6

Applications of Industrial Robots

6.1 Basic Industries Involved in Manufacturing

The purpose of this chapter is to provide an introduction to manufacturing processes and describe some of the applications of robots in accomplishing these tasks. We will concentrate on proven applications of industrial robots to provide a basis for understanding how they have been used and how they can be used more widely in industry. We will see how robots may be used in all the manufacturing industries. However, to provide a reference point, let's first review the basic processes involved in manufacturing.

Manufacturing is the process by which goods are made available to us as consumers. It involves many industries. These industries concentrate on production. Production is the basic process of transforming raw materials into goods that have a value in the marketplace. The individual steps required are called production operations. Each step adds a certain value to the final product. A look at these basic industries will lead us to an understanding of the scope of applications in which robots are being used and may be used to increase productivity.

The basic industries are represented by public corporations whose stocks are traded on the major stock exchanges. These may be grouped into the following markets (Groover, 1982).

Advertising
Aerospace
Automotive
Beverages
Cement
Chemicals
Clothing
Construction

Drugs, soaps, cosmetics
Equipment and machinery
Financial (banks, investment and loan companies)
Foods (canned, dairy, meats, others)
Hospital supplies
Hotel/motel
Insurance
Metals
Natural resources
Paper
Publishing
Radio, television, motion pictures
Restaurant
Retail (food, department stores, others)
Shipbuilding
Textiles
Tire and rubber
Tobacco
Transportation (railroad, airline, trucking, others)
Utilities (electric power, natural gas, telephone)

The companies may also be grouped in several other ways. For our purpose let's first think of a division into companies that produce goods and those that produce services. Although great potentials exist for service-performing robots, we will concentrate on those used to produce goods. The following is Groover's list of goods-producing industries with representative companies listed.

These industries may also be divided into two groups: manufacturing industries and process industries. The manufacturing companies are identified with discrete items, such as cars, computers, machine tools, and the components for these items. The process industries are represented by the food products, chemicals, plastics, soaps, steel, and cement industries.

Robots have mainly been used in the manufacturing industries, as shown in the following table (Robotics, 1983, p. 165).

The RIA estimated that, by the end of 1982, 6300 industrial robots were in use in the United States. Of these, 2453 were used for welding, 1060 for machine loading and unloading, 875 in casting, 1300 in materials handling, 490 in painting and finishing, and the remaining 122 in assembly and other areas. Since the market is new, we may expect some of the distribution to change each year.

Another way to classify the industries is into the three categories of basic producer, converter, and fabricator. Together, then, these three types of industries form a chain in the transformation of raw materials into consumer products, from natural resource to basic producer to converter to fabricator to consumer.

The basic producers take the natural resources and transform these into raw materials used by the other firms. The converter takes the raw materials, such as steel

Basic industry	Representative industry
Aerospace	Boeing
Automotive	General Motors
Beverages	Coca-Cola
Building materials	U.S. Gypsum
Cement	Lone Star Enterprises
Chemicals	duPont
Clothing	Hanes
Drugs, soaps, cosmetics	Procter & Gamble
Equipment and machinery	
Agricultural	Deere
Construction	Caterpillar Tractor
Electrical	General Electric
Electronics	Hewlett-Packard
Household appliances	Maytag
Industrial	Ingersoll-Rand
Machine tools	Cincinnati Milacron
Office equipment, computers	IBM
Railroad equipment	Pullman
Steam generating	Combustion Engineering
Foods	
Canned foods	Green Giant
Dairy products	Borden
Meats	Oscar Mayer
Packaged foods	General Mills
Hospital supplies	American Hospital Supply
Metals	
Aluminum	Alcoa
Copper	Kennecott
Steel	U.S. Steel
Natural resources	
Coal	Pittston
Forest	Georgia-Pacific
Oil	Exxon
Paper	Kimberly Clark
Textiles	Burlington Industries
Tire and rubber	Goodyear

ingots, and performs the intermediate step of transforming them into industrial products and some consumer goods. For example, chemical firms convert petroleum products into plastics. The typical output of a converter is in a simple form. The third category of manufacturing firms is the fabricator. These companies assemble and fabricate final consumer products. The final products are either consumer goods or components for consumer goods. For example, automobiles and tires could be final products.

Application	United States (%)	Japan (%)
Welding	35	15
Machine loading	20	40
Foundry	15	
Painting	15	
Assembly	10	30
Other	5	15

Let us now restrict attention to manufacturing rather than process firms, and look at the fabrication firm in particular. The sequence of events between the reception of raw materials or components and the shipping of the final product is called the manufacturing cycle. Typical steps in this cycle are

1. Sales and marketing
2. Product design and engineering
3. Manufacturing engineering
4. Industrial engineering
5. Production planning and control
6. Manufacturing
7. Quality control
8. Shipping and inventory control

These steps vary with the type of industry, kind of product, company size, and management style; however, this division of responsibilities is traditional.

The manufacturing process can be summarized as consisting of four functions:

1. Materials processing and assembly
2. Materials handling and storage
3. Control—from the plant to the operations levels
4. Information system with a manufacturing data base to support the other activities

Materials processing includes those operations that transform a workpiece from one state of completion to another. Basic operations, such as metal casting and plastic molding, would be one step. Secondary processes, such as machining or pressworking, would be the next. Operations to enhance physical properties, such as heat treatment to strengthen metal parts, would be another. Finally, finishing operations, such as painting, polishing, or chrome plating, would be a final process on the workpiece.

Assembly and joining operations are the second type of manufacturing operation. Processes for fastening, such as using screws, nuts, and adhesives, welding, or soldering, might be used. In general, the assembly operations follow the processing operations.

Materials handling and storage is required to get the materials from one operation to another. A significant portion of the total time that a workpiece spends in the factory may be involved in this operation.

The control function can be divided into several levels. At the plant level, the control is concerned with the effective use of labor, proper utilization of resources, shipping products of good quality on time, and keeping plant operating costs at a minimum. At the process level, control involves achievement of performance objectives.

The information function is required to efficiently organize the production functions. A manufacturing data base, including material specifications, part drawings, bills of material, route sheets, tool inventory records, method description, production schedules, and inventory records, must be generated, maintained, and disseminated to support the plant operations.

Industrial robots have been used directly for the materials processing, assembly, and materials handling and storage operations. They may also be integrated into the overall control function of the plant and may directly call upon the information data base. Before considering the fundamental robot applications, let's briefly review the overall strategies that lead to efficient and effective manufacturing.

Groover describes certain fundamental strategies, which he calls automation strategies, that can be used to improve production. These are

1. Specialization of operations
2. Combined operations
3. Simultaneous operations
4. Integrated operations
5. Reduce setup times
6. Improved materials handling
7. Process control and optimization
8. Computerized manufacturing data base
9. Computerized manufacturing control

The realization of these automation strategies is called data-driven automation. The totally automated factory may require the use of all these strategies to provide a competitive edge in the worldwide market. Not surprisingly, manufacturing cost is the largest single factor in determining the selling price of a manufactured product. A typical breakdown (Kutcher, 1983) is

Manufacturing cost—40 percent
Marketing, sales, and administrative costs—25 percent
Profit—20 percent
Engineering costs—15 percent

A graph of the total costs as well as a finer breakdown of the manufacturing costs of a product is shown in Figure 6–1 and listed as

