment. Suffice it to say here that assembly robots are viewed as the number one growth application of the future. There are considerable ongoing research and development efforts in this area, but presently robots cannot perform most assembly tasks with consistency in an industrial environment at a reasonable cost. The trade literature implies that all of the problems will be solved very soon, and assembly robots will shortly thereafter proliferate in factories all over the world. Others are not so certain.

In sum, the proven applications of robots today are welding, painting, and various pick-and-place operations, while assembly tasks hold promise for the future. Given all of the media attention to robots, it is surprising that there are so few actually in operation. Part of the reason is to be found in the limited industrial applications perfected so far. For a more thorough technical (yet accessible) discussion of robot applications and capabilities, the interested reader should consult the book listed in the bibliography by Joseph L. Engelberger, generally acknowledged as the father of robotics.
Robots in the Productive Process

The auto industry is the primary user of robots today. In fact, the auto industry pioneered many of the current robot applications and continues considerable research and development efforts in the industrial application of robots. Virtually all robots today are utilized in manufacturing firms, and the bulk are located in what might loosely be called metalcutting or metalbending industries (sometimes referred to as the metalworking sector—fabricated metal products, machinery, transportation equipment) and, to a lesser extent, in instruments and related products. Again, the surprise is that so few industries are actually using robots, but it is also true that these industries are particularly concentrated in the five Great Lakes States.

Robots should be viewed as another form of automated equipment. Generally, we can think of two extremes: custom production or dedicated automation. In custom production, general purpose machines are usually hand operated by skilled workers to produce a single item or small lots of that item. Capital equipment costs may be low but total unit costs are high because set-up time can be considerable, individual machining can be a demanding and time-consuming task, and all of the costs must be spread over a very small number of units produced. At the other extreme stands dedicated (or hard) automation, where the initial fixed capital investment can be quite high but total unit costs are typically very low because the automation of production increases speed and insures constant quality. The highly specialized equipment (dedicated automation) is set up once and thereafter production of a single product can flow continuously.

Robots are not identified with either of these extremes. Set-up time for a robot exceeds that of a human operator in custom production, and the speed of a robot is no match for dedicated automated equipment. Instead, robots are a com-
promise between these two extremes in terms of cost, flexibility and capability. The fixed capital costs of a robot installation exceed that for custom production but are less than dedicated automation; total unit costs are likewise between the two extremes. In terms of capability, robots are no match for the subtle skills of a precision machinist, nor can a robot repeat a single task as perfectly as highly specialized automated equipment.

In terms of flexibility, the robot once again is no match for a skilled human operator that can adjust a workpiece, correct a minor flaw, and carefully check each and every piece as it is produced. On the other hand, the robot can do different tasks (if it is preprogrammed for those tasks), unlike dedicated automation which is capable of producing a single product only. Specialized hard automation sometimes must be scrapped when the product is changed, whereas in theory the robot can be reprogrammed to perform a new task at any time.

Despite the fact that robots represent a compromise between the extremes of custom production and dedicated automation in terms of cost, capability and flexibility, robots today are being applied primarily in mass production facilities where the human worker or the type of work itself already limits the speed of the overall facility. Thus they are serving primarily as a less expensive alternative to dedicated automation rather than being applied to automate batch production facilities. The robot, once installed, appears to be just an extension of the dedicated automation.

Frequently, one robot that operates alone in the sense that it is not interfaced with other robots but only with the plant equipment which it services is termed a stand-alone unit or robot. In this lexicon, a robot system, then, is simply two or more robots that are integrated with each other and the plant equipment as necessary. Neither stand-alone robots nor
robot systems require central computer control over the entire operation, although sufficient limit switches are needed. Stand-alone robot installations dominate today and will continue to do so, at least through the mid-1980s; but robot systems will likely become more important later in the decade.

Some experts think that the greatest potential for robots in the future is the automation of small batch production facilities. (Ayres and Miller, 1981-82, p. 42) This encompasses the ability to reduce batch sizes in production that now require mass production or very large batch facilities (i.e., dedicated automation). The concept appears to promise a capability of production of a family of parts or products as the need arises. Such systems are usually called flexible manufacturing systems, but there is no universally accepted definition. It is unclear how the dedicated machinery for fabrication of manufactured articles would be designed for these new systems, but computer control appears paramount because the automation would require off-line programming of robots and possibly other plant equipment to switch from batch to batch. Ultimately, the individual flexible manufacturing systems would be linked together and lead to the completely automated factory, what some people apparently mean by the term "factory of the future."

