CHAPTER 1

Introduction

1.0 OBJECTIVES

After studying this chapter, the reader should:

1. Be acquainted with automation and robots
2. Know some of the history of robots
3. Understand the technology of robots
4. Recognize the economic and social issues associated with robots
5. Have some familiarity with present and future applications of industrial robots

1.1 AUTOMATION AND ROBOTS

(The field of **robotics** has its origins in science fiction. The term **robot** was derived from the English translation of a fantasy play written in Czechoslovakia around 1921. It took another forty years before the modern technology of industrial robotics began. Today, robots are highly automated mechanical manipulators controlled by computers.)

Automation and robots are two closely related technologies. Both are connected with the use and control of production operations. In an industrial context, we can define automation as a technology that is concerned with the use of mechanical, electrical/electronic, and computer-based systems to control production processes.) Examples of this technology include transfer lines, mechanized assembly machines, feedback control systems, numerically controlled machine tools, and robots. (Accordingly, robots are mechanical devices that assist industrial automation. There are three types of industrial automation: fixed automation, programmable automation, and flexible automation.)

(**Fixed automation** is used when the volume of production is very high and it is, therefore, appropriate to design specialized equipment to process products at high rates and low cost.) A good example of fixed automation can be found in the automobile industry, where highly integrated transfer lines are used to perform machining operations on engine and transmission components. The economics of fixed automation is such that the cost of the special equipment can be divided over a large number of units produced, so that the resulting unit costs can be lower relative to alternative methods of production. The risk encountered with fixed automation is that the initial investment cost is high and if the volume of production turns out to be lower than anticipated, then the unit costs become greater.

(Another problem with fixed automation is that the equipment is specially designed to produce only one product, and after that product's life cycle is finished, the equipment is likely to become obsolete. Therefore, for products with short life cycles, fixed automation is not economical.

Programmable automation is used when the volume of production is relatively low and there is a variety of products to be made. In this case, the production equipment is designed to be adaptable to variations in a product configuration. This adaptability feature is accomplished by operating the equipment under the control of a "program" of instructions that has been prepared especially for the given product. The program is read into the production equipment, and the equipment performs the particular sequence of operations to make that product. In terms of economics, the cost of the programmable equipment can be spread over a large number of products even though the products are different. Because of the programming feature, and the resulting adaptability of the equipment, many different and unique products can be processed economically in small batches. There is a third category between fixed automation and programmable automation, which is called flexible automation.

Flexible automation has only developed within the past twenty-five or thirty years. This type of automation is most suitable for the mid-volume production range. Flexible automation possesses some of the features of both fixed and programmable automation. Other terms used for flexible automation include **Flexible Manufacturing Systems (FMS)** and **Computer-Integrated Manufacturing (CIM)**. Flexible automation typically consists of a series of workstations that are interconnected by material-handling and storage equipment to process different product configurations at the same time on the same manufacturing system. A central computer is used to control the various activities that occur in the system, routing the various parts to the appropriate stations and controlling the programmed operations at the different stations. The three types of industrial automation and manual labor are illustrated in Figure 1.1.1.

One of the features that distinguish programmable automation from flexible automation is that with programmable automation the products are made in batches. When one batch is completed, the equipment is reprogrammed to process the next batch.

With flexible automation, different products can be made at the same time on the same system. This feature allows a level of versatility that is not available in pure programmable automation, as we have defined it. This means that products can be produced on a flexible system in batches, if desirable, or that several products can be mixed on the same system. The computational power of the control computer is what makes this versatility possible.

Of the three types of automation, robots coincide most closely with programmable automation. The "official" definition of an industrial robot is provided by the **Robotics Industries Association (RIA)** as follows:

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> An industrial robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks.

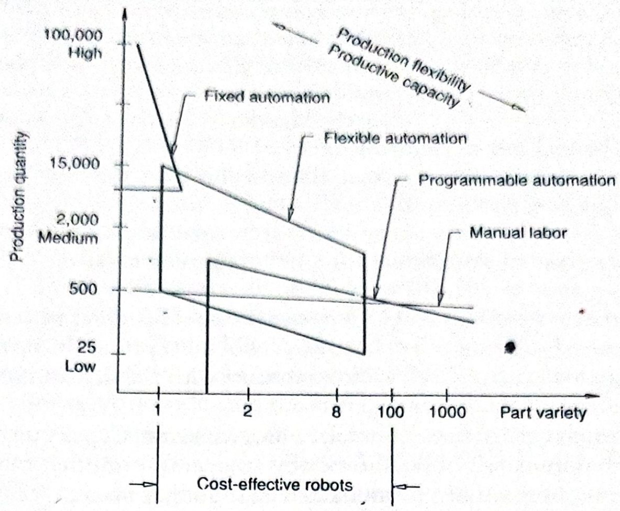

Figure 1.1.1 The three types of production automation and manual labor as a function of production volume and product variety relative to cost-effective robots

Though the robots themselves are examples of programmable automation, they are sometimes used in flexible automation and even fixed automation systems. These systems consist of several machines and/or robots working together, and are typically controlled by a computer or a programmable controller. Such a system might appropriately be considered a high-production fixed or flexible automation system.