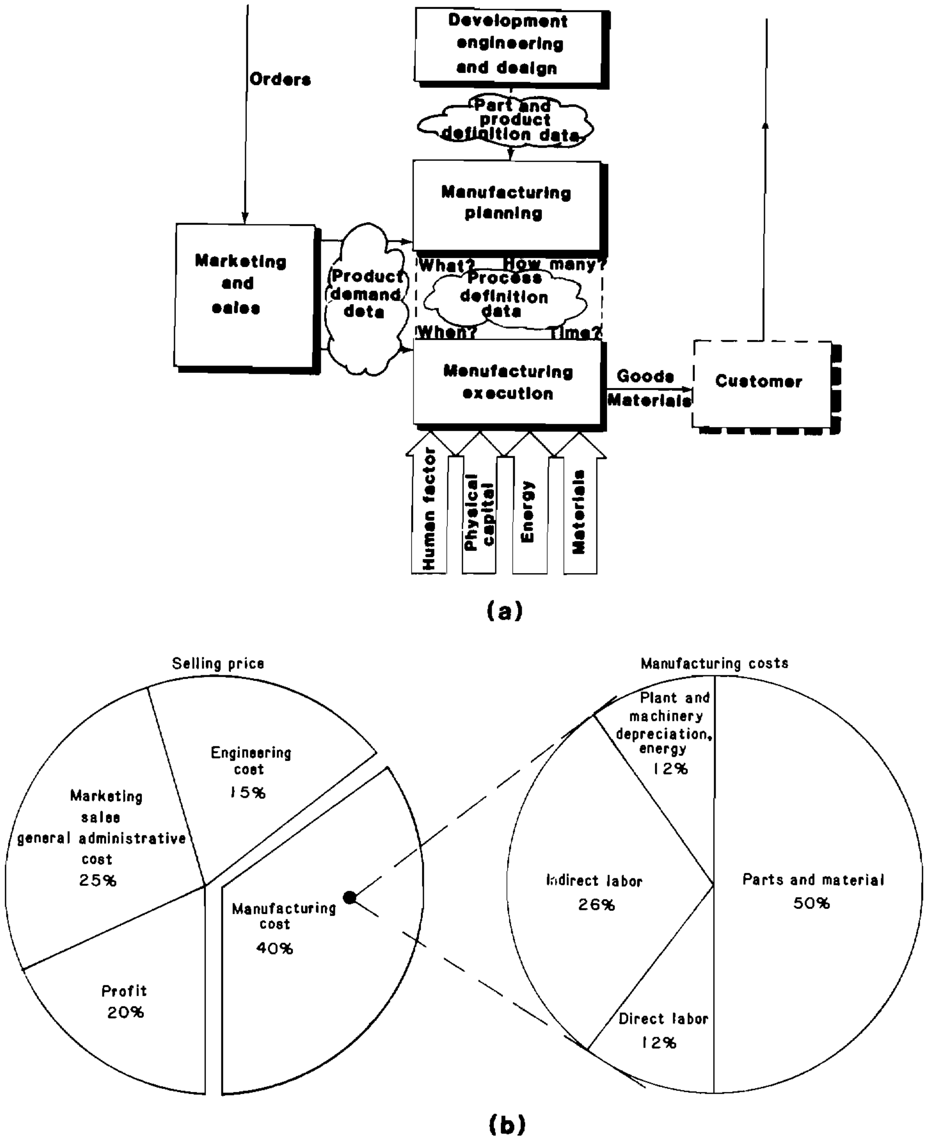


Figure 6–1. Production process and costs of manufacturing a product. (a) Data are both transferred and transformed in a manufacturing enterprise as they go from one entity to another. Product demand data and parts and product definition data are transferred to the planning function in manufacturing. It, in turn, transforms these data into process definition data, which tells the executive function how to produce the product. (b) Manufacturing costs is the largest single factor covering the selling price of a product in batch manufacturing. Direct labor is usually the target of automation but accounts for only 12 percent of manufacturing costs, even though many view it as the sole factor in increasing productivity. Data-driven automation, on the other hand, can dramatically cut all the costs shown. (Adapted from M. P. Groover, "Fundamental Operations," *IEEE Spectrum*, May 1983. Reprinted by permission, Copyright 1980 by IEEE.)

Parts and material—50 percent
Indirect labor—26 percent
Plant and machinery costs—12 percent
Direct labor—12 percent

Improving productivity and maintaining profitability can be accomplished by reducing costs in each of these categories: reducing waste, such as eliminating scrap material, increasing efficiency by automating all areas of the enterprise—white collar, as well as blue collar labor—and minimizing energy and maintenance expenses of the plant and machinery. The integration of computer-aided manufacturing (ICAM) is aimed at improving operations in all levels within the factory.

A research study group was recently established at the National Bureau of Standards to address the problems in manufacturing (McLean et al., 1983). Integration from the facility level to the shop level, the work cell, the work station, and finally to the equipment level is being considered. Each level has its own set of computer controllers for internal use as well as a connection to an overall communications network. Figure 6–2 illustrates the model of the National Bureau of Standards Automated Manufacturing

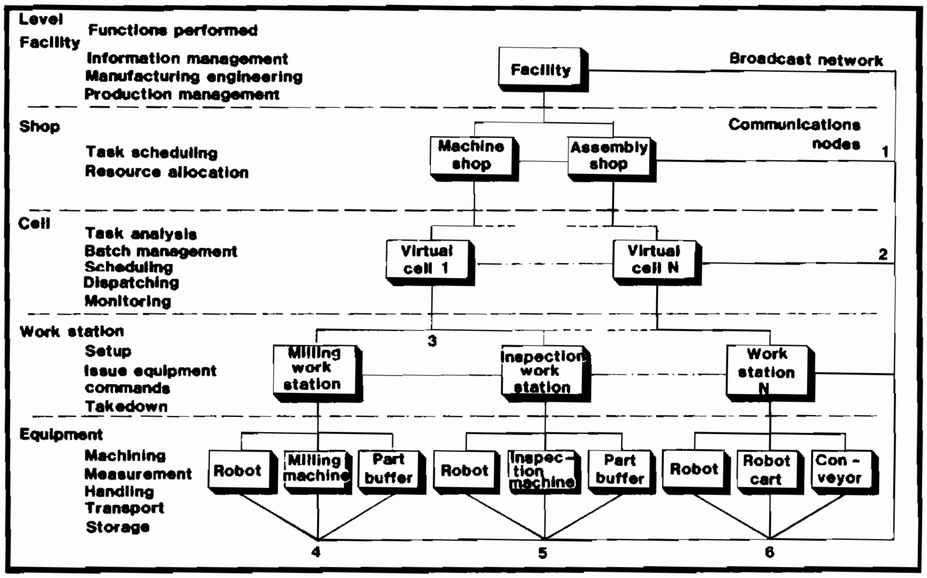


Figure 6–2. Block diagram of the National Bureau of Standards Automated Manufacturing Research Facility. The facility is divided into a five-level command hierarchy: facility, shop, cell, work station, and equipment. Each function box, be it machine shop, milling work station, or robot, has its own set of controllers for its internal control process. All the function boxes communicate along a facility broadcast system through communication nodes. (Adapted from C. McLean, M. Mitchell, and E. Barkmeyer, "A Computer Architecture for Small Batch Manufacturing," *IEEE Spectrum,* May 1983. Reprinted by permission, copyright by IEEE.)

Research Facility. Flexible manufacturing cells with robots are being developed. The entire process is coordinated by computer controllers and a data-administration system.

The overall tasks are divided so that individual work stations receive the parts or materials needed to produce the required product. The equipment included in a work station are the machinery and robots designed to perform the specialized tasks. Let's now consider the types of processing in more detail.

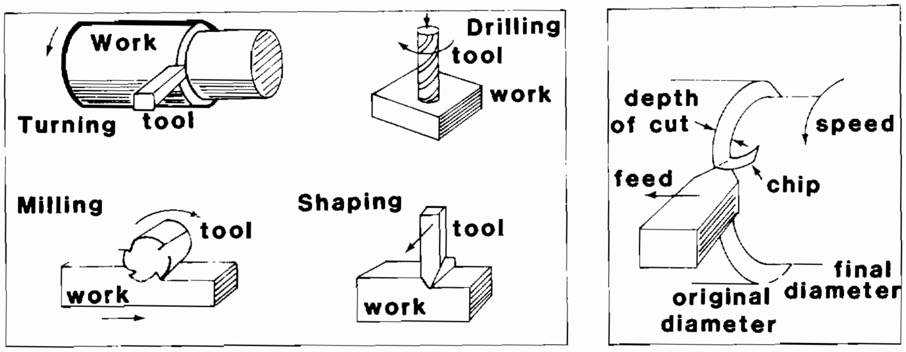
6.2 Fundamental Operations in Material Processing and Assembly

The basic manufacturing operations include machining, forming operations, such as founding and heat treatment, joining operations, such as spot and arc welding, assembly, inspection, and materials handling and storage. Industrial robots have been and are being integrated into the factory of the future in all these operations.

Machining

The machining process is at the very core of manufacturing. The four basic machining processes are turning, drilling, milling, and shaping. When used together, almost any contour can be produced on a workpiece. The turning operation can produce a cylindrical shape on the outside of a workpiece. Drilling can produce a cylindrical space inside the workpiece. Milling and shaping tools create planar surfaces. Modern machine tools are capable of accuracies measured in ten-thousandths of an inch. The speed, feed, and depth of cut determine the time required to produce a part. These three controls determine the rate at which materials are removed from the workpiece as chips or swarf. Figure 6–3a illustrates the four basic machining processes, and Figure 6–3b shows the three variables of speed, feed, and depth of cut for turning on a lathe. This rate is important, since it not only determines the productivity rate, but also the amount of tool wear. The depth of the cut is usually defined by the geometry of the workpiece. Therefore, the speed and feed are the primary control variables. The faster material is removed, the faster the tool wears. Since the tool bears a cost, and replacement takes time, a balance between material removal rate and tool wear must be maintained. High-performance cutting materials, such as tungsten carbide, are now used for making machine tools, and cutting rates of about 2500 feet/minute may be obtained for machine-soft metals.

