7

Economic Considerations and Justification of Industrial Robots

7.1 Economic Considerations

When robots were first developed, they were very expensive, requiring large amounts of capital investment in a new, untried technology. Now, however, many robots have been installed with great success, leading robot producers to manufacture more robots at lower prices. Although robots are still a considerable investment, they no longer represent an untested production method. Thus, more businesses are deciding to invest in robots. The purpose of this chapter is to consider the economic aspects of robot ownership by industry or by individuals.

The cost of an industrial robot is often less than that of a house. The price range for industrial-quality robots in the United States is between $14,000 and $150,000, according to the RIA *Worldwide Directory*. A robot is therefore within the purchasing power of individuals or groups of individuals. What circumstances would lead one to purchase a robot? When can the purchase of one or more robots be justified? What conditions must be met to make these purchases attractive to the investor? These are some of the questions we consider in this chapter.

The prices of robots run from about $35 for a Tomy toy manipulator arm to $100 million for the space shuttle manipulator arm. Computer-controlled robots start at about $300 for the Turtle. High-accuracy industrial robots are around $50,000. This range of prices shows that robots are in the range of affordability for many people, but what would we have it do? Hugh Hefner has one to bring him drinks and greet guests. Our son told us he would like a robot to make money for him so that he could buy all the toys he wanted. Then he would want the robot to help him bring all those toys home and help him put together any that came unassembled. We all would undoubtedly like a robot to make money for us so we could buy what we want. What can a robot do to make money? Well, it can work, that is, produce goods or provide services, just like humans. We have already discussed several of the jobs that robots can do—welding, painting, parts manipulation, and assembly. What can a robot build?

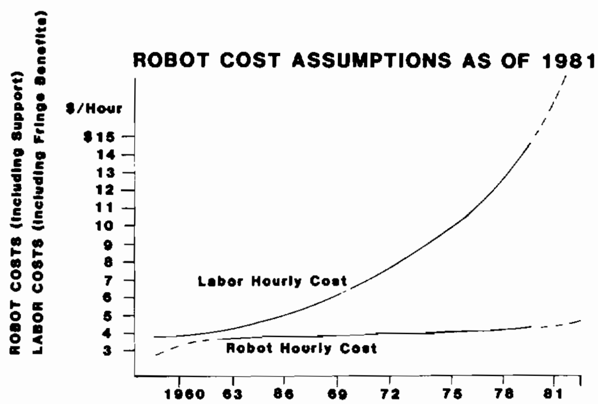
As an exercise in a robotics class, the students were asked to design a single robot system that could build computers. The motivation for this project was that if a single robot could take the components of a computer and put it together, any student could have a computer for the cost of the components, which is about 40 percent of the usual retail price of most computers. After 3 months, the students had come up with designs of several systems that could assemble a computer. The size of the best overall system was about that of a dining-room table. The cost of the robot and sensors was about $50,000. The time required to assemble the small, single-board computer was about 5 minutes. Running 24 hours/day, this robot assembly system could theoretically produce 288 computers per day, or 105,120 per year. This could supply even the largest college with at least one for each student, faculty, and staff member. If only $100 were saved on each computer, this single robot system could save $1,051,200 in 1 year as compared with purchased systems. A $1 million return on a $50,000 investment is rather attractive. The students did not have time to actually build the systems they designed, but similar exercises are being done in industry for real dollars. Many brilliant designers are probably thinking about how robots can make money, but we may never learn of their efforts until we see their results at the local shopping mall in the form of better products at lower cost.

Industrial ownership of robots is currently the most economically practical method of ownership in our country. Any major departure from our existing free enterprise system is highly unlikely in the near future. Corporations have the resources, the skilled designers, and the artisans to make just about anything we will buy. Competition between domestic and international manufacturers is very tough. As consumers, we benefit from this competition. As competitors, however, we must use every possible resource available to stay in the race. Robots are a very useful resource.

What are some of the considerations on which potential buyers of robots need to concentrate? Probably the most important is how to justify the costs associated with buying and using robots. We perform a sample economic justification and break-even analysis later in the chapter, but to get an overall idea of how the cost of robots compares with the cost of alternative forms of manufacturing, let's examine the basic reasons robots are now being considered by many businesses that formerly believed robots were too expensive.

The need for robots arose from the need for flexible, programmable automated machines to perform a variety of tasks in a variety of situations. The major benefits arising from the use of industrial robots, such as increased productivity, improved product quality, greater resistance to inflation or sudden product changes, fewer employee injuries, continuous output, and better inventory control, made robots desirable to many businesses. However, the cost of robots as compared with human labor costs precluded their purchase except by large or wealthy businesses. Then, the cost of labor began to rise. It is now at a point where the robot has become less expensive in comparison. Figure 7–1 shows a graph of hourly labor costs as compared with robot hourly costs from 1960 to 1981. Note that the ratio of human-robot labor costs is almost 4:1 in this example.