X Today, the human analogy of an industrial robot is very limited. Robots do not look or behave like humans. Instead, they are one- or multiarmed machines that almost always operate from a fixed location on the factory floor. Future robots are likely to have greater sensor capabilities, more intelligence, higher levels of manual dexterity, but a limited degree of mobility as compared to humans. There is no denying that the technology of robots is moving in a direction to provide us with more and more capabilities similar to those of humans.

1.2 BRIEF HISTORY

X The word *robot* was introduced in 1921 by the Czech playwright Karel Capek, in his play *R.U. R. (Rossum's Universal Robots)*, and is derived from the Czech word *robota*, meaning "forced labor." The story concerns a brilliant scientist named Rossum and his son, who develop a chemical substance similar to protoplasm to manufacture robots. Their plan was that the robots would serve humankind obediently and do all physical labor. Finally, after improvements and eliminating unnecessary parts, they develop a "perfect" robot, which eventually goes out of control and attacks humans.

Although Capek introduced the word *robot* to the world, the term *robotics* was coined by Isaac Asimov in his science fiction story "Runaround," first published in the March 1942 issue of *Astounding*, where he portrayed robots not in a negative manner but built with safety measures in mind to assist human beings. Asimov established in his story the three fundamental laws of robotics as follows:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings, except where such orders would conflict with the first law.
3. A robot must protect its own existence as long as such protection does not conflict with the first and second laws.

In a broader sense, Capek's term *robot* meant a manipulator that was activated directly by an operator or other mechanical or electrical means. More generally, an industrial robot has been described by the **International Standards Organization (ISO)** as follows:

> A machine formed by a mechanism, including several degrees of freedom, often having the appearance of one or several arms ending in a wrist capable of holding a tool, a workpiece, or an inspection device. In particular, its control unit must use a memorizing device and it may sometimes use sensing or adaptation appliances to take into account environment and circumstances. These multipurpose machines are generally designed to carry out a repetitive function and can be adapted to other functions.

According to Miller (1987), robots were introduced to industry in the early 1960s. Initially, robots sold for an average of $25,000 with a life expectancy of about eight years, cost approximately $4.00 per hour to operate, and had to compete for jobs with human workers earning slightly more per hour than the robot hourly operating cost. Robots, originally, were used in hazardous operations, such as handling toxic and radioactive materials, and loading and unloading hot workpieces from furnaces and handling them in foundries. Some rule-of-thumb applications for robots are the four *D*s (*d*ull, *d*irty, *d*angerous, and *d*ifficult, including demeaning but necessary tasks) and the four *H*s (*h*ot, *h*eavy, *h*azardous, and *h*umble).

By 1970 approximately two hundred robots were in use in U.S. manufacturing facilities. The jobs to which robots were assigned during that decade were primarily hazardous, strenuous, or repetitious and required the robot to respond only to simple input commands. Control and feedback technology at this evolutionary point remained relatively basic, limiting robots to jobs requiring a lot of "brawn" but very little "brain."

During the 1970s, with nationally declining productivity and increasing labor rates, a significant increase in robot usage began. Many improvements in controls increased the flexibility and capabilities of robots. The first robots had been introduced in the automotive industry. Ten years later, the same industry was contributing most to the growth of robotics by its widespread acceptance. The average prices of robots increased, to approximately $45,000, life expectancy remained at about eight years, operating costs rose to approximately $5.00 per hour, and the average direct labor cost in the automotive industry was twice the hourly operating cost of an industrial robot.

In 1980, there were approximately 4,000 robots in the United States and 26,000 robots worldwide. By the mid-1980s, there were approximately 17,000 industrial robots in the United States. The average price was approximately $60,000, life expectancy increased to fifteen years, operating costs were in the range of $5.50 per hour, and—again using the automotive industry as a comparative example—labor rates were escalated to over $14.50 per hour.

By the end of 1997, RIA estimates, some 84,000 robots were in operation in U.S. factories, placing the United States second in the world to Japan. According to Dave Lavery, manager of the robotic program at NASA, there are some 650,000 robots at work today worldwide, and the average price is approximately $72,000, life expectancy over seventeen years, and operating costs in the range of $7.00 per hour as compared to average wages of over $24.00 in the automotive industry. Figure 1.2.1 shows the history of labor and robot cost in the automotive industry.

Over the past decade, highly selective applications for robots resulted in so-called "islands" of automation. With the development of more sophisticated automation concepts, such as Computer-Integrated Manufacturing (CIM) and Flexible Manufacturing Systems (FMS), users learned that industrial operations are usually best automated through the integration of robots with machines, which