However, flexible manufacturing systems will not dominate immediately and the completely automated factory is even farther in the future. Bela Gold, an economist at Case Western Reserve who has studied technological change for over 25 years, stresses the many human and economic prob-

1. The forerunners of these systems are machining centers in which one or more robots service various numerically controlled machine tools to produce precision-cut metal parts. Such machining centers are available today.

2. The terms factory of the future, flexible manufacturing systems and others are encountered frequently in the popular media and trade literature, but they have no consensus definitions at this point.
lems in moving toward the factory of the future. (Gold, 1981a, pp. 30-32, pp. 37-38; and Gold, 1979, pp. 298-302, 310-314) But there are also numerous technical problems. Computer memory systems today are quickly exhausted in controlling even a small manufacturing cell, let alone an entire factory. (Albus, pp. 65-67; Alexander, p. 145; and Wisnosky, p. 22) The integration of individual automated systems in factories involves very complex problems of coordination and transfer. Finally, among the technical problems in robots we note that there are no universal grippers, and off-line programming has not yet been perfected. (Gevarter, p. 37) Today's continuous path robots, for the most part, are "taught" their work task by physically moving the manipulator through the desired sequence of motions.

Our study is focused on the development and introduction of industrial robots and robot systems in manufacturing industries by 1990. Flexible manufacturing systems, the factory of the future, etc., are beyond the scope of the study because their impacts lie beyond 1990, except on an experimental basis. We simply do not find that this technology is sufficiently close to routine implementation to make accurate predictions of its extent or its impact at this time.

**Technological Analogies**

Since the robot industry is very young today but does have a bright future, it is useful to compare it to other analogous technologies. Such analogies do not prove anything, but they can provide a perspective with which to assess the likely development and diffusion of industrial robots. We briefly review the development of digital computers, certainly one of the most significant technologies of several decades, and numerically controlled machine tools, the most closely related capital equipment to industrial robots.
Before beginning, an important distinction is needed between product technology and process technology. As the names imply, *product* technology is the specific technology that is embedded in a final product, such as calculators or TV's, whereas *process* technology is the technology that is embedded in the capital equipment that makes the final products. Robots are definitely process technology and will likely remain so in the foreseeable future. We do not see an early development of an extensive home market for robots. This distinction is important because there is ample evidence that new product technology tends to diffuse more rapidly than new process technology. (Gold, 1979, pp. 183-184; Mansfield, 1971b, pp. 77 and 84; and Sahal, p. 312)

The growth of digital computers from 1961 to 1979 is presented in table 1-1. The year 1961 was selected because that was the first year in which shipments of computers exceeded 2,000 units, roughly the position in which the robot industry finds itself today. The annual percentage increase in the total population of digital computers averaged 26 percent throughout the 19-year period. There were only three years in which annual shipments declined from the prior year level: 1965, 1967, and 1975. Not surprisingly, relative growth was slightly higher in the earlier years when the total population of computers was smaller, but even in the most recent 10-year period, 1969-1979, the annual growth in the population of computers approximated 24 percent.

What does the growth of computers suggest for the growth of industrial robots, if anything? Digital computers can be classified as process technology in that the computer is not a direct part of the final product (microcomputers for the home market are excluded from the data). Rather, the computer provides information processing—cost accounting, recordkeeping, etc.—that in turn supports the production of a final product. The revelation is that computers, widely heralded as the most significant technological innovation of
the 1960s and 1970s, expanded at a growth rate of about 25 percent. Yet some are implying vastly higher growth rates for industrial robots.