The next most important consideration in determining whether a robot purchase is justified is how robot systems can improve productivity. Robots can do this in several ways. They can improve throughput efficiency, consistency, and product quality. In some applications, such as arc welding, productivity can increase several hundred percent, depending on labor costs, operations, and other related costs. Another obvious benefit in productivity is improved product quality and consistency. This improvement is made because robots, unlike humans, cannot grow tired, bored, or careless with their work. When humans tire, they sometimes make mistakes in their work, resulting in the need to scrap or rework parts of the product. This costly reworking and scrapping of unfit products is nearly eliminated with robots. The robotics system will produce the same part exactly the same way many thousands of times without a breakdown. Robots can also represent a savings in direct labor costs in its particular operation, since one robot can usually do the work of three to five humans. There are also savings in associated costs, such as lighting and heat, that are incurred in a workplace where human comfort is a consideration. Robots can work in the dark and in temperatures uncomfortable for



ASSUMPTIONS

Unimate price	$50,000
Useful life	8 years at two shifts per day
Cost of money	15 percent
Installation cost	Two at $12,000 per installation
Maintenance	$1.15 per hour
Power cost	$0.40 per hour
Overhaul (Two)	$0.40 per hour
Depreciation	$1.56 per hour
Installation	$0.80 per hour
Money cost	$1.10 per hour
Hourly operating cost, 1981	$5.41

Figure 7–1. History of labor and robot costs. (Cost estimates supplied by Unimation, Inc.)

humans. Savings may also be made in safety costs, such as those resulting from compliance with government standards for high-risk jobs. Savings may result from more accurate forecasting of production schedules. If a robot system is programmed to produce a certain number of parts per hour, then that is how many parts will be produced, barring mechanical failure. Failure rates among the robots produced by major manufacturers are usually quite low. Many robot designs reach a mean time between failure of 500 hours without incurring prohibitive costs.

The next most important consideration is the type of robot hardware, software, and power supply called for. Although we have already described the various types in earlier chapters, let's go over them very generally again. The manipulator of a robot can vary according to the kind of dexterity the potential application requires. The number of manipulator axes that are available on most industrial robots ranges from two to six. The four types of robot designs most widely available are based on their manipulators' geometries. These are Cartesian, cylindrical, spherical, and articulated. Each different application requires an end effector designed to perform the needed task. These can be grippers, drills, magnets, spray guns, welding units, or others. Many tasks sometimes require custom-built end effectors, although standard welding guns, spray-paint guns, and grippers are available for robots. The power supply for the robot can be hydraulic, pneumatic, or electric. Hydraulic-powered robots are generally called for when the application involves handling heavy materials, or where dexterity and resilience are required. Pneumatic robots perform best when the application calls for very rapid movement or in handling very light materials. Electric robots can achieve a higher degree of repeatability and accuracy as long as the payload involved is not heavy. The current trend is toward all-electric robot systems, particularly when the system involves sensory accessories. The controls for the system can range from basic programming controls to minicomputers, depending on the type and complexity of the operation required of the robot system. In most applications calling for frequent human intervention and/or adjustment, such as in arc welding, an operator control station that has a teach pendant, keyboard, and CRT display is supplied.

The next most important consideration is the robot system software. Control software is supplied with the robot control. Applications software to integrate the robot with other equipment in the factory is custom-built. The complexity and expense involved in the software again depend on the application of the robot system. It can range from simple single-cell robot controls to hierarchical computer packages that interface with robot communications. The type of software needed is also affected by the type of robot operation called for in the application, whether servo or nonservo. Servo robots can perform point-to-point, continuous path, and controlled path operations; nonservo robots are limited to simple line transfer and materials-handling operations. Most robots manufactured and sold today are of the servo type.

Another important consideration for the user is to what kind of application robot systems are best suited. Proven applications for robot systems have been detailed in Chapter 6, but let's go over the list of most frequent applications to date. These are:

Spot welding
Arc welding

Palletizing
Stacking and unstacking
Stamping press loading and unloading
Drilling
Painting
Handling and moving hot parts
Assembly
Machine loading and unloading
Injection molding
Die casting
Shell molding for investment castings
Deburring, grinding, and milling
Gluing
Handling and moving toxic, dangerous, or heavy parts

This list is by no means exhaustive, but because they are proven applications, they represent references for the potential buyer and user. Robots can be beneficial in both large and small operations, for both long runs and small batch operations. Robots can come freestanding, in single-cell applications packages, or in integrated applications systems that can be interfaced with other manufacturing equipment. An evaluation of a robot's potential benefits for a particular facility should be made. In making such an evaluation, the following questions should be answered for each individual application.