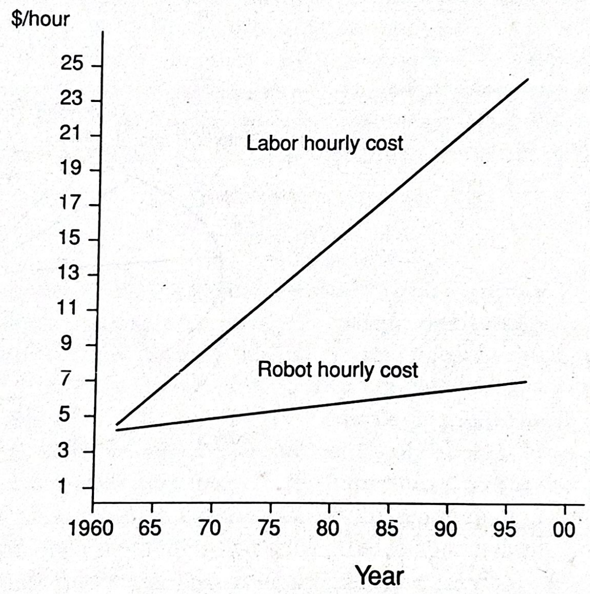

Figure 1.2.1 Hourly cost of a robot versus human labor in the automotive industry

are referred to as a **workcell**. This integration, which causes the need for knowledge about robots, has become very important in automated manufacturing today.

Robots can be used in any industry providing work and services, and can also be adapted easily to numerous job functions with uncanny skill and unmatched endurance.

These factors and many others, such as reducing production cost, improving quality, and increasing productivity, to name just a few, have contributed to the growth of robots and will continue to impact their evolution, both in pace and direction.

Robot application areas as a percentage of total robot population for the year 1996 are shown in Figure 1.2.2. Robot shipments from U.S.-based companies for the period 1993–1997 are shown in Figure 1.2.3.

Two reasons are given for selecting a robot to operate in a production line: (1) to reduce labor costs, and (2) to perform repetitive work that is boring, unpleasant, or hazardous for human beings.

Computer-controlled robots were commercialized in the early 1970s, with the first robot controlled by a minicomputer appearing in 1974. Table 1.1 presents a chronological list that summarizes the leading developments related to current robot technology.

The primary purpose of the robot as a machine is controlled motion: If it does not move, it is not a robot. All robotic design endeavor has controlled, sensitive, and intelligent motion as its collective goal. The variety of uses for robots is increasing, although their main use still seems to reside in automotive manufacturing.

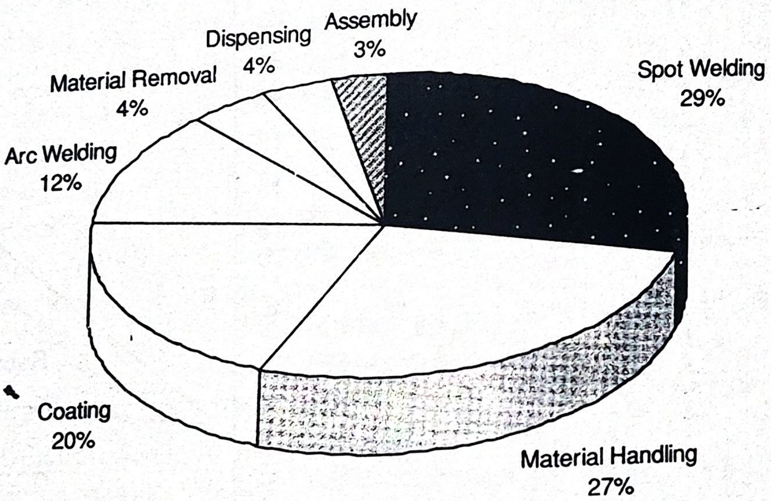

Figure 1.2.2 A comparison of leading robot applications in 1996. *(Source: RIA)*

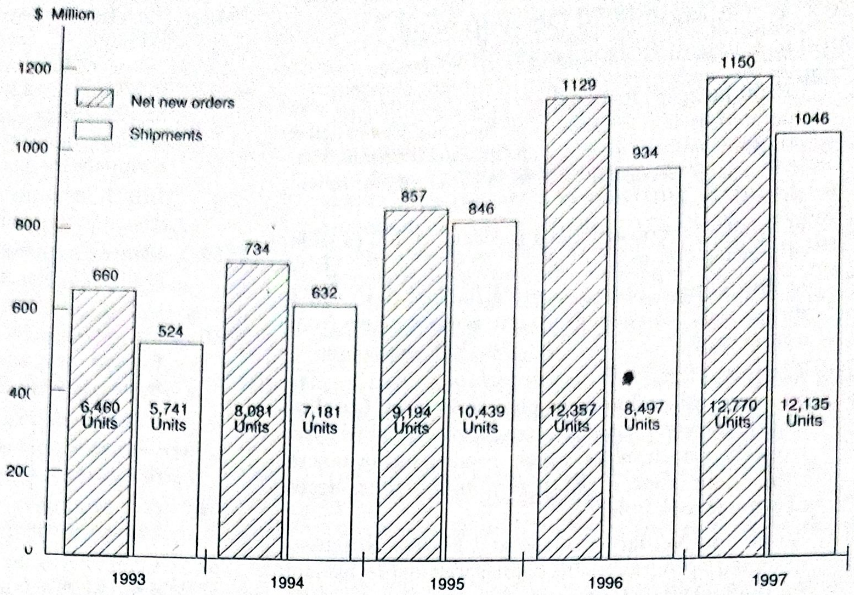

Figure 1.2.3 U.S. robot sales for the period 1993–1997 (*Source: RIA*)

A decade ago the projection was that robots would begin to grow in popularity about the year 1998 after the general public—as well as engineers and scientists—had learned to routinely accept them in their work environments, and that no robot would act or feel like a human being in the foreseeable future. These projections are still true. The primary driving force behind the renewed interest in robots will be lower unit cost, greater reliability, and simpler operation.