### Table 1-1

**Growth in Digital Computers in the U.S., 1961-1979**

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual shipments (thousands)</th>
<th>Total digital computers (thousands)</th>
<th>Percentage increase in total population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>2.2</td>
<td>7.6</td>
<td>30.3</td>
</tr>
<tr>
<td>1962</td>
<td>2.3</td>
<td>9.9</td>
<td>30.3</td>
</tr>
<tr>
<td>1963</td>
<td>3.0</td>
<td>12.9</td>
<td>41.1</td>
</tr>
<tr>
<td>1964</td>
<td>5.3</td>
<td>18.2</td>
<td>27.5</td>
</tr>
<tr>
<td>1965</td>
<td>5.0</td>
<td>23.2</td>
<td>27.5</td>
</tr>
<tr>
<td>1966</td>
<td>7.9</td>
<td>31.1</td>
<td>34.1</td>
</tr>
<tr>
<td>1967</td>
<td>5.9</td>
<td>37.0</td>
<td>19.0</td>
</tr>
<tr>
<td>1968</td>
<td>9.5</td>
<td>46.5</td>
<td>25.7</td>
</tr>
<tr>
<td>1969</td>
<td>10.3</td>
<td>56.8</td>
<td>22.2</td>
</tr>
<tr>
<td>1970</td>
<td>11.5</td>
<td>68.3</td>
<td>20.2</td>
</tr>
<tr>
<td>1971</td>
<td>14.9</td>
<td>83.2</td>
<td>21.8</td>
</tr>
<tr>
<td>1972</td>
<td>20.8</td>
<td>104.0</td>
<td>25.0</td>
</tr>
<tr>
<td>1973</td>
<td>29.3</td>
<td>133.3</td>
<td>28.2</td>
</tr>
<tr>
<td>1974</td>
<td>37.9</td>
<td>171.2</td>
<td>28.4</td>
</tr>
<tr>
<td>1975</td>
<td>37.4</td>
<td>208.6</td>
<td>21.8</td>
</tr>
<tr>
<td>1976</td>
<td>45.0</td>
<td>253.6</td>
<td>21.6</td>
</tr>
<tr>
<td>1977</td>
<td>68.7</td>
<td>322.3</td>
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<td>1978</td>
<td>82.1</td>
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<tr>
<td>1979</td>
<td>87.0</td>
<td>491.4</td>
<td>21.5</td>
</tr>
</tbody>
</table>


There are important differences between computers and robots that must be mentioned. It was realized almost from the beginning that computers were widely applicable in both
business and government, but robots have only limited applications in the manufacturing sector today. An individual firm can potentially use many more robots than computers; however, robots are directly applied to the firm’s production technique. This necessitates careful design, application and integration with the existing production process, while computers are really an adjunct to the production process. There are obviously many differences between computers and robots that make comparisons hazardous, but the fact remains that the growth of the most significant recent innovation in process technology spread or diffused at a rate of about 25 percent annually.

The growth of numerically controlled machine tools is examined because they are more closely related to industrial robots. In fact, robots themselves can be regarded as machine tools. There is also an interesting parallel to robotics technology in the batch production mode. As with robots, numerically controlled machine tools were billed as capable of bringing mass production cost levels to batch production processes because of their great flexibility through reprogramming.

Originally, numerical control meant that the machine tool (lathe, drill press, milling machine, etc.) was controlled by instructions contained on paper tape or cards, while today microprocessor control is becoming more common. The aircraft industry, with research support of the U.S. government, developed numerically controlled machine tools to improve the precision of aircraft parts. This new process technology became available commercially in the mid-1950s; it was widely heralded as applicable in industry anywhere metalcutting was done. By the early 1960s, growth in employment of machine tool operators was thought to be seriously threatened. (Macut, pp. 1-6)
The actual growth of numerically controlled machine tools from 1965 to 1981 is presented in table 1-2. Except for the years 1966-68, the growth of numerically controlled machine tools remained under 20 percent annually. In fact, in 7 of the 16 years in the table, annual shipments declined from prior year levels. The annual growth rate was about 15 percent for the entire period, but averaged only 12 percent for the most recent 10-year period. After 25 years, only 3 to 4 percent of all metalcutting machine tools are numerically controlled. In short, the growth of numerically controlled machine tools has been much less than predicted.

There are many reasons why the growth of numerically controlled machine tools fell far short of expectations, but only three will be mentioned here. First, the applicability of numerical control technology to other industries was significantly overestimated. It appears to have no advantage over conventional machine tooling unless great precision or moderate sized batch production (but less than that needed for justification of dedicated machine tools) is required. (Nabseth and Ray, p. 45; and Mansfield, 1971a, p. 201) Clearly, there must be an opportunity to recover the increased capital investment costs of such technology if it is to be efficient.