Is there a sufficient volume of parts or number of operations the robot will perform to make its purchase economically feasible? Or, is the volume so large and unchanging that hard automation is more economical?

Is the contemplated robot system compatible with the present process? That is, are the changes that will be necessitated by the system feasible and cost-effective? Is the production line speed needed in the application within the limits of the contemplated robot system?

Can the robot system be reprogrammed or retooled to accommodate anticipated product or operation changes without prohibitive additional cost?

Is the robot system capable of handling the required payload with maximum efficiency?

Does the contemplated system have sufficient operating range?

What degree of repeatability is required for the application?

Are software and memory available for the contemplated system in sufficient degree to handle anticipated changes or adjustments in the application?

Does the control system need to be easily or frequently changed? How easily can the robot system be retrained?

How much adaptability and interface is required of the sensors?

How much robot can the facility handle? Are there adequate floor space, floor strength, and power supply? Some industrial hydraulic robots can weigh 4 tons.

How much downtime can be accommodated? The industrial standard for most robot systems is currently about 2 percent, but this does not include peripheral equipment. In most applications, the uptime reported for robots is 98 percent. This indicates that the robot would be down only 40 hours in a 2000-hour year.

Stauffer (1982) summarizes the four basic types of robot installation. These are the single, stand-alone robot, multiple cells, each with a robot, an integrated line with similar robots performing similar tasks, and an integrated line with different robots doing various tasks. He reports that, since the current trend is toward integrated installations, one of the most important considerations for the potential user is how future requirements will fit into the robotic system they choose. For example, if there is a possibility of adding a robotic vehicle transport system, automatic storage and retrieval systems, or off-line CAD programming within 10 years of the first robot system installation, then that first system should be chosen carefully to accommodate these anticipated systems.

Computer simulation of robotic systems is a valuable tool that allows potential users to predict production times and to comprehend how the system will work, how the system can be integrated into the present production process, how the selected system compares with alternative production processes or systems, and how anticipated additions, such as additional systems or peripherals, can best be integrated into that system. These simulations can be in color and in three dimensions and can be done by independent organizations to ensure objective comparisons.

Before performing an economic analysis, the human relations aspects should be openly and honestly considered by management, shop employees, union representatives, and any others concerned with the company remaining in business.

The human factors involved in the application of any robot installation are of paramount importance because the system will only be as successful as the people involved allow it to be. Howard (1982) lists the following factors that should be considered before integrating any robotic system in a factory.

1. *Work environment*. Assess the physical and psychological surroundings and the adaptations workers will make in response to them.
2. *Worker/machine interface*. Analyze the manner in which the humans and the machines will function together to design a system that maximizes the capabilities of both. For example, if the robot system will move at one speed and humans at another speed, the production must be coordinated to accommodate both without penalizing either.
3. *Job design*. Analyze the capabilities and limitations of humans and machines to determine which jobs are most satisfactorily and/or efficiently performed by humans and which jobs should be performed by the machines.
4. *Selection and training*. Identify which workers have the skills or abilities to operate, maintain, and program the robots and which will need training to perform these tasks, then decide the kind and extent of training that will be needed.
5. *Maintainability*. Since most of the cost of maintenance is incurred in diagnostics, the persons performing the maintenance on the robot system should be those persons already familiar with the robot's environment who have received further training in robotics maintenance.

6. *Safety*. Protect the robots and the humans from each other by designing safe production layouts, educating workers about potential hazards, providing workers with protective equipment if necessary, developing clear safety guidelines, and assigning responsibility to a given department or group of workers for ensuring that safety regulations are followed.
7. *Management*. The decision to automate should not be made without the full knowledge, consideration, and cooperation of affected employees. Workers' resistance to changes in production and task assignment is lowered when such plans include their input. Some of the issues that should be considered in such plans include labor grades, pay scales, training, departmental transfer, and operator responsibilities.
8. *Communications*. Continuous, open communication between workers and management will ensure optimum implementation of the contemplated robotics system. Both formal and informal lines of communication should be established between those who are indirectly and directly involved in the automated process.

Howard emphasizes that these factors should be considered from the very beginning of considering a robotics system installation to the actual implementation of the system. They will continue to be important throughout the operation.

Another way to help ensure a successful installation is to follow Susnjara's (1982) five cardinal rules of robot installation.

Rule 1. Think simple. In considering the use of industrial robots in an existing plant, a survey of possible applications should be made. For the first robot installation, this first rule would advise us to go for a simple, proven application. For example, if the choice is between spot welding and assembly, the more proven spot-welding application should be selected. Thinking simple might also mean that the installation that has the greatest possibility for increasing profits might be delayed until the installation with the greatest degree of success has been made. Susnjara states that "a successful robot installation even in a simple application will quiet the skeptics, convert the doubters, quell most of the fears of labor and management people, and set the stage for future successes."