1.3 THE TECHNOLOGY OF ROBOTS

A robot is a machine constructed as an assemblage of joined links so that they can be articulated into desired positions by a programmable controller and precision actuators to perform a variety of tasks. Robots range from simple devices to very complex and "intelligent" systems by virtue of added sensors, computers, and special features. Figure 1.3.1 illustrates the possible components of a robot system.

There are several hundred types and models of robots. They are available in a wide range of shapes, sizes, speeds, load capacities, and other characteristics. Care must be taken to select a robot to match the requirements of the tasks to be done. One way to classify them is by their intended application. In general, there are industrial, laboratory, mobile, military, security, service, hobby, home, and personal robots. Figure 1.3.2 illustrates the general configuration and operating parameters of an industrial robot.

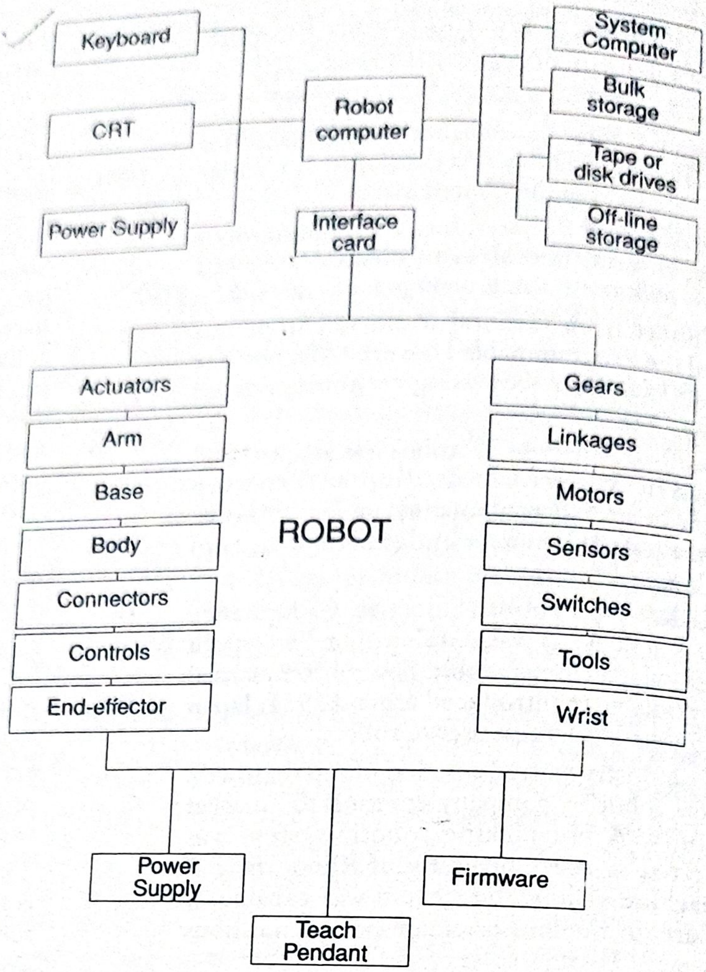

Figure 1.3.1 Schematic of a robot system

In the last three decades, the robotics field benefited considerably from the advancement of microelectronics, computer science, and improved design of electrical, electromechanical, and hydromechanical servo systems.

The industry continues to grow and expand. Currently, there are approximately thirty robot manufacturers in the United States and over five hundred worldwide. The annual growth rate of the industry is approximately 35 percent per year, and continued market expansion is expected. RIA estimates that annual sales volumes for 1998 will be in the $2 billion range; for the year 2000 it is predicted to be about $7 billion. Spot-welding still remains the largest application area for robots today.

Competitive forces are beginning to segment the market with many manufacturers focusing on specific industries or applications. This specialization approach will speed technological advancements and enhance robot capabilities in specific areas. More attention is being paid lately by manufacturers to sensor