Another set of operations called forming bends, squeezes, or stretches metal to impart new sizes or shapes, or both. In a forming operation, stresses are applied to deform the part plastically. Sheet metal bending is one example in which a punch and die bend the metal workpiece. Drawing is another forming operation that can be used to change the cross-sectional area of a workpiece by using a pulling motion. This process may be used for wire drawing or metal spinning. Extrusion is the process in which compression forces are used to change the cross section of a workpiece by squeezing it. Cold rolling also uses compressive forces to shape the workpiece. In hot forming operations, the workpiece is heated above its recrystallization temperature but below its melting point. The recrystallization temperature is that point above which the metal will



(a) (b)

Figure 6–3. Basic machining processes. (a) The four basic machining processes: turning, milling, drilling, and shaping. A combination of these processes can theoretically produce any desired shape on a workpiece. (b) In any of the basic machining processes, speed, feed, and depth of cut determine the productivity rate. The three variables are shown here for a turning operation on a lathe. (Adapted from M. P. Groover, "Fundamental Operations," *IEEE Spectrum,* May 1983. Reprinted by permission, copyright by IEEE.)

form larger, strain-free grains when it re-forms. Heat forming is usually employed with compressive processes. Cold forming is done below the recrystallization temperature to increase the strength of the material.

Presses are used for many metal forming operations. Shearing, which deforms a material past its breaking point, may be used to cut one portion of the material from another. Embossing may also be done on a press. Figure 6–4 illustrates some of these forming operations.

Some of the newer machining methods that have come into use are electric discharge, ultrasonics, chemical, and laser beam machining, and plasma-arc cutting. Electric discharge machining uses a highly concentrated, high-energy electric spark to remove metal. Ultrasonic machines direct abrasive particles in a liquid slurry against the workpiece surface. In chemical machining, corrosive substances that dissolve metal in a controlled manner are used. Laser beam machining uses a high-energy laser beam to make small, precise cuts. Finally, in plasma-arc cutting, high-temperature directed plasma beams are used to cut sheet and plate metal.

Robots may be used to perform these operations by moving a process tool, such as a laser, around the workpiece, or by moving the workpiece under the process tool. Let's now examine some robot applications in the materials processing area.

Processing of Raw Materials

The processing of raw materials into a form suitable for other manufacturing processes is the beginning of the production cycle. The melting and heat treatment of metals provide an excellent example of these processes. The melting and pouring of a substance, such as metal, into molds to set in the shape of the mold is called the "founding" process.

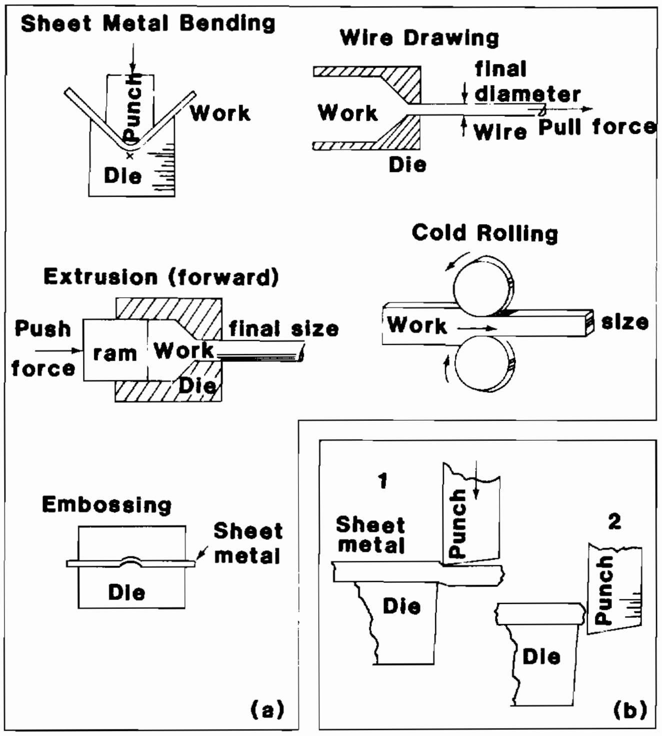


Figure 6–4. Basic forming operations. (a) Sheet metal bending, wire drawing, extrusion, cold rolling, and embossing are forming operations that bend, squeeze, or stretch metal to impart new sizes or shapes. (b) Shearing produced by a punch and die deforms metal beyond its breaking point, thereby separating one portion of metal sheet from another. (Adapted from M. P. Groover, "Fundamental Operations," *IEEE Spectrum,* May 1983. Reprinted by permission, copyright by IEEE.)

Founding is a primary manufacturing process. However, in terms of work environment, human operators may be required to work in high-temperature, noisy environments with noxious fumes, splashing molten metal, and large pieces of moving machinery that can be hazardous. Yet this is at the very start of the manufacturing cycle, and thus all later steps are dependent on it. Automobiles, farm machinery, and many other industries depend upon the materials supplied by foundries. Founding is ranked sixth in the United States on the basis of value added to the raw materials by the processes performed on it (Engleberger, 1980, p. 225). Robots are used to load and unload castings, presses, and many other machines for materials processing tasks.

Casting Process

The casting process consists of four main steps. First, the material is heated until it is molten. Then, it is poured into a mold. After the material has cooled, the mold is removed. Finally, the casting is finished. Finishing may involve removal of excess material or other operations.

Robots have been used in foundry applications for preparing the molds, ladling the materials into the molds, removing the castings, and for finishing operations, such as deflashing (Engelberger, 1980, Chap. 18).

Heat Treatment

Materials are often processed by heat treatment operations designed to modify the atomic structure to improve such characteristics as hardness, strength, ductility, or electrical conductivity. The process consists of placing the material in a furnace where it undergoes controlled heating, then removing the material and placing it in a location for controlled cooling.

Such parts as forgings, castings, or cold worked materials are often heat treated. The type of operation required may be a simple pick-and-place operation, which is easy for a robot. Furthermore, because of the high temperatures encountered, the work environment is more suited to robot rather than to human operation.

Robots are ideal for working in such high-temperature environments. One application is shown in Figure 6–5. In this example, which is from an International Harvester factory, harrow disks are heat treated to toughen the parts against breakage when struck by objects, such as rocks, when in use. In this operation three robots are used. Robot 1 stands at the entry conveyor system for the furnace. Its hand is equipped with a vacuum gripper. The gripper comes down vertically and lifts the top disk from a palletized stack of about 50 disks and transfers the disk to the conveyor, which carries it into the furnace. The furnace temperature is 1650 degrees Fahrenheit. If the robot hand finds no disk on the stack, the vacuum cup rests on the framework of the pallet, and a pneumatic pressure sensor terminates the program while a new stack of disks is moved into position. When this is accomplished, a signal restarts the program.

Robot 2 is equipped with a two-fingered gripper that grasps the disk on its outside diameter. As each disk emerges from the furnace it continues on the conveyor until it reaches a "pop-up" station, which positions it for the robot to pick up. A gating system holds subsequent disks until the pop-up station has dropped back into position. Robot 2 then picks up the disk, rotates 160 degrees, and loads it into the die of a press. Before the robot hand enters the press, three conditions must be met. First, the die must be open, which is indicated by a ram limit switch. Next, robot 3 must signal that it has removed the previous disk from the press. Finally, an infrared scanner must indicate that the disk has reached the proper operating range of 450 to 600 degrees Fahrenheit. If the sensor indicates that the disk is too hot or cold, robot 2 switches to a reject program. Robot 3 unloads the press and swings around to place the disk on the incoming conveyor of a washing and drying unit, which cleans off the solid salt remaining from the quench process.

This example clearly illustrates the effectiveness of robots in heat treatment processing.

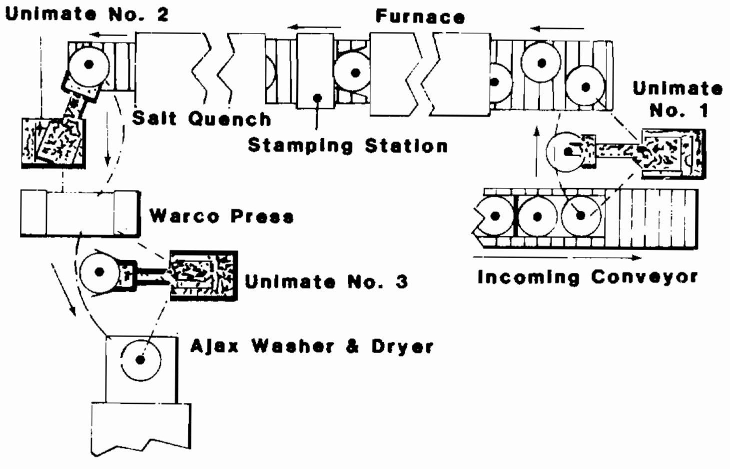


Figure 6–5. Diagram of the International Harvester facility using robots for heat treatment of harrow disks. (Courtesy of Joseph F. Engelberger.)