Rule 2. Be thorough. The purpose of this rule is to avoid "surprises" in the selected application. Perhaps a production technique with which everyone is familiar but that has not been considered in the initial survey will be encountered, or perhaps some unreported variation in the process to which the human operator has adapted in the past will be uncovered. Such surprises could determine the success or failure of the installation. To avoid these potential problems, Susnjara advises involving both the production employees who are intimately familiar with the process and the supervisors in the planning of the robot installation. Being thorough involves long-range planning and profitable use of the industrial robot. This includes many factors past the initial design and installation. Maintenance, training, and continued concern about the operation are essential.

Rule 3. Be reasonable. This rule involves an awareness of what the robot can and cannot do. Researchers are available to attempt the challenging and unsolved problems. Installation of a robot system for a given application should generally not be made until its efficiency has been proven. This rule also involves having reasonable expectations of the robot manufacturer. They cannot be expected to do detailed applications engineering work as part of the purchase price of the robot. Finally, being reasonable involves being realistic in expectations and planning.

Rule 4. Be honest. This rule applies to every phase of the robot installation, from the initial survey to analysis after years of successful use. It refers not only to technical appraisal but also to open and honest discussions with the people at all levels involved with the robot, and even includes community relations. The help and encouragement of management, employees, union representatives, and the community depend upon fair and accurate reporting of the robot's implications.

Rule 5. Be careful. Safety is always of prime concern and requires proper awareness by everyone involved. Training and retraining are also part of being careful. Casual familiarity with robot systems and procedures can lead to carelessness, with unfortunate consequences. Being careful with the computer programs by keeping current backup copies can also save weeks or months of effort from a system or medium malfunction that could destroy the information saved.

These five rules and perhaps others you devise help ensure the success of a robot installation. A machine as powerful and versatile as an industrial robot cannot be installed and forgotten. Constant training, retraining, and attention to safety considerations are necessary.

7.2 Economic Justification of a Robot

There are several reasons for installing an industrial robot. The increased productivity that can result from the more consistent operation and constant throughput of the robot is an important issue. Recall the popular folk song about the contest between John Henry, the steel-driving man, and the automatic spike-driving machine—no matter how hard or fast he worked, the machine outperformed him. A robot may be justified on productivity increases alone, since it is not limited to an 8-hour day. An increase in productivity can be measured in the number of parts produced per day. This factor alone may make it clear that a robot installation is justified.

Improved quality is another reason for installing an industrial robot. The consistency of the robot operation can be translated into consistency in the quality of the product. In conjunction with improved quality is the reduction of defects and scrap materials produced by the operation. For example, in a spray-painting operation, greater consistency may be realized in the form of more uniform thickness of the applied material. Since the layers of paint may be only one-thousandth of an inch thick, the application of a coating two-thousandth of an inch thick would be barely perceptible to a human operator but would use twice as much material. One manufacturer of food products installed a device for measuring the amount of cheese in a pound package of cheese. The savings to the manufacturer in not giving away more cheese than required and in reduced time satisfying the government inspectors paid for the machine in just a few months. Another company involved in manufacturing cathode-ray tubes was almost put out of business because of the uncontrolled method it was using to deposit phosphor on the faceplate. As the price of phosphor increased over the years, competitive companies automated the process and were able to offer a higher quality product at half the cost. Even in applications in which the robot is not considerably faster than humans, the consistency of operations may provide a definite advantage. For example, in die casting or plastic molding, the constant cycle time of the robot can permit the temperature of the product to stabilize and thus produce more consistent goods. Furthermore, the continuous operation of an industrial robot can eliminate the need for intermittent rest breaks that can result in inconsistent quality in a product. Welding is another application in which consistency can lead to considerable savings and prevent costly failures.

Improving the quality of work by eliminating health risks to humans in hazardous tasks is another major consideration in the use of industrial robots. For example, since the beginning of serious work with radioactive materials began in the 1940s, some type of remote manipulator or robotic device has been needed. Perhaps not so obvious but just as important are the many toxic environments encountered in spray-painting, chemical-processing, or other dusty manufacturing environments. One company we visited makes products from asbestos. Breathing microscopic asbestos particles can lead to severe lung disease. This company had spent over a million dollars installing ventilation equipment in a large high-bay factory to satisfy Occupational Safety and Health Administration (OSHA) standards. Looking back is always easier; however, it seems possible that a better solution might have been a confined space and robot installations. Many robots could be purchased for a million dollars.

Applications for robots to perform undesirable tasks due to difficult working conditions, such as noisy, dirty, or hot environments, those with noxious fumes, or simply fatiguing jobs requiring lifting heavy loads or working at a very fast or monotonous pace, might be more difficult to economically justify but have a significant humane value. Many manufacturing jobs fall into these categories.