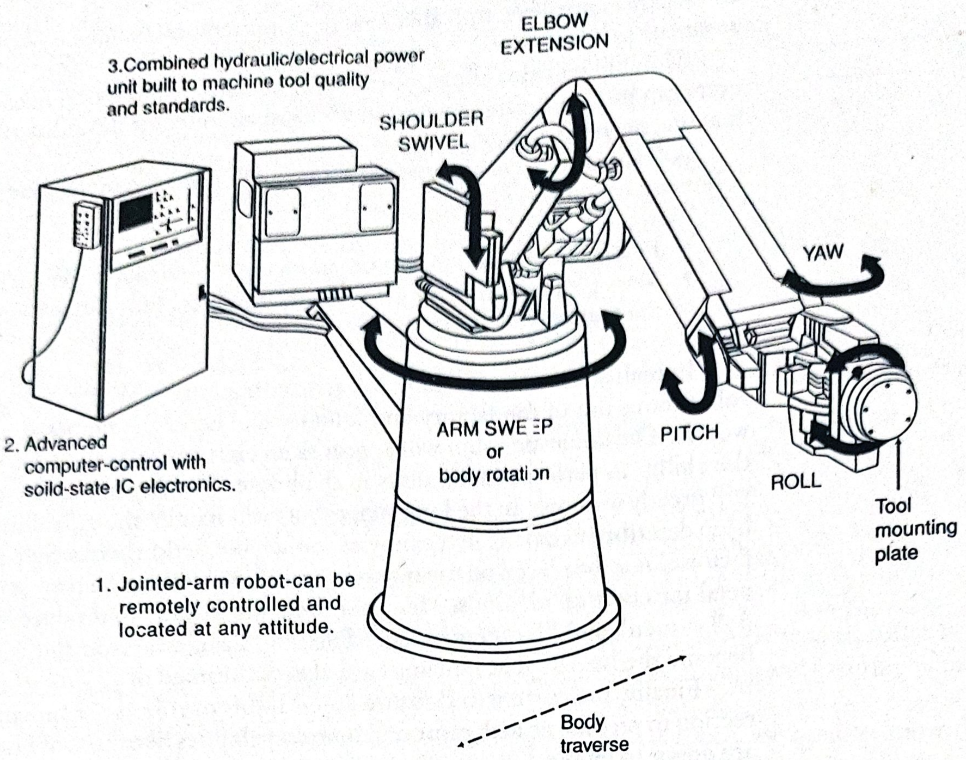

Figure 1.3.2 The general configuration and operating parameters of the Cincinnati Milacron T^3 series industrial robot

integration. More and more robots are sold with standard or optional capabilities, such as vision and tactile sensors and even fuzzy logic controls.

More-intelligent robots will be the result of such efforts. The robot manufacturers will continue to quickly implement the computer-industry improvements and expanded capabilities to raise the "IQ" of robots to handle more data and process it faster. The move is well under way to utilize more AC electric servo systems to power robot motions. It is expected that this trend will continue along with CAD/CAM integration, which is a logical direction for the users of robotic technology.

Computer graphics technology is also rapidly advancing to provide us with "simulation" capabilities to analyze manufacturing approaches and methods prior to implementation. "Off-line" programming, a necessary component to realize full CAD/CAM capability benefits, is now being offered. The "universal robot controller" finally emerged in 1998 into the market to eliminate those nuisance programming languages that are different for each robot model. This will replace all factory controllers with this new one and reduce the unnecessary islands of automation.

Mobility will also allow robots the necessary freedom of movement so that users can more fully appreciate and utilize their inherent flexibility throughout a manufacturing facility.

A dramatic decrease in cost of robots can be expected in the near future if the following conditions exist:

- Fewer manufacturers will be supplying robots to a larger market.
- Mass production methods with advanced technologies are applied to the manufacture of robots.

VII In reality, robot technology has an exciting future. We can expect to see the robot move out of the factory and foundry and enter the domestic and business worlds. The domestic robot will appear as an electronic pet and soon will develop the ability to perform useful tasks in the home. The sensory ability of all robots will greatly improve. In the long run, robots will acquire the capabilities they have been described as having in the movies and science fiction books. Self-reproducing factories may be placed on the moon or on other planets to help meet our growing need for energy and goods. Medical robots will be able to produce "six-million-dollar men" and "bionic women." Exciting changes are on the way as robots become the helpers that humans have always dreamed of.

Finally, the current and future applications of robots are moving in the direction to provide us with more and more capabilities like those of humans, which are going to increase our quality of life and the global economy.

1.4 ECONOMIC AND SOCIAL ISSUES

Although it is certainly true that robots can relieve humans of the need to perform what have been called "4 D jobs" (dull, dirty, dangerous, and difficult), the fact remains that manufacturing plant managers are extremely concerned with the "bottom line." A survey of robot users conducted in the 1980s by the Carnegie-Mellon University Robotics Institute indicates that the primary reason for selecting a robot is to reduce labor costs. Table 1.2 shows how potentially beneficial robots may appear to be with respect to humans. If robots cannot be justified economically, they should not be purchased or used in production lines. The purpose of this section is to present briefly some simple techniques that have been used to demonstrate how robots can easily be shown to be an economically justifiable capital expenditure. It is not the intention, however, to develop sophisticated economic theories—that is beyond the scope of this book.

Today, the price of a single industrial robot ranges from about \$5,000 to well over \$100,000. To this must be added the cost of the associated tooling and fixturing that are to be used within the robot workcell and the total installation cost. It has been found that approximately 55 percent of the overall system cost is for the robot, 30 percent is for the additional tooling, and about 15 percent is for installation. Consider a system with a total cost of \$100,000 broken down as follows:

Table 1.2 Reasons for Using Robots

Ranking	Potential Benefits
1	Reduce labor costs
2	Eliminate dangerous jobs
3	Increase output rate
4	Improve product quality
5	Increase product flexibility
6	Reduce material waste
7	Comply with OSHA
8	Reduce labor turnover
9	Reduce capital cost

- Material-handling robot $55,000
- Tooling and fixturing $30,000
- Installation $15,000

It should be noted that the figure used for this type of robot is about the current average in the United States. Also, the tooling and fixturing figure includes engineering development costs.