Second, there was a significant lack of knowledge about numerical control, and the new technology not only altered the basic production structure but also required the new skill of programming. (Nabseth and Ray, p. 52; and Mansfield, 1971a, p. 201) Thus the human resource limitations were important as well. Third, the price of numerical control ($150,000-$200,000 today for just the hardware) was perceived by many small firms as too high. Many small shops simply do not have the capitalization to afford such investments. Even as recently as 1978, in a survey done of small machine tool firms of 50-100 employees who were nonusers of numerical control but likely candidates for
utilization of the technology, it was found that over 72 per-
cent of the surveyed firms had not even evaluated numerical
control. (Putnam, p. 100)

Table 1.2
Growth of Numerically Controlled Machine Tools
in the U.S., 1965-1981

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual shipments (thousands)</th>
<th>Total NC machine tools (thousands)</th>
<th>Percentage increase in total population</th>
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</thead>
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<td></td>
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<tr>
<td>1966</td>
<td>2.9</td>
<td>11.0</td>
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<tr>
<td>1967</td>
<td>3.0</td>
<td>14.0</td>
<td></td>
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<tr>
<td>1968</td>
<td>2.9</td>
<td>16.9</td>
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<td>7.1</td>
</tr>
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<td>1973</td>
<td>2.7</td>
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<td>11.3</td>
</tr>
<tr>
<td>1974</td>
<td>4.2</td>
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</tr>
<tr>
<td>1975</td>
<td>4.0</td>
<td>34.9</td>
<td>12.9</td>
</tr>
<tr>
<td>1976</td>
<td>3.9</td>
<td>38.8</td>
<td>11.2</td>
</tr>
<tr>
<td>1977</td>
<td>4.5</td>
<td>43.3</td>
<td>11.6</td>
</tr>
<tr>
<td>1978</td>
<td>5.7</td>
<td>49.0</td>
<td>13.2</td>
</tr>
<tr>
<td>1979</td>
<td>7.2</td>
<td>56.2</td>
<td>14.7</td>
</tr>
<tr>
<td>1980</td>
<td>8.9</td>
<td>65.1</td>
<td>15.8</td>
</tr>
<tr>
<td>1981</td>
<td>7.9</td>
<td>73.0</td>
<td>12.1</td>
</tr>
</tbody>
</table>

Once again, too much can be made of the comparison between numerically controlled machine tools and robots, and there are substantial differences as well as similarities. However, the growth and diffusion of numerical control illustrates the general obstacles to the rapid diffusion of process technology in general.3

**Historical Analogies**

The purpose of the foregoing discussion was to develop a more rational perspective of technological change by briefly looking at two earlier new technologies related to robots, whereas the purpose of this section is to briefly discuss economic change in general. The fear of unemployment and massive displacement caused by labor-saving technology is not new. Such fears began with the dawn of the industrial era in the late 18th century; they continue today with the growth of industrial robots.

For example, the U.S. economy recovered very slowly from the deep 1958-59 recession and then experienced another recession in 1961. The “automation problem” was of urgent national concern, and in 1962 the U.S. Congress passed the Manpower Development and Training Act to address the retraining needs of technologically displaced workers. Then, in 1964, the President appointed a National Commission on Technology, Automation, and Economic Progress to determine the impact of automation and technological change on the U.S. economy.

But the economy was already beginning to recover significantly in 1964, and by the time the Commission rendered its final report in 1966, the economy was near full employment. Historical events ultimately obviated the need for and impact of the Commission; the problem seemed to

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3. The interested reader should consult the recent works of Sahal and Gold listed in the bibliography for a review of this literature.
have gone away. To no one's surprise, the Commission's conclusion was that a sluggish economy was the major cause of unemployment rather than automation. (Bowen and Mangum, pp. 3-4)

The recessionary phase of any business cycle is difficult and traumatic for workers, particularly in a state like Michigan with its durable goods-oriented economy. The clear danger is that we may wrongly attribute the short run cyclical problem to other factors, such as automation. Walter Buckingham issued a grim forecast at the time of the 1961 recession: "There are 160,000 unemployed in Detroit who will probably never go back to making automobiles, partly because the industry is past its peak of growth and partly because automation has taken their jobs." (Buckingham, pp. 117-118) Subsequently, however, the auto industry set new employment peaks in the middle of the 1960s, and the auto-dominated Michigan economy boomed once again. (Verway, p. 1) We suffered through another such cycle, although attenuated, with the 1974-75 recession. Yet the auto industry went on to its all-time peak employment in 1978.

The general comparison between the early 1960s and the early 1980s appears compelling in our judgment. History does not and will not repeat itself, but history can provide a more objective perspective within which to judge the current (new) situation. Employment in the auto industry may not recover to its 1978 peak, but employment gains will be significant during the recovery phase of the business cycle.