Welding Applications

Spot Welding. Welding is the most common robot application in the United States. Welding is the process of joining metallic parts by heating and allowing the metal to flow together or fuse. In spot welding, metal parts are joined at a number of small localized areas. This is accomplished by passing a large electric current at low voltage through the metals, which are held together under high pressure. The electric current generates heat from the work required to overcome the small but finite resistance of the metals being joined. In practice, the metals are clamped together with a high pressure between copper or copper-alloy electrodes, which conduct the welding current to the weld spot. As current flows from the power source, through the electrodes and through the workpiece, heat is generated at the point of contact. If the heat is sufficient to melt the materials, a fusion of the materials takes place. The amount of current and duration of flow must be controlled to provide high-quality welds. Poor-quality welds may have no fusion or may burn through. Modern spot-welding machines are equipped with automatic controllers that can be set up to perform the required sequence of weld operations. The sequence consists of a squeeze step in which the two electrodes are forced together with a pressure from 800 to 1000 pounds per square inch. Next, the weld step in which the current is turned on and flows through the materials is executed. Then, a hold step is performed in which the current is turned off but the tips are held together long enough for the materials to cool. Finally, a wait step is included in which the machine is turned off until the tips are cool enough for the next operation.

Spot welding is most suitable for ferrous metals, which are electrical conductors with enough resistance to generate the desired heat. Applications for spot welding include automobile bodies, appliance cases, and sheet metal fabrication. The spot-welding guns may weigh as much as 200 pounds since they include the heavy-duty movable electrodes, electrical cables capable of carrying as much as 1500 amperes of current, and often a coolant, such as water, for the electrodes. Spot welding requires positioning the welding gun perpendicular to the workpiece. This requires great dexterity but is ideally suited for a 6-degree-of-freedom industrial robot.

Robots for spot welding are widely used in the automotive industry. One example of a spot-welding system is shown in Figure 6–6. This application was developed for the Chrysler Newark assembly plant and uses a shuttle system that moves the automobile bodies off the main assembly line for the spot-welding operation. The shuttle line has seven stations with a total of 12 Unimate robots. The line is indexed so that the welding operations may be performed on stationary workpieces. Each robot performs a sequence of welds at its station. After the welding is completed the workpiece is transferred back to the moving line. One of the main advantages of robot welding in this application is in the consistency of the welds. Consistency permits a reduction of the number of weld locations in comparison with those required for human welds.

Another example of a spot-welding application is shown in Figure 6–7, which clearly shows the hazardous sparks generated in a spot-welding application.

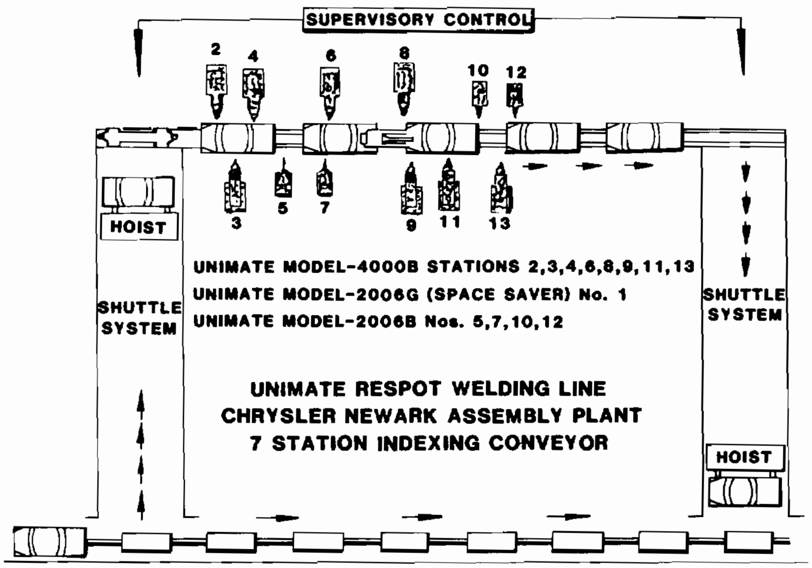


Figure 6–6. Example of spot and seam welding performed by Unimate robots at the Chrysler Newark assembly plant. A shuttle conveyor system is used to provide a stationary workpiece during the spot-welding operation and not slow down the assembly line. (Courtesy of Joseph F. Engelberger.)

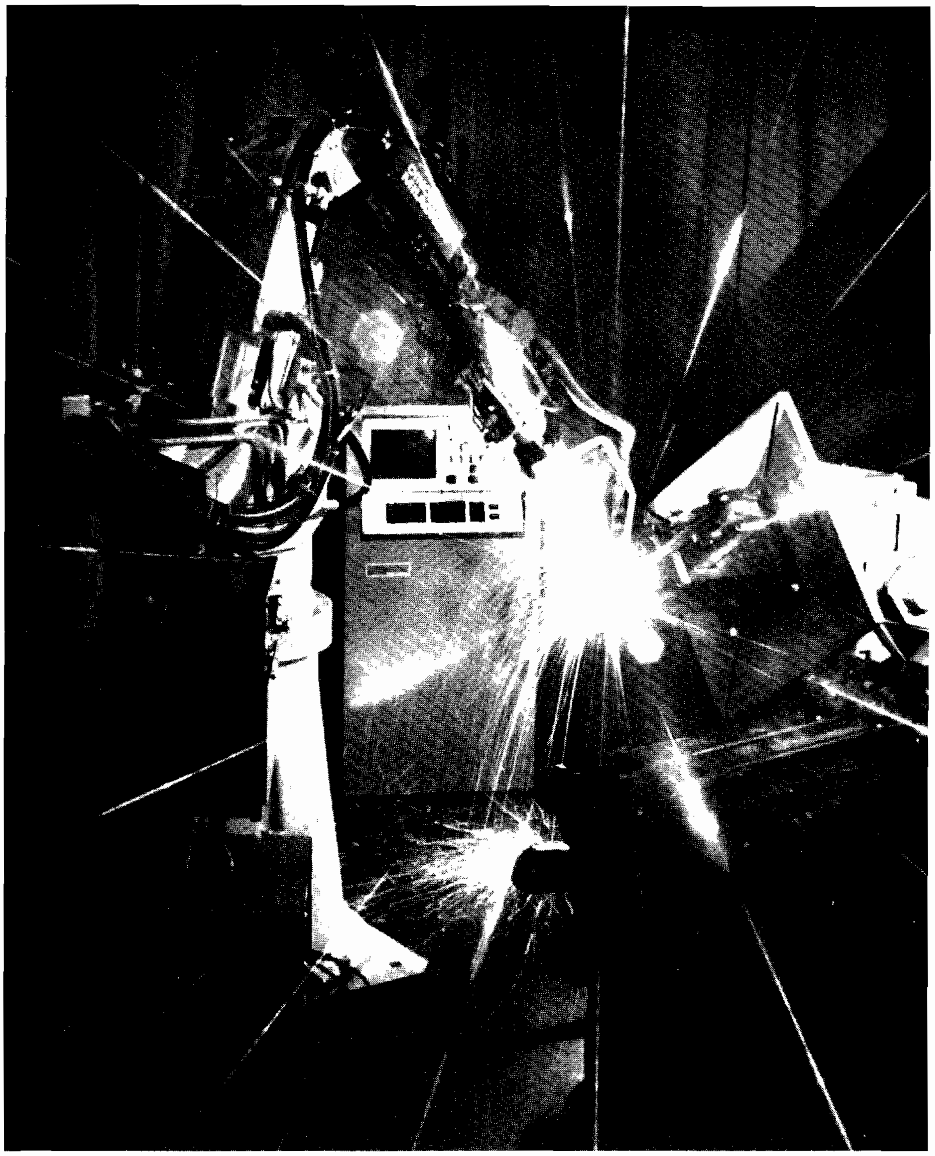


Figure 6–7. Cincinnati Milacron robot spot welding. (Courtesy of Cincinnati Milacron.)

Arc Welding. Whenever a gas-tight seal or a long path weld is required, spot welding is not appropriate. The arc-welding process can accomplish these procedures. The electric arc-welding process fuses the metal surfaces together with the heat generated by an electric arc between an electrode and the workpiece. The arc is generated between the two by connecting the workpiece to the power source so that it becomes the second electrode. The electric arc welder generally operates from a direct current source capable of supplying 100 to 200 amperes of current at 10 to 30 volts.

In manual operation, the operator connects the workpiece to one terminal of the supply with the electrode connected to the other. To start the arc, the operator touches the electrode to the workpiece. This essentially short-circuits the supply and starts a large current flow, which is accompanied by heat generation and sparking. The operator then withdraws the electrode a short distance and maintains an arc discharge. If the distance is too great, the arc stops. If the distance is too short, the electrode may stick to the workpiece.

By monitoring the voltage between the electrode and workpiece a signal can be obtained that may be used to regulate the distance. Before contact, this voltage will equal the supply voltage. Upon contact, the voltage drops to near zero. At the correct distance, an intermediate value of voltage is obtained.

For high-quality welds, the material in the weld pool must also be controlled. If the electrode is not made of a material similar to that of the workpiece and melts into the pool, an inconsistent weld may result. One solution is to use electrodes made of tungsten, which has a much higher melting temperature than the typical workpiece. However, if excess material is needed it must be added from a separate filler supply. Also, oxidation reactions with the molten materials must be avoided to prevent inconsistent weld density. One method used to prevent oxidation is to flood the weld pool with a flux or an inert gas, such as helium or argon.