To determine the economics of such a robot, we need to know the cost of labor and of the operation of the robot itself.

It was estimated that in 1995, an automobile worker earned about $17 per hour, including fringe benefits. In addition, the Draper Laboratory at MIT has estimated that it costs about $6 per hour to run a robot based on operating sixteen hours per day (i.e., two shifts per day) and a useful life of about eight years. (Although other sources suggest a figure of $2 per hour, many robot manufacturers use the more conservative number.) Because a worker will normally put in about two thousand hours per year (forty hours per week for fifty weeks), it can be seen that the $11 per hour differential in labor costs ($17 – $6) produced by the robot results in a yearly "saving" of about $22,000. Thus, it will take about 2.8 years to pay back the original cost of the robot ($55,000/$22,000). After this time, the user will be "making" $22,000 per year or, more correctly, will be experiencing a positive cash flow. If we assume a two-shift-per-day activity, the payback period will be only 1.4 years, after which time a cash flow of $44,000 per year will occur.

Obviously, this analysis is an oversimplification because it does not look at all economic factors, such as the cost of money and the escalation of labor costs. Nevertheless, it does provide one with the idea that robots can be justified economically, and rather easily at that. Now refine the analysis somewhat by including such factors as corporate tax rates, depreciation, and the savings resulting from using less material in a particular process. It can be shown that the payback period Y can be calculated from the following equation:

$$Y = \frac{(P + A + I) - C}{(L + M - O)H(1 - TR) + D(TR)} \qquad \text{(Equation 1.4.1)}$$

Where Y = number of years required to break even
P = price of the robot = \$55,000
A = cost of the tooling and fixturing = \$30,000
I = installation cost = \$15,000
C = investment tax credit (assumed to be 10%) = \$10,000
L = hourly cost of labor, including fringe benefits = \$17
M = hourly savings in the cost of materials = \$1
O = cost of running and maintaining the robot system = \$6
H = number of hours per year per shift = 2,000
D = annual depreciation assuming an 8-year "tax life," the straight-line method, and a salvage value of \$10,000 = (\$100,000 – \$10,000) /8 = \$11,250
TR = corporate tax rate assumed to be 40% (= 0.4).

Substituting these values into the equation gives a payback period of 2.7 years for a double-shift operation. Another economic yardstick that is often used in determining whether a particular capital expenditure is warranted or not is the return on investment (ROI).

$$ROI = \frac{\textit{total annual savings}}{\textit{total investment}} 100\% \qquad \text{(Equation 1.4.2)}$$

In terms of the quantities defined above, this can be expressed as

$$ROI = \frac{(L + M - O)H - D}{P + A + I - C} 100\% \qquad \text{(Equation 1.4.3)}$$

Using our example values in this equation indicates that the ROI is only 14.2% for a single-shift operation. However, this figure increases to an impressive 40.8% when the robot is used two shifts per day. When compared with the 9% cost of borrowing money today, it appears that a robot used in a single or multiple-shift application is clearly a good investment. It is important to realize that a more or less favorable result will be obtained if different assumptions are made concerning labor and/or robot costs. For example, if we use \$2 per hour for the running and maintenance of a system, the one- and two-shift ROIs become 23.1% and 58.6%, respectively.

One final point is worthy of mention. The quantitative measures just described do not take into consideration the economic benefits that can be derived from using a robot to produce a product that is of a consistently high quality.

The important results of the example given here demonstrate clearly that from an economic point of view, robots seem to make a great deal of sense. However, what about the human element? What will be the impact on the workers themselves of introducing these devices into the workplace?

The problems created by the introduction of automation into the workplace are not new. There is no question that the principal purpose of robots and manufacturing automation is to make processes more efficient.

Robots are usually justified on the basis of labor-cost savings, and this means that robots are doing jobs that were formerly performed by human workers. Even in new processes for which no human worker has been employed, the use of a robot means that one or more human worker(s) will not be employed in that job. The replacement rate is not one-to-one either. Robots can often perform an operation at speeds equal to or faster than the human operator and can work three shifts per day, seven days per week, which is the equivalent of four human workers. Even considering downtime for maintenance, a robot can often replace more than one worker.

There are, of course, many reasons for employing robots and manufacturing automation other than the drive for higher efficiency. Improving quality, enhancing safety, and removing tedious, fatiguing, or boring tasks are all worthwhile objectives, but are they worth the price of sacrificing workers' livelihoods? On the other hand, without automation, whole industries and all jobs in these industries can be lost to competition. The savings from these productivity improvements exceed total profits, and if the savings had not been there, the company would not have survived.

If we look at the larger picture and include a count of workers worldwide, we would undoubtedly find that automation is reducing the number of jobs required to sustain a given level of output. But because automation is here, failure to use it by any one company is almost surely to result in failure of the company and elimination of all jobs in that company. Therefore, without automation, industries in countries such as the United States would have little chance of survival against industries employing low-cost labor in foreign countries.