Since the jobs are now being done by humans, there is an economic baseline for comparison with a proposed robot installation. In such cases, a careful economic analysis is required.

To illustrate how the many factors interact that determine whether a robot installation is a good investment, let's consider the following hypothetical example developed by University of Cincinnati Professor Ronald Tarvin. This economic analysis would logically follow a survey of a plant in which it has been determined that at least one potential robot application exists. For the economic analysis, we will be concerned with such factors as the payback period, the return on investment, a cash flow analysis, tax credits, depreciation, and the tax bracket the company is in.

Example Economic Justification. The installation of a robot would first require a capital investment. For this example, we will assume that sufficient capital is available to cover the initial costs. If the capital is not available, then the cost of borrowing the funds must also be included. Susnjara provides tables of the cost of capital borrowed at various interest rates for various periods of time that may be used to include this element.

Suppose that the items to be purchased include the following.

One industrial robot with options	$60,000
Gripper or process tooling	1,500
Safety equipment	2,000
Sensors and interface	1,250
Conveyors	1,750
Total capital investment	$66,500

These costs are typical of a robot installation. The price of the robot alone may only be $50,000. However, most manufacturers offer certain options useful in particular applications. For example, the software and hardware for tracking a moving conveyor may be required. The cost of the gripper or process tooling is also listed separately, since these come in such a variety of types. The safety equipment may consist of simply a chain barrier or perhaps a fence or wall. This is, again, very dependent on the application. Conveyors that may be needed to transport parts to and from the robot have also been included. This example illustrates that the capital investment required is more than the cost of the robot alone.

There would also be some expenses necessary for starting up the installation. We will assume the following.

Feasibility study (400 hr @ $20/hr)	$ 8,000
Engineering time (200 hr @ $20/hr)	4,000
Site preparation (80 hr @ $15/hr)	1,200
Installation (60 hr @ $15/hr)	900
Total installation costs	$14,100

The feasibility study would be done before installation but could be directly associated with it. The cost estimate is based on 10 weeks of engineering time to survey the facility and determine the most appropriate installation, talk to the employees, management, and union representatives, and provide a report. The engineering time includes 5 weeks to design specialized tooling, perform plant layout changes, fabricate accessories, and attend training classes on the operation of the robot. The site preparation would include the cost of constructing safety barriers, providing power sources, and other necessary renovations. Finally, the cost of installation, which would normally be done by the robot manufacturer personnel, is included.

Thus far, the robot has been purchased and installed at a cost of \$80,600. Let's now consider how these costs might be offset.

First, let's assume a modest increase in productivity, perhaps due to the decreased break times no longer needed for the operation. Suppose eight more parts per day can be produced and that each part is worth \$20. The annual increase is

\$20/part × 8 parts/day × 250 days/yr = \$40,000
Total productivity: \$40,000

This increase would double if a two-shift operation were used. However, for this example, we will consider only one shift.

There could also be a savings due to the robot shifting a worker to another operation in the plant. Suppose that the robot has taken over a hot, dirty, or difficult part of the operation and reduced the number of workers from five to four. The shifted worker would result in a cost savings for the operation of

\$11/hr × 2000 hr/yr × (1.5 benefit factor) = \$33,000
Total labor savings: \$33,000

The labor cost of \$11 per hour for 2000 hours/year is multiplied by a fringe benefit factor to provide this total cost.

Thus far, the savings resulting from increased productivity and labor costs is \$73,000. However, we will encounter some costs in operating the robot. If the robot requires 30 kilowatts of electric power purchased at 4 cents per kilowatt hour, the annual power cost would be

30 kW-hr × \$0.04/kW-hr × 2000 hr/yr = \$2400
Total power cost: \$2400

Periodic maintenance would also be required. We will assume the cost of this maintenance to be 3.75 percent of the equipment costs of \$66,500, or

Total maintenance costs: \$2500

The total operation expenses per year would be \$4900.

Adequate portrayal of other factors, such as depreciation and tax deductions, requires a cash flow analysis. This is simply a tabulation of the costs encountered during the lifetime of the equipment. For this example, a 5-year time period is assumed for the depreciation of the equipment. Of course, the robot would still be functioning after 5 years. One expert estimates that the average lifetime of an industrial robot is 8 or 9 years. Many of the early industrial robots are still functioning after more than 10 years. There would also be a salvage value to the robot after 5 years, since it might contain some 6000 pounds of metal. However, for this example, the salvage value will not be considered.