Automation is not the cause of the U.S. or Michigan's unemployment today any more than it was in the early 1960s. That is not to imply that we should take a "rah rah robots" approach to the coming technological change; however, neither should we adopt a doomsday attitude that attributes most or all unemployment during major recessions
to automation. In fact, one might plausibly argue that some of our basic industries suffer more today from a lack of automation and the rational organization of that automation vis-a-vis our European and Japanese competitors than from too much automation.

It is possible to develop a more dispassionate view of technological change, or more specifically, of the introduction of industrial robots. First, let us admit that most technological change throughout American history has been labor-saving, and that means job displacement. By job displacement we mean the elimination of job tasks, not necessarily implying worker unemployment. As will be discussed later, they are not the same thing by any means.

The powerful job displacing effect of technological change is illustrated in table 1-3; it lists hypothetical job displacement in manufacturing in the U.S. and Michigan from 1979 to 1990, assuming a fixed output and a continuation of the slow annual growth in output per worker experienced in the late 1970s of 2.1 percent. (U.S. Department of Labor, 1981c, p. 24) The base year employment for the calculations is 1978. Under the unrealistic assumption of constant output, if the annual growth in output per worker of 2.1 percent continues throughout the decade of the 1980s, then cumulative job displacement by 1990 will approximate 4.6 million in the U.S. and 265,000 jobs in manufacturing in Michigan.

Stated in relative terms, 22 percent of all existing jobs in manufacturing could disappear by 1990 as a result of increases in productivity. Of course, worker productivity gains are not solely the result of new labor-saving technologies, but the total effect is the same; gains in productivity, whatever the source, can cause considerable and sometimes dramatic displacement effects on the existing job base if they are examined in isolation.
Table 1-3
Illustrative Displacement Impact of General Productivity Gains, Michigan and U.S. Manufacturing

<table>
<thead>
<tr>
<th>Year</th>
<th>Michigan</th>
<th>U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>24,772</td>
<td>430,605</td>
</tr>
<tr>
<td>1980</td>
<td>49,023</td>
<td>852,167</td>
</tr>
<tr>
<td>1981</td>
<td>72,765</td>
<td>1,264,876</td>
</tr>
<tr>
<td>1982</td>
<td>96,009</td>
<td>1,668,919</td>
</tr>
<tr>
<td>1983</td>
<td>118,764</td>
<td>2,064,477</td>
</tr>
<tr>
<td>1984</td>
<td>141,042</td>
<td>2,451,728</td>
</tr>
<tr>
<td>1985</td>
<td>162,852</td>
<td>2,830,847</td>
</tr>
<tr>
<td>1986</td>
<td>184,204</td>
<td>3,202,004</td>
</tr>
<tr>
<td>1987</td>
<td>205,107</td>
<td>3,565,367</td>
</tr>
<tr>
<td>1988</td>
<td>225,571</td>
<td>3,921,099</td>
</tr>
<tr>
<td>1989</td>
<td>245,606</td>
<td>4,269,361</td>
</tr>
<tr>
<td>1990</td>
<td>265,220</td>
<td>4,610,309</td>
</tr>
</tbody>
</table>

NOTE: The 1978 base year employment figures are 1,179,600 for Michigan and 20,505,000 for the U.S., as found in U.S. Department of Labor, Bureau of Labor Statistics, Employment and Earnings, May 1981, pp. 39 and 125.

Second, the dramatic job displacing effects of technological change have not caused massive unemployment in the American economic system because in normal times they have been accompanied by significant economic growth, i.e., output has not been constant. Displaced workers are reemployed in other sectors of the economy, or they may gain new jobs in the same firm if demand increases sufficiently after the introduction of new technology. The heart of the problem appears to be the perception that there is only a constant amount of work to be done, so a machine or robot eliminates not only the job task but also the need for that worker. Historically, this has not generally been true.
Third, the association of technological change and economic growth is not just a coincidence; the two are intertwined and inseparable. That is not to imply that adoption of new technologies necessarily insures economic growth, or that displaced workers will always find new jobs. However, it does mean that we all have a vital stake in productivity gains (i.e., in displacing jobs) because that is what allows the possibility of economic growth. The price of a growing, dynamic economy that raises incomes and makes more goods and services available to all of us is job displacement, or the elimination of jobs through technological change.

Fourth, although the long-run impact of technological change has been favorable on the American economy, job displacement in the short run can be traumatic for the workers involved, who usually are concentrated geographically and occupationally. Displaced workers may find it difficult to learn new tasks. Severely impacted regions may not have the resources to cope with those displaced. Job displacement in the short run may require significant public and/or private retraining efforts. Furthermore, the public education system must insure that entry-level workers possess the requisite new skills and not old, obsolete skills.