Early in the twentieth century, an automobile was as extravagant a luxury as the personal airplane is today. But Henry Ford's assembly lines and Detroit-style automation made automobiles available to the average person and resulted in huge demands for automobiles in the 1920s. Along with the huge volumes came millions of jobs for persons employed by the automobile and related industries. Today, automation breakthroughs, such as the computer industry, are increasing volumes of sales of other products and at the same time creating more jobs and ensuring better quality of life for our people.

1.5 PRESENT AND FUTURE APPLICATIONS

The state of the art of robotic applications is, in some ways, paralleling the development of digital computers. When they were first introduced, computers were used for tasks that had previously been performed by people. This was a natural application, for it was obvious that the new device would be able to perform such jobs much faster and even more reliably than people could perform them. However, as time progressed, it was recognized that tasks that had previously been rejected as being impossible to undertake because of excessive personnel and/or time requirements were now possible to attempt.

In the 1960s, it was feared that computers would reduce the number of white-collar jobs, such as accounting clerks. Instead, the computer has increased the number of these jobs by creating such new occupations as computer operator, computer programmer, and systems analyst. By making more information available, computers have generated and increased desire for information in our society. Now in the 1990s, there is fear that robots will reduce the number of blue-collar jobs, but it is more likely that robots will cause a total increase in jobs. Some of these may be white-collar jobs. New human jobs such as robot supervisor, robot programmer, robot setup person, robot trainer, and robot repair person are sure to emerge from the widespread use of robots in industry. Right now, new types of manipulator joints, actuators, and grippers are under development. Japanese researchers are experimenting with **shape-memory alloy,** a new actuator for humanlike hands. A wire made of shape-memory alloy (composed of nickel and titanium) is used.

At present, robots have little or no judgment and decision-making capacity, and their sensory capabilities are quite poor. Consequently, they are not yet ready to perform most complicated tasks. The advancement of the robot to the state shown in such films as *Star Wars* and *Star Trek* must await breakthroughs in the areas of artificial intelligence, voice interfacing, and vision and touch sensors. Considerable research is going on in these areas, and it is only a matter of time before the objects of today's laboratory curiosity become economical enough for use in robots.

Robots would advance much faster if the future products were needed now. Economics is a major driving force in research and development, as is the government, through its military and space programs. The government was responsible for much of the development of electronics and the electronic computer, for instance. Today, the Atomic Energy Commission is sponsoring research in robotics for advanced nuclear reactors, where robots will have to work in extremes of temperature, humidity, and radiation level and will have to be able to climb over obstacles. The military is hoping to make up for its shortage of personnel by using robots to make the human forces more efficient. Even in their present state of development, robots are finding more and more jobs. They have already been successfully used as brain surgeons, window washers, lab technicians, and in hospital applications. One of their newest uses occurred on February 22, 1988, when ABC began employing robots to run the television cameras for its national news broadcasts. This allows the cameras to be operated by remote control from the control booth by a single person.

The automated robot cook, maid, butler, or gardener is still far from becoming a reality. However, a robot chauffeur can be built with today's technology, if someone is willing to pay the high cost. The navigational computers and sensors necessary for getting around safely in city traffic already exists. As it merges with the electronic computer, the robot is evolving toward the point where it could be viewed as a new **life-form.**

Although artificial intelligence is still in its infancy, it has already shown great promise for robots. Work has begun on the development of self-reproducing machines. Robert A. Freitas has written an article on the prospects for a self-replicating factory to be practical by the early twenty-first century. Located on the moon and running on solar power, this factory would use the moon's raw materials to reproduce itself and to manufacture additional solar cells, which could then be hauled away for a nearby solar-powered generation station satellite to beam to earth as electrical power. NASA has proposed a four-part program along these lines, where part one is a robot in a warehouse assembling other robots and part four is a self-reproducing factory the size of a football field.

Robots are currently used in education as tools for teaching various topics. The show robot is very useful for working with abused children whose bad experiences often make it hard for them to trust and talk to adults. Show robots are also useful for working with shy children. Programmable mobile devices such as the Big Trak tank (robot) can be used to teach programming; because they deal with motion rather than with numbers, they are easier for children to relate to. Educational robots are used to teach applications programming for industrial robots.

Looking forward may show us future consequences of current policies and actions, which may help us make informed decisions now. The future is controlled by events from the past and present, and by our imaginations. Important products of imagination include art, fiction, science literature, cinema, and children's toys.

Computer memory devices have been quadrupling in capacity and speed and the price reduced by half every three years. The personal computers of today have more memory and run faster than did the mainframe computers five years ago. Jules Verne predicted many of the mechanical inventions of the twentieth century in the middle of the nineteenth century. Hugo Gernbeck predicted many of the electronic devices—including radar and solar energy devices—of the late twentieth century during the early twentieth century.

As recently as ten years ago, it was estimated that 50 percent of the adult population of the United Sates suffered from **cyberphobia**—an unreasonable fear of computers. Children are not afraid of computers, however, because they are being brought up with them. The same will be true of children's attitudes toward robots when these become widely available as toys. However, there will be a short-term problem with reassigning persons who are displaced from simple manual-labor jobs by robots. Some will find more interesting and rewarding jobs, others may be given early retirement, and still others will require retraining at the company's or government's expense. But, in time, the problem will disappear because no one new will be joining the workforce in these areas.