The most commonly used method for arc welding on an assembly line is called metal inert gas (MIG) welding. This process uses a continuously fed metal electrode selected for the particular material to be welded to provide a filler material. Also, an inert gas surrounds the arc and weld pool to shield the pool from any oxidation reaction. The filler and gas are supplied by threading the electrode through a gas line. The control equipment feeds the wire at a selected rate and regulates the flow of the gas.

Proper arc welding requires accurate location of the welding gun along the weld path in position, orientation, and speed. A typical sequence of operations to perform a weld starts with a preflow condition in which the gas is turned on. Next, the weld period commences in which the wire feed is started and the power applied. After the weld is finished, a burn-back period is used in which the wire feed stops and the wire tip burns off until the distance is too great to sustain the arc. Next, a postflow period is started in which the power goes off with the gas flow continuing, permitting the weld to cool. Finally, the sequence is completed and the gas flow stops.

A Unimate apprentice robot is shown in Figure 6–8. Note that the operator, who is simply supervising the robot, must wear protective goggles to avoid the infrared radiation emitted by the arc and protective clothing to prevent burns. Also, since an ozone atmosphere is generated that cannot be breathed, using the robot permits the operator to work at a safe distance.

An ASEA robot is shown arc welding in Figure 6–9. Note that the operator is not in the hazardous environment. Next, a Hitachi welding robot is shown in Figure 6–10. This robot is one of a pair used to assemble, tack weld, and seam weld motor frames. The frame is a steel tube, which is moved into position in front of the robots by conveyors. One robot picks up the cooling fins, support braces, and conduit box mounting support

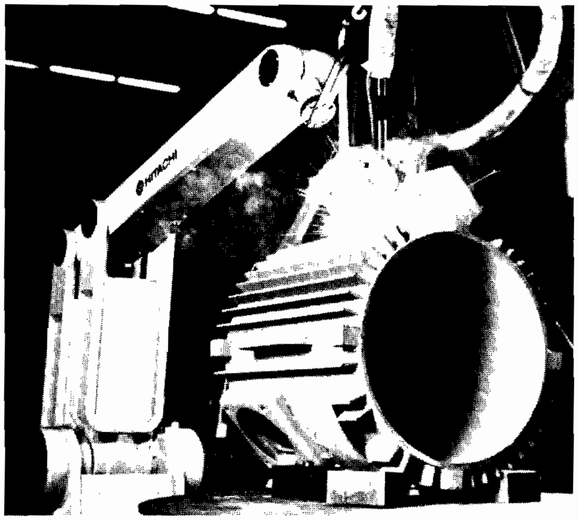


Figure 6–10. Hitachi robot seam welding. Over 500 hardworking Hitachi Process Robots have been installed in industrial applications, many of which have been arc welding. This photograph demonstrates a very good example of flexible automation. Shown is one of two Process Robots working as a team to assemble, tack weld, and then seam weld (5 to 200 horsepower) motor frames. A pretaught program for a particular frame size is selected at the touch of a button. The frame is a steel tube, which is moved into position in front of the Process Robots by conveyors. One robot picks up cooling fins, support braces, and the conduit box mounting support and locates the items one at a time on the tube frame. The other robot tack welds and then seam welds each item to the frame. Welds are high quality, which assures good heat transfer. The conveyor then removes the completed motor frame and brings the next tube. (Courtesy of Hitachi America, Ltd., Allendale, New Jersey.)

and locates the items one at a time on the tube frame. The robot shown tack welds and then seam welds each item to the frame. The completed motor frame is then placed on the outgoing conveyor. A Cincinnati Milacron robot is shown welding a curved metal flange of a pipe in Figure 6–11. The dexterity of the three-roll wrist and the controlled path motion are especially important in welding curved surfaces.

Assembly Operations

Discrete parts assembly is a growing application area for robots in the United States and is the largest application in Japan. Typical assembly operations include picking, placing, fastening, connecting, and using such tools as screwdrivers and wrenches. Assembly operations require greater repeatability and more sensors than most other applications. However, the advantages of consistent quality and improved production rates provide motivation for many applications.

The Cincinnati Milacron T3 726 robot is shown inserting screws in an assembly

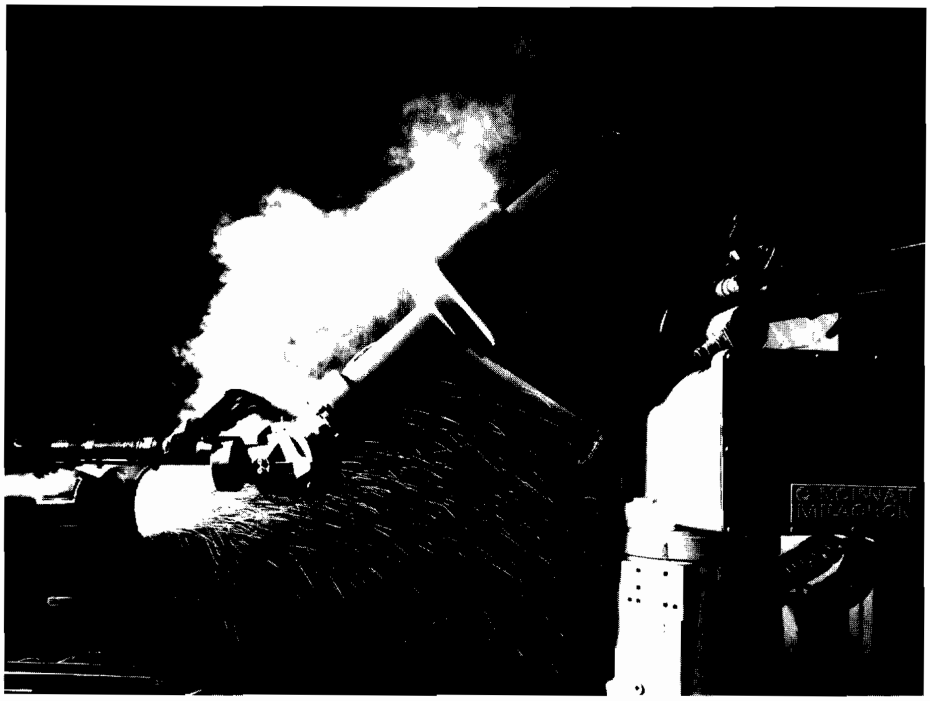


Figure 6–11. A Cincinnati Milacron welding robot. (Courtesy of Cincinnati Milacron.)

operation in Figure 6–12. The robot shown could work side by side with humans on an assembly line; however, humans could not maintain the speed of operation for this task. A General Electric robot is shown in a large part assembly application in Figure 6–13. In this application, the GP 132 robot is shown assembling the two major components of a Hotpoint refrigerator in the GE Cicero manufacturing plant. The parts are fed from two conveyor lines, and the GP 132 is mounted on a traversing base so that it can pick up moving parts and move between fixtures. In this application, the robot replaced the lifting task required by one person who removed liners from an overhead conveyor and two who placed the liner in the case.

Finishing Applications

Many finishing operations are also performed by robots. Sharp edges on objects are often produced in machining operations. A deburring operation is used to shape the edges of the workpiece to a given contour. This deburring operation is illustrated in Figure 6–14, which shows a Cincinnati Milacron T3 726 robot maneuvering an air-powered deburring tool around the complex contour of a housing. Polishing and buffing operations may also be accomplished.

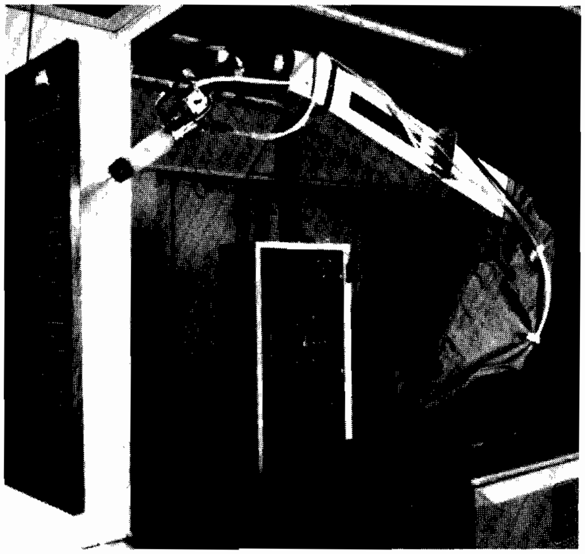


Figure 6–16. DeVilbiss/Trallfa robot painting metal shutters in a finishing operation. (Courtesy of DeVilbiss Co., Toledo, Ohio.)