We will also assume that a simple straight-line depreciation is used. That is, each year, one-fifth of the equipment cost of $66,500, or $13,300, may be used as a tax depreciation. We will also assume that the corporation is in the 50 percent tax bracket. This means that for each $2 profit, $1 will be paid in taxes, and that for each $2 deduction, $1 in taxes will be saved. Finally, an inflation rate of 10 percent/year is assumed. This affects the labor savings, which will be increased by this amount each year.

The total cash flow analysis is shown in Table 7–1. In the starting year, year 0, the initial investment for the equipment and start-up costs is made. In the first year, called year 1, the effects of this investment begin to appear. The first item listed is a 10 percent tax credit for investing in capital equipment. Also, the start-up expense has been listed as a tax deduction, which results in a tax savings of $7050, since the corporation is in the 50 percent tax bracket. The equipment depreciation is also used as a deduction, resulting in a tax savings of $6650. The wages and benefits of the displaced worker provides a savings of $33,000, but half this amount, or $16,500, must be paid in taxes. Similarly, the production increase of $40,000 is considered income, so half of it, or $20,000, must also be paid in taxes. The maintenance expense of $2500 is listed as a deduction, resulting in a tax savings of $1250. Similarly, the energy expense of $2400 results in a tax savings of $1200. The total cash savings for the first year is $54,400. In the following years, the main difference is that the labor savings is increased by the assumed inflation rate. Note that, although the initial cost of the robot and start-up expenses were $80,600, the total savings over the 5-year period is $254,828.

Financial analysis also looks at two other quantities that may be determined from

Table 7–1 Cash Flow Analysis for an Industrial Robot Installation

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Initial investment	–66500					
Tax credit (10%)		6650				
Start-up expense	–14100					
Tax credit		7050				
Equipment depreciation		13300	13300	13300	13300	13300
Tax cost		–6650	–6650	–6650	–6650	–6650
Wages and benefits of replaced worker		33000	36300	39930	43923	48315
Tax cost		–16500	–18150	–19965	–21962	–24158
Productivity increase		40000	44000	48400	53240	58564
Tax cost		–20000	–22000	–24200	–26620	–29282
Maintenance expense		–2500	–2750	–3025	–3328	–3660
Tax credit		1250	1375	1513	1664	1830
Energy expense		–2400	–2640	–2904	–3194	–3514
Tax credit		1200	1320	1452	1597	1757
Annual cash savings		54400	44105	47851	51970	56502
		Average annual savings = $50,966				

Source: Ronald Tarvin.

the cash flow analysis. One is called the internal rate of return on the investment, which for this example is 56 percent. Another is the payback period, which is the reciprocal of the internal rate of return and is 1.79 years for this example. This value is determined by equating the total initial cost to the sum over the number of years of the equipment's lifetime of the cash savings for each year, divided by 1 plus the internal rate of return on the investment raised to the power corresponding to the year index. This involves an iterative calculation best done on a computer. The internal rate of return on investment may be interpreted as the average percentage return on the capital investment. Most companies would consider a rate of 56 percent a healthy investment.

Several other factors, such as the savings due to less reworking of the product and reduced materials costs from less scrap produced, could also be included in the analysis. Also, other intangible benefits, such as reduced costs of OSHA compliance, improved utilization of floor space, increased machine cycle rates, quicker new-run changeovers, and greater system flexibility, could become important.

This example illustrates the economic justification of a single industrial robot. Let's now consider the economics of a work cell that includes a robot and a sensor system, such as vision sensors, to see how the costs and justifications might change.

Let's imagine that we had an application requiring a two-shift operation of a materials-handling robot and a vision system. Furthermore, in this application, the two workers currently doing this job were retained. One was retrained to operate and program the robot. The other was transferred to another location in the plant to keep pace with the increased production rate made possible by the robot.

To evaluate the economics of the robot installation, the following assumptions were made: a 5-year, straight-line depreciation; a 5 percent rate of inflation per year; a 50 percent corporate tax rate; and no salvage value of the equipment after 5 years.

The initial investment expenses include

Industrial robot	$66,800
Gripper	4,000
Safety equipment	4,000
Vision sensor	40,000
Conveyors	5,000
Other fixtures	5,000
Total capital investment	$124,800

The start-up expenses are

Feasibility study (400 hr @ $20/hr)	$8,000
Engineering time (200 hr @ $20/hr)	4,000
Site preparation (80 hr @ $15/hr)	1,200
Installation (80 hr @ $80/hr)	1,600
Total installation costs	$14,800

In this application, no savings due to wages and benefits of replaced workers results. However, a considerable savings resulted from an increased production rate. In particular,

Parts per day increase	20
Working days per year	200
Amount per part	$50
Total productivity savings: $200,000	

The energy expense of the new equipment is

30 kW-hr × 0.04/kW-hr × 4000 hr/yr = $4800
Total power cost: $4800

For periodic maintenance, we again assume the cost to be 3.75 percent of the original equipment cost, or

$124,800 × 0.0375 = $4680
Total maintenance cost: $4680

In this example, we also include an equipment insurance expense of 5 percent of the equipment cost, or

$124,800 × 0.05 = $6240
Total insurance cost: $6240

We may now determine the cash flow analysis for the industrial robot installation. This is shown in Table 7–2.