1.6 SUMMARY

Automation and robots are two closely related technologies. Both are concerned with the use and control of production operations. Robotics (the study of robots) is a form of industrial automation. There are three types of industrial automation. Fixed automation is used for high production volume and utilizes expensive special equipment to process only one product. Flexible automation is used for medium production volume and utilizes a central computer to control the process of different products at the same time. Programmable automation is used for low production volume operated under control of a program. It processes one batch of similar products at a time. When one batch is completed, the equipment is reprogrammed to process the next batch.

Robots are examples of programmable automation; however, they are often used in flexible or even fixed automation systems.

Tracing the sequence of events that led to the development of industrial robots currently available is presented in Table 1-1.

The two reasons for selecting a robot to operate in a production line are first to reduce labor costs, and second to perform work that is boring, unpleasant, or hazardous for human beings.

Robots can perform repetitive tasks at a steady pace, be programmed to achieve and perform different unpleasant tasks, operate for long hours without rest or break periods, and respond in automated manufacturing operations on a continuous basis.

Without automation and robots our industries would be lost to competition. Automation reduces unit cost and increases volumes of sales, which creates jobs on other products, and ensures better quality of life.

Finally, the current and possible future applications of robots are moving in the direction to provide us with more and more capabilities like those of humans.

1.7 REVIEW QUESTIONS

1.1 Discuss the differences between fixed, flexible, and programmable automation.

1.2 What other terms are used to describe flexible automation?

1.3 What is the RIA definition of a robot?

1.4 Identify an early design that demonstrates the mechanical operation found in later industrial robots.

1.5 What is the ISO definition of a robot?

1.6 What company was the first to control a robot with a minicomputer?

1.7 Discuss at least three reasons for using robots instead of humans to perform a task.

1.8 Discuss several reasons why robots should be used in the workplace even though human beings may initially lose some jobs.

1.9 Explain briefly the CMU Robotics Survey in respect to human beings.

1.10 Explain why automation breakthroughs create more jobs and ensure better quality of life.

1.11 How might robots be advanced faster in the workplace?

1.12 Explain how the future of robots is controlled and what applications can be foreseen.

1.8 PROBLEMS

1.1 A new production machine costs $90,000 installed and is expected to generate revenues of $50,000 per year for 7 years. It will cost $20,000 per year to operate the machine. At the end of 10 years the machine will be scrapped at zero savage value. Determine the payback period for this investment.

1.2 Two production methods, one manual and the other automated, are to be compared. The data for the manual method is the same as Problem 1.1. For the automated method the initial cost is $135,000, the annual operating cost is $5,000, and the service life is expected to be 5 years. In addition, the equipment associated with the alternative will have a salvage value of $70,000 at the end of the 5 years. Revenues for either alternative will be $50,000 per year. Compare which method is more profitable.

1.3 A batch of 50 parts is to be processed through the factory for a particular customer. Raw materials and tooling are supplied by the customer. The total time for processing the parts is 100 hours. Direct labor cost is $12.00 per hour. The factory overhead rate is 125% and the corporate overhead rate is 160%. Compute the cost of the job.

1.4 A manually-operated production machine costs $66,063. It will have a service life of 7 years with an anticipated salvage value of $5,000 at the end of its life. The machine will be used to produce parts at a rate of 20 units per hour. The annual cost to maintain the machine is $2,000. A machine overhead rate of 15% is applicable to capital cost and maintenance. Labor to run the machine costs $10.00 per hour and the applicable overhead rate is 30%. Determine the profit break-even point if the sale price of parts is $1.00 per unit.

1.5 Two alternative production methods have been proposed; one with manual feeding, the other with a robot. Data are given in the following table. Select the more economical alternative method.

	Manual	Robot
Initial cost	$15,000	$96,000
Annual operating cost	$30,000	$10,000
Salvage value	0	$15,000
Service life (years)	10	8

1.6 The cost of a robot is $60,000, and the price of tooling and fixturing is $15,000. The installation cost is $20,000. Use 10% as the rate of investment. The cost of labor is $18 per hour, and the savings in the cost of materials is $2. The actual cost of running and maintaining the robot system is $5. The number of hours per year per shift is assumed to be 2,800.

Assume an annual depreciation on an 8-year tax life and the savage value to be $10,000. Use a corporate tax rate of 40% to determine the number of years that are required to break even.

1.7 Solve Problem 1.6 to determine if the return of investment is justified with 14% interest on the borrowing money.

1.8 A proposed robot is to be used exclusively to assemble one work part in a production line. The initial cost of the robot is \$50,000, and its expected service life is 3 years with a salvage value of \$20,000 at the end of the 3 years. The robot will be operated 4,000 hours per year (two shifts) at \$8.00 per hour (labor, power, maintenance, and the like). Its production rate is 10 units per hour. Excluding raw material costs, compute the production cost per unit using a rate of return of 25%.

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