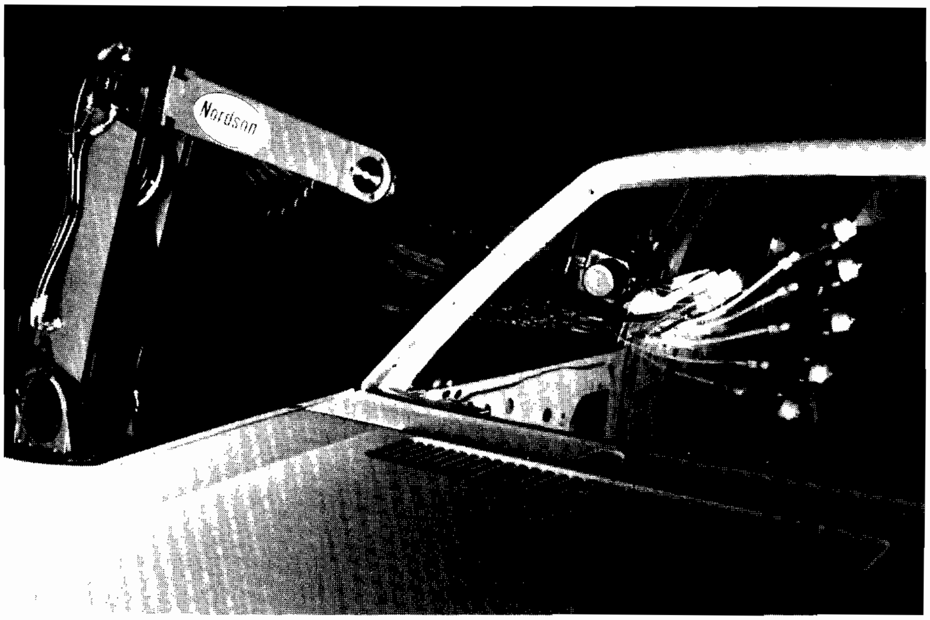


Figure 6–17. Nordson spray-painting robot. (Courtesy of Nordson Co., Amherst, Ohio.)

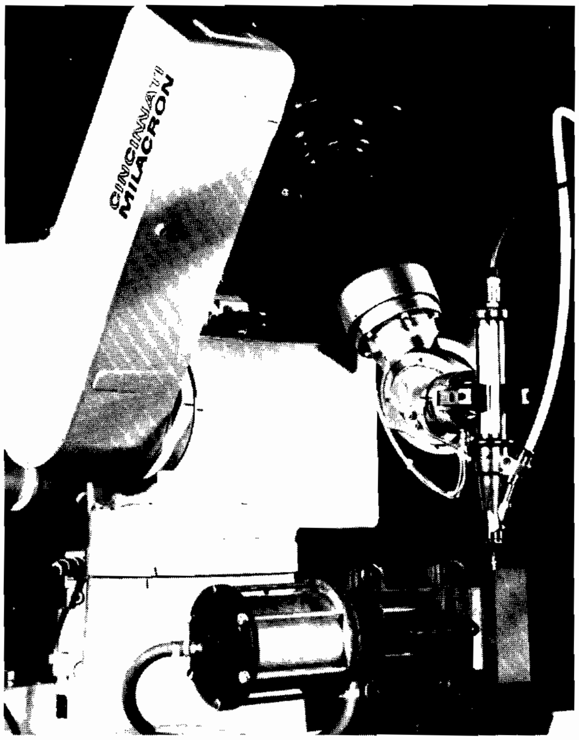


Figure 6–12. A Cincinnati Milacron robot using a screwdriver in an assembly operation. (Courtesy of Cincinnati Milacron.)

Spray painting is currently the largest finishing application for industrial robots. The spray-painting process is used to coat a surface with a liquid mixture, with a solid pigment suspended in the liquid. Painting may be used for protection or decoration. The technique and special fast-drying paints were developed in the automotive industry to provide a high-quality finish for this important mass-produced item.

In manual spray painting, the operator holds a pressurized spray gun, which is fed from a paint reservoir. The distance from the gun to the workpiece is critical, to provide an even coating and avoid runs. The operator usually moves the gun back and forth over the surface to apply thin coatings that build up to a layer of even thickness.

Spray-painting robots not only provide greater productivity by increasing throughput, but also reduce paint costs by eliminating wasted paint, reduce energy requirements by eliminating needless motion, reduce rejects by providing consistent quality, and increase production flexibility because of robot programmability.

Programming a spray-painting robot is often said to be done best by the best painter on the best day, as already mentioned. Continuous path motion is used to provide the control path for the robot. It is difficult for a human to repeat a continuous motion path.

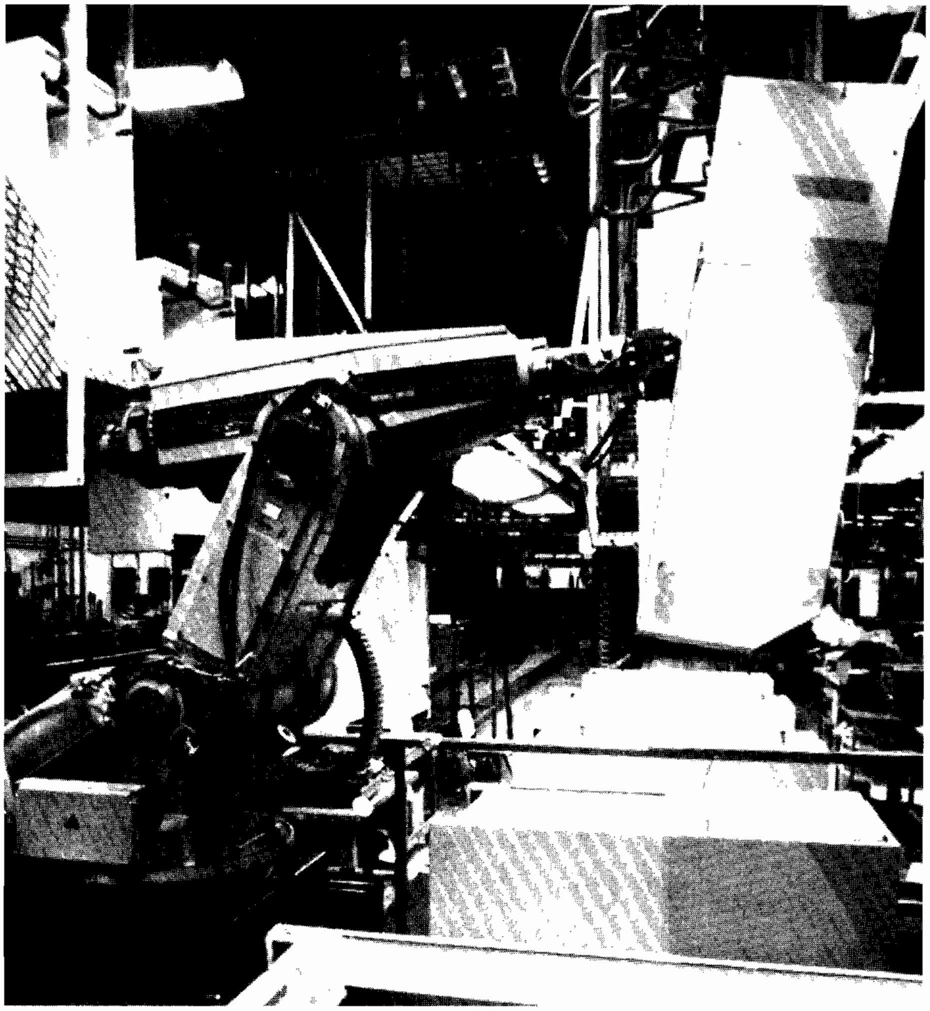


Figure 6–13. General Electric Company's GP 132 assembly robot. In this application, the GP 132 is assembling the two major sheet metal components of a Hotpoint refrigerator in the GE Cicero manufacturing facility. The parts are fed from two conveyor lines, and the GP 132 is mounted on a traversing base so it can pick up moving parts and move between fixtures. The two parts to be assembled are the liner and case. The liner is the white sheet metal part fed from an overhead conveyor and suspended on a swiveling hanger. The robot body moves along its traversing base to match the speed of the part on the conveyor as it removes the part from the hanger. An array of six vacuum suction cups grabs the liner and allows the robot to move it. After briefly stopping to align the liner in a stationary fixture, the robot then places it inside the case. The case is lifted above its conveyor line by hard automation (piston and cylinder and others) and held stationary during the insertion procedure. Inserting the liner is a delicate procedure since any side-to-side motion of the liner in the case would result in an unacceptable deformation or breakage of the Styrofoam seal on the inside edge of the case. The robot replaces one person who removed liners from the overhead conveyor and two who placed the liner in the case. The GP 132 is a six-axis, electric robot designed for loading and unloading, spot welding, palletizing, and other materials-handling applications. It can handle up to 132 pounds. (Courtesy of General Electric Co., Bridgeport, Connecticut.)