Finally, we must guard against the temptation to view technological change as revolutionary; the fear that tomorrow we will awaken to the unmanned factory and a world of robots without workers. Technological change tends to be evolutionary, especially in process technology. There are physical, financial, and human constraints on the rate of change of process technology. While no one would dispute that computers have changed our world, this has taken a quarter of a century.

In summary, industrial robots are simply one more piece of automated industrial equipment, part of the long history of automation of production. Robots will displace workers
in the same way that technological change has always displaced workers. There is a possibility that this job displacement will be a significant problem, particularly in given occupations, industries, or geographical areas. These questions are examined later in the study. There is also the certainty that robots will create jobs, and that also is examined later in the study. Robots will not guarantee economic growth and we cannot be assured that displaced workers will be reemployed, although there is reason for some optimism historically. In the short run, there will likely be some worker dislocation, and that dislocation may be concentrated geographically. Policy issues raised by these changes will be addressed after their magnitude is determined.

**The Carnegie-Mellon Study**

We conclude this chapter with a discussion of the only study which has examined the job displacement impacts of robots in great detail, the Carnegie-Mellon study. Actually the Carnegie-Mellon study is not one published document, but several that originated from a project in which Robert Ayres and Steven Miller were the principal investigators. (Ayres and Miller, 1981a)

The fundamental basis of the job displacement estimates of Ayres and Miller is a survey of corporate users of robots (with 16 respondents) that asked them to provide estimates of potential job displacement in 32 occupations by today's commercially available robots (Level 1) and tomorrow's robots that would be sensor-based with rudimentary tactile and/or visual perception (Level 2). The occupations were chosen by Ayres and Miller as those most likely to be robotized. The responses were weighted by size of firm (six classes) to obtain a weighted average response. These sampled occupations were then combined with other nonsampled occupations (based on similarity) and job displacement
estimates were derived for the metalworking sector and for all manufacturing.

Perhaps Ayres and Miller best summarize their conclusions in a *Technology Review* article:

> Based on these results, we estimate that Level 1 robots could theoretically replace about 1 million operators, and Level 2 robots could theoretically replace 3 million of a current total of 8 million operators. However, this displacement will take at least 20 years. By 2025, it is conceivable that more sophisticated robots will replace almost all operators in manufacturing (about 8 percent of today's workforce), as well as a number of routine nonmanufacturing jobs. (Ayres and Miller, 1982b, p. 42)

According to Ayres and Miller, 4 million manufacturing operative jobs are subject to robotization over the next 20 years or more, and all operatives in manufacturing may be replaced by 2025. The emphasis is clearly on theoretical displacement in the indefinite future rather than actual or probable displacement by some specific date.

We doubt that production techniques, even theoretically, are as homogeneous across manufacturing as Ayres and Miller imply; by industry, by size of firm, or by type of product. But those doubts are minor in the context of theoretical estimation of the unbounded future. As Ayres and Miller themselves point out, their estimates are really only rough guesses to obtain "a feeling of how many people will be involved in 'first order' adjustment processes." (Ayres and Miller, 1981a, p. 100)

Ayres and Miller go on to conclude that their study has highly significant policy implications. They talk of an "institutional failure" in that our public education and training
programs reflect obsolete rather than emerging needs. (Ayres and Miller, 1981a, pp. 22-23) They are particularly critical of CETA, vocational schools and government occupational forecasters, none of which in their opinion recognize the future employment needs of society. (Ayres and Miller, 1982a, p. 21) Ayres and Miller conclude, “the transition to the factory of the future is occurring now. . . . If appropriate measures are not taken, the nation will experience unnecessary economic distress and lost opportunities.” (Ayres and Miller, 1982b, p. 46)

We do not concur with Ayres and Miller that their estimates of theoretical displacement by occupation at some undefined point in the future are proof that our public institutions today are training their clientele in obsolete skills. Furthermore, Ayres and Miller offer no evidence whatsoever about the emerging occupations, so their criticism in that regard is especially puzzling. In our judgment, if policy responses to the challenges of the future are to be formulated, including the possible effects of robotics technology, then the assessment must proceed based upon the most likely or probable events that are expected to occur within a definite time horizon. That is what we will endeavor to do in the remainder of the study.