The internal rate of return on the investment is again calculated by equating the initial investment of $138,800 to the sum of the cash savings per year, divided by 1 plus the internal rate of return raised to the power of the year.

The following BASIC program was used to calculate the internal rate of return, which was 80 percent, and the payback period of 1.24 years.

```
10    REM INTERNAL RATE OF RETURN
15    EMIN=999999
20    FOR I = 0 TO 1 STEP 0.001
30       E=139600-124500/(1+I)-109227/(1+I)**2
40       E=E-114064/(1+I)**3-119143/(1+I)**4-124475/(1+I)**5
50       IF ABS(E) < ABS(EMIN) THEN IR=I
60       IF ABS(E) < ABS(EMIN) THEN EMIN=E
70    NEXT I
80    PRINT "INT RATE OF RET";IR; "PAYBACK PERIOD";1/IR
90    END
```

Table 7–2 Cash Flow Analysis for Robot Visual Inspection Example

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Initial investment	–124,800					
Tax credit (10%)		12,480				
Start-up expense	–14,800					
Tax savings		7,400				
Depreciation		24,960	24,960	24,960	24,960	24,960
Tax cost		–12,480	–12,480	–12,480	–12,480	–12,480
Wage savings		0	0	0	0	0
Productivity increase		200,000	210,000	220,500	231,525	243,101
Tax cost		–100,000	–105,000	–110,250	–115,763	–121,551
Maintenance expense		–4,680	–4,914	–5,160	–5,418	–5,689
Tax savings		2,340	2,457	2,580	2,709	2,844
Insurance expense		–6,240	–6,552	–6,880	–7,224	–7,585
Tax cost		3,120	3,276	3,440	3,612	3,792
Energy expense		–4,800	–5,040	–5,292	–5,557	–5,834
Tax savings		2,400	2,520	2,646	2,779	2,917
Annual savings	–139,600	124,500	109,227	114,064	119,143	124,475
	Average annual savings = $118,282					

7.3 Economic Justification of a Work Cell

The industrial robot often serves as the central element in an automated work cell in which an entire product or assembly is produced. We will now briefly describe an example justification developed by Holmes (1979) to illustrate the economic justification of an entire work cell.

A comparison will be made between a manufacturing cell consisting of two manned CINTURN turning centers (TC) and one in which the identical turning centers are loaded and unloaded with a Cincinnati Milacron T3 robot and a single operator. The comparison will be made on a two-shift operation basis for a 1-year period. A table of the productivity factors for the two alternatives is given as follows.

	Human-operated	Robot
Available cut time	120 min/hr	120 min/hr
System attention	9 min/hr	12 min/hr
Efficiency	80%	90%
Total utilization	88.8 min/hr	97.2 min/hr

The available cutting time is simply the sum of the cutting times for both machines.

Loading and unloading the systems are reflected in the system attention times. The overall efficiency of the robot process is slightly greater than for the human-operated centers because of the greater consistency of the robot. The total utilization factors are determined by subtracting the attention time from the available time and then multiplying by the efficiency.

The next set of factors relate to the times involved in actually making a part.

Part cycle time (min)		
Load/unload	1.29	0.37
Cutting time	2.50	2.50
Total time (min)	3.79	2.87

Note that the robot can load and unload the turning center slightly faster than a human because it is in a fixed location. The cutting times are identical for both.

Next we include a fatigue factor.

Fatigue factor 1.04 1.00

This factor simply reflects the consistency of the robot compared with that of a human. The total time for producing the product can now be determined by multiplying the total machine time by the fatigue factor.

Total part time 3.94 min/piece 2.87 min/piece

We may now determine the throughput, or the number of pieces that can be produced per hour.

Throughput: Human-operated 22.5 pieces/hr; robot 33.9 pieces/hr

We now have enough data to determine the increased productivity, which is simply (33.9 – 22.5)/22.5, or 50.7 percent. This increase in productivity is as much as could be produced by an added turning center.

Let us now consider the factors that will lead us to the return on investment of the robot center. We will assume a labor cost of $8.25 per hour. Other factors, such as taxes and insurance, maintenance, energy, and tooling costs, will also be tabulated.

Annual operating cost, attended	**Three-TC operator attended**	**Two-TC robot**
Labor cost/year	$46,530	$15,510
Taxes and insurance	13,465	14,100
Maintenance	21,500	22,500
Power cost	10,500	8,800
Annual fixed tooling cost	1,500	1,000
Total	$93,555	$61,910

The equipment costs for three manually operated versus two robot turning centers will now be totaled.