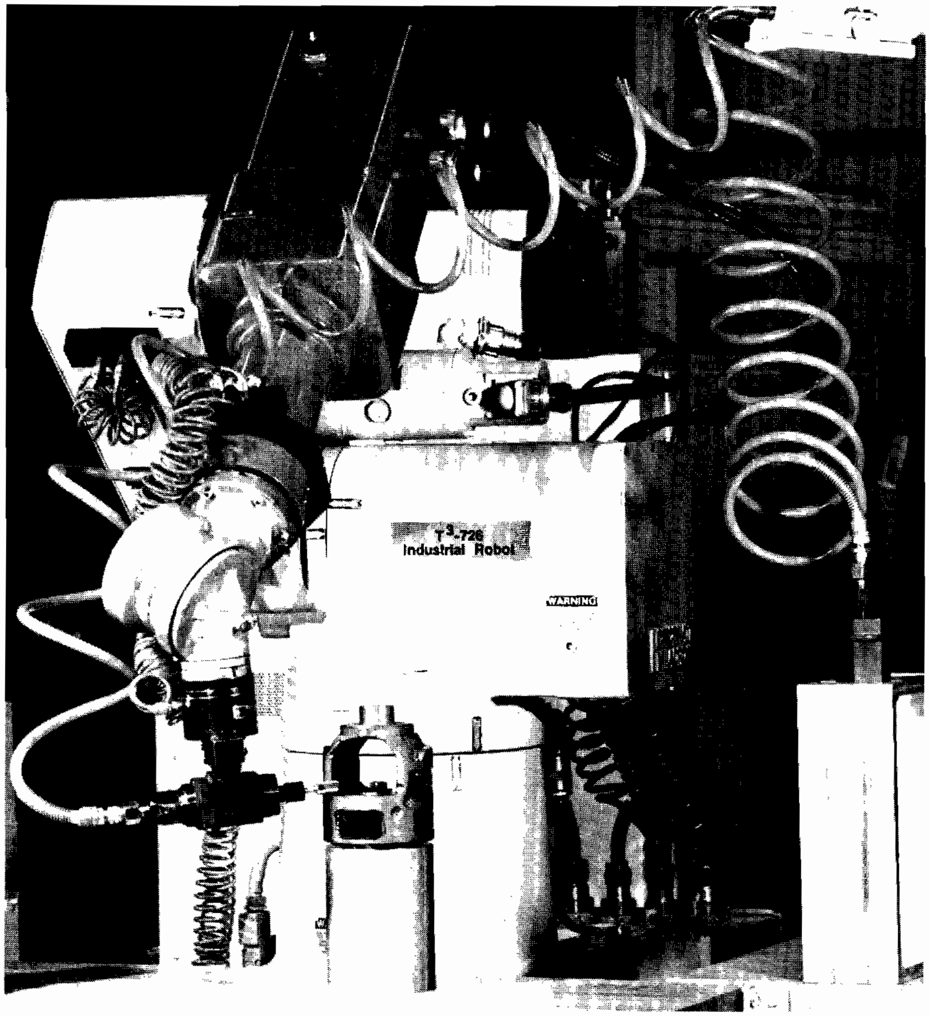


Figure 6–14. A Cincinnati Milacron robot used in a deburring operation. (Courtesy of Cincinnati Milacron.)

Automatic part identification and color changing may also be used in robotic spray painting, which eliminates the need for a human to be in the spray environment.

A typical layout of a spray-painting booth is shown in Figure 6–15. The robots may be enclosed in a booth with a controlled air supply in a compact arrangement that provides efficient use of floor space and protects humans from a hazardous environment. An important feature of the industrial robot in this application is its programmability. A continuous throughput can be maintained for a particular part once the operation is set up. However, even when the workpiece changes, only the program requires changing,

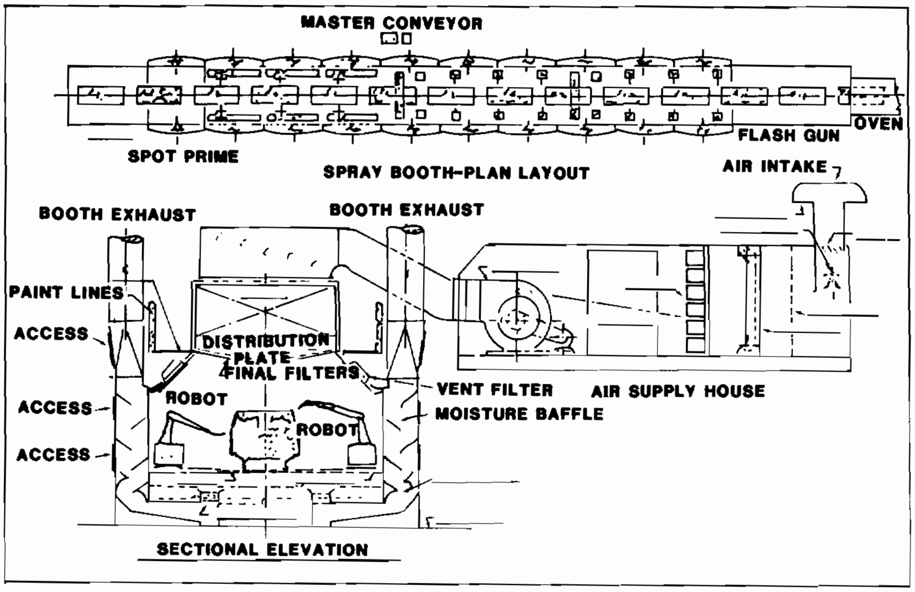


Figure 6–15. A spray-painting booth layout. (Courtesy of Joseph F. Engelberger.)

which is much easier than changing the major machines. Furthermore, much of the programming can be done off-line before the change and simply downloaded to the robot controller.

A DeVilbiss/Trallfa robot is shown in Figure 6–16, painting metal shutters in a finishing operation. The various positions of the spray gun are shown in Figure 6–17, in which a Nordson Company robot is stimulating painting the interior of an automobile.

6.3 Materials Handling and Storage Applications

Industrial robots are excellent for performing many materials handling and storage applications, such as machine loading and unloading, material transfer, palletizing, and bin picking. In many applications, back-breaking tasks for humans are easily done by a robot.

Machine Loading and Unloading

The general layout of a flexible manufacturing cell is shown in Figure 6–18. The robot is placed in the center with the machine tools within its work space. A cycle time analysis with various machine placements may be used to optimize the placements. Several machines are grouped around the robot because its operations are much faster than the operations of the machine tools. This clustering of machine tools around a central robot

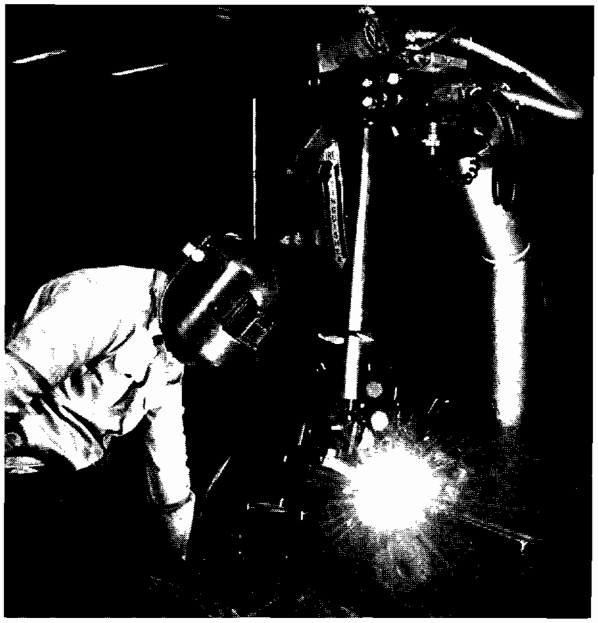


Figure 6–8. Unimate apprentice robot. (Courtesy of Joseph F. Engleberger.)

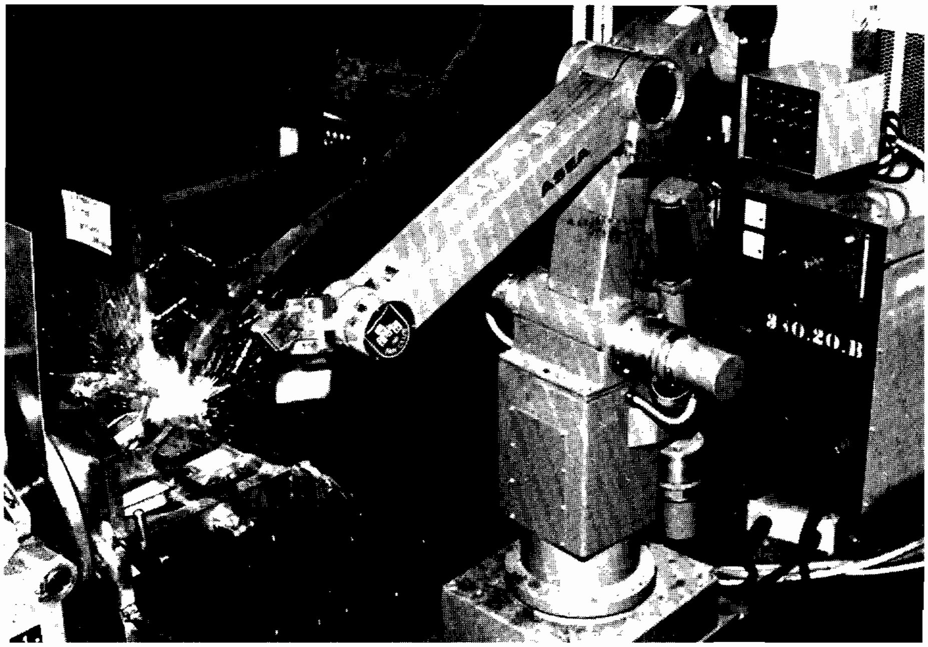


Figure 6–9. ASEA welding robot. (Courtesy of ASEA.)