Equipment	\$573,000	\$600,000
Installation (80 hr @ \$7.5/hr)	600	600
Total	\$573,600	\$600,600

The tax factors will now be added.

Investment tax credit (10% of capital equipment)	\$57,300	\$60,060

Maintenance will again be assumed to be 3.75 percent of the equipment costs.

Maintenance	\$21,500	\$22,500

Energy costs must also be added.

Energy costs	\$10,560	\$8800

Finally, taxes and insurance will be considered to be 2.35 percent of the capital investment.

Taxes and insurance	\$13,465	\$14,100

Enough information is now available to determine the payback period and rate of return on investment. The total equipment costs are \$516,012 for the three turning centers versus \$540,312 for the two centers and robot, for an increase of \$24,300 for the robot system. However, the annual operating costs are \$93,555 for the human-operated center versus \$61,910 for the robot center, for a savings of \$16,455 for the robot system. The cash payback period is 1.5 years, and the rate of return on investment is 65 percent for the automated work cell.

This example illustrates that the costs involved in a robot-centered work cell are substantial; however, the rate of return on this capital investment is quite attractive. Many costs not directly associated with the robot must be considered in the economic analysis. A combination of savings due to productivity increases, labor savings, increased efficiency, and greater cutting time make the robot work cell an attractive method.

An operator is still available for the robot work cell. The human's adaptability is now used to greater advantage in such tasks as ensuring that the raw materials supply for the cell is available, monitoring the process for tool breakage or other problems, and coordinating the off-line support to ensure the successful operation of the system.

7.4 Economic Considerations for the Automated Factory

We have now considered the justification of a single robot and an automated work cell. Recall that the capital investment for the single robot was about $80,000, but that for the automated work cell was about $540,000. We might expect that the costs of an automated factory will be substantially larger.

The factory of the future will include all the functions that must be accomplished in a discrete product-manufacturing plant, such as parts transport, inventory storage, processing, assembly, and inspection. However, these automated functions will be integrated into a consolidated system. A distributed computer information and control system will automatically route the raw materials through the plant to the warehouse. Robots will be used in materials handling, painting, welding, machine loading and unloading, and all major manipulative actions. Customer order information can be used to determine the proper routing of materials to fill the order. Inspection work will be done by industrial robot systems equipped with vision, tactile, and other sensors. Inspection will be done on a 100 percent basis rather than by sampling a small percentage from each batch. Humans will still be required to perform the management, operation, and maintenance functions.

Shunk et al. (1982) suggest that the factory of the future must be defined in terms of its systems. That is, the factories will be groups of manufacturing cells that work in conjunction with each other to perform the entire production's operations. Whereas most industries today use "islands of automation" in conjunction with human or fixed automation operations, these new factories will be composed entirely of flexible automation cells. The key to the success of these factories will be their tremendous potential for flexibility, efficiency, and effectiveness. The concept of such a factory must involve both hard-technology and soft-technology considerations. The hard-technology view concentrates on the actual production of the product; the soft-technology view concentrates on the communications needed for monitoring, controlling, and reporting the condition of the systems. In making such systems mesh in a successful manner, a critical factor is the amount of user involvement in defining the systems. Designers and potential users must be able to communicate effectively about such things as what functions are to be performed by what (or by whom), how the systems will interact, what information will be needed, and how people will need to interact with each system. In determining such systems, a simulation is strongly recommended. Computer-aided simulation can allow both designers and users to see how the systems will work before they are built, eliminating the need to redesign or scrap the systems after they have been built.

Questions

1. Determine the internal rate of return on the investment and payback period for an industrial robot system that requires an initial investment of $137,600 and produces annual cash savings in the first 5 years of $119,650, $109,833, $114,644, $119,696, and $125,001, respectively.

2. Determine the internal rate of return on the investment and payback period for a robot installation that requires an initial equipment investment of $65,200 and start-up costs of $14,400 and produces annual cash savings in the first 5 years of $54,400, $44,105, $47,871, $51,900, and $56,502, respectively.
3. List five benefits that frequently are achieved through the application of industrial robots.
4. If an industrial robot costs $53,000 and a 5-year straight-line depreciation with a first-year 20 percent acceleration, what is the total first-year depreciation?
5. In the first installation of an industrial robot at your plant, there seem to be several alternative courses of action. Discuss the prudence of the following options: building your own robot; selecting a proven task and application; selecting the task with the highest production volume; selecting the lowest priced available system; and disregarding the human relations aspects.
6. The initial investment and start-up expenses for an industrial robot installation do not include the cost of retraining. Why? Where should this cost be covered?