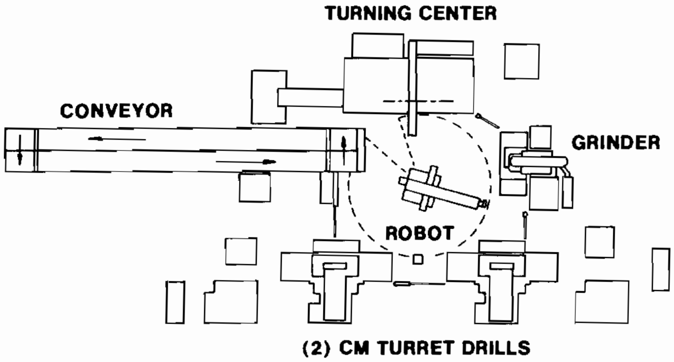


Figure 6–18. A diagram of a flexible manufacturing system. (Courtesy of Cincinnati Milacron.)

provides a flexible manufacturing operation not only because of the flexibility of the robot but also because modern machine tools also have great flexibility, including automatic tool changing. During operation, parts are fed from the incoming conveyor. The robot picks up the part and moves it through the desired cycle. At the completion of the processing, the robot places the finished part on the outgoing conveyor. An actual cell with Cincinnati Milacron robots and machine tools is shown in Figure 6–19.

A Prab Robots, Inc., robot performing machine loading and unloading operations as the central element in another flexible manufacturing cell is shown in Figure 6–20a. The robot is again capable of servicing several different machine tools, including three drilling and boring machines. The installation of this work cell was at the Fluid Power Operations of Eaton Corporation in Marshall, Michigan. The part to be machined was a 20-pound malleable iron casting used for a locking differential for three-quarter-ton trucks. A pair of bell-shaped housings arrive at the work cell on an indexing conveyor precisely oriented on a fixtured pallet for the robot to pick up. Photoelectric cells are used to communicate to the robot that parts are in position and ready to pick up. The machines are designed to pick up two housings at a time. To accomplish this, the robot's gripper was designed to pick up and simultaneously move two parts through the three machines.

The first machine performs a drilling operation. This is followed by a boring operation in the second machine. Both these machines require the parts to be oriented end to end with the housing sides exposed for machining. The third machine performs a drilling operation and requires the parts to be oriented side by side. The dual grippers mounted on a rotary cylinder attached to the robot arm accomplish this repositioning.

Following the last drilling operation, the robot moves the parts to an unloading fixture on an outgoing conveyor. The actual installation is also shown in Figure 6–20b. During the first 2 years of operation, productivity was increased by 60 percent, direct labor costs were reduced, and a back-breaking job was eliminated.

This example is typical of the many machine loading and unloading applications of the industrial robot. The robot is the central element of the flexible manufacturing cell.

Figure 6–19. An actual robot manufacturing cell consisting of two CINTURN NC turning centers, gaging station, incoming stop-station conveyor, and unload system. (Courtesy of Cincinnati Milacron.)

Palletizing

Palletizing is another important robot application. If the objects to be palletized are of the same type, an indexing program may be easily developed. An example is shown in Figure 6–21. This 19-foot-tall palletizing robot is capable of lifting 1300 pounds, which far exceeds the capability of a human. The robot shown is lifting heavy rolls of plastic.

Another palletizing example is shown in Figure 6–22. A vacuum gripper is used to lift containers and place them on a pallet. This heavy lifting task is easily accomplished by the heavy-duty Cincinnati Milacron T3 industrial robot. The programming for palletizing is also simplified by a special indexing feature in the T3 language. Palletizing fixed-size parcels, which are normally encountered in manufacturing, is a well-proven application of industrial robots.

Interestingly, if the parcels are of mixed size, shape, and weight, as may be encountered in the distribution stage, the problem is much more complicated. Sensors to determine these sizes and shapes are required. Also, an artificial intelligence algorithm for filling a three-dimensional space with these parcels is needed. The general form of

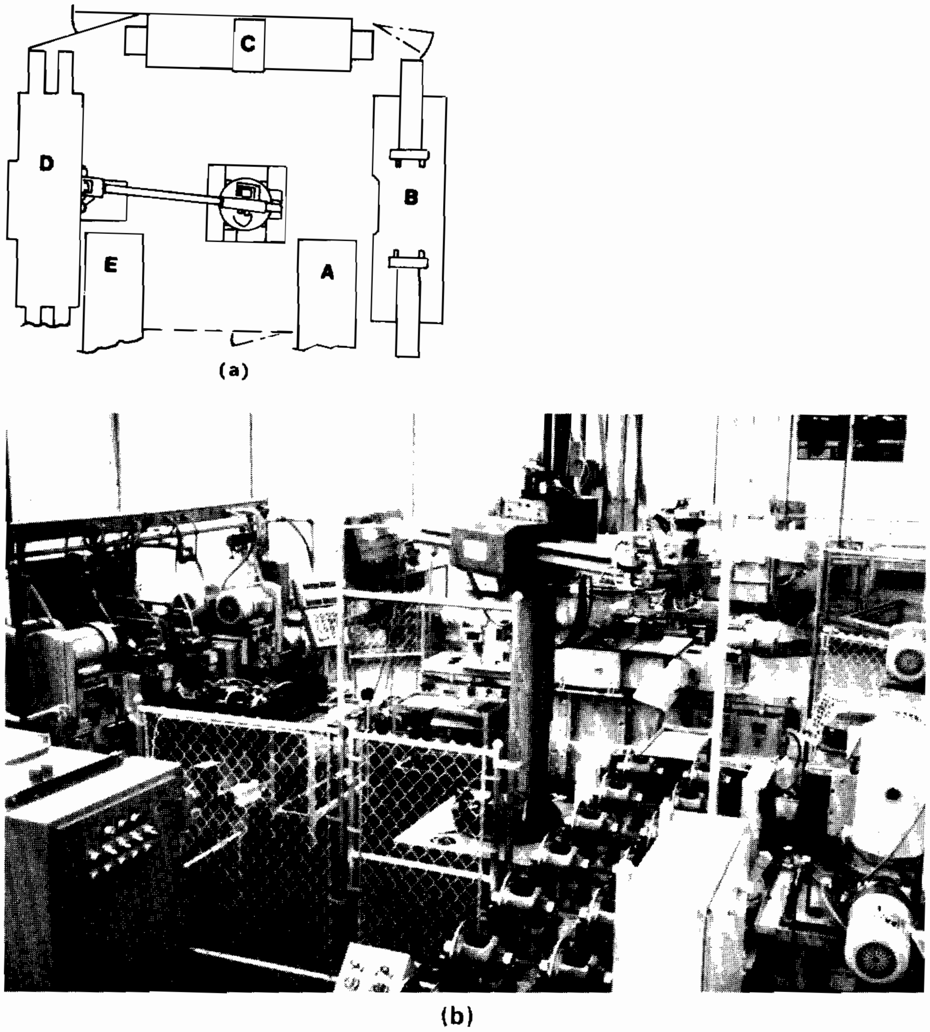


Figure 6–20. (a) Line drawing of a machine loading and unloading work cell. (b) Machine loading and unloading by a Prab Model FA robot. The work cell is installed at the Fluid Power Operations of Eaton Corporation in Marshall, Michigan. The part to be machined is a 20-pound malleable iron casting used for a locking differential for three-quarter-ton trucks. A pair of bell-shaped housings arrives at the work cell on an indexing conveyor precisely oriented on a fixtured pallet for the robot to pick up. Photoelectric cells communicate to the robot that the parts are in position and ready to pick up. The machines are designed to accept two housings at one time. Therefore, the robot's end effector is designed to pick up and move two parts simultaneously through the three machines. The first machine performs a drilling operation. This is followed by a boring operation by the second machine. The first two machines require identical positioning of the part, but the third machine performs a drilling operation requiring the parts to be oriented side by side. Between the second and third machines the parts are repositioned. The dual grippers mounted on a rotary cylinder attached to the robot arm are programmed to accomplish this repositioning. Following the last drilling operation, the robot moves the parts to an unloading fixture on an outgoing conveyor. The robot performs a sequence of 49 steps to complete the cycle. (Courtesy of Prab Robots, Inc., Kalamazoo, Michigan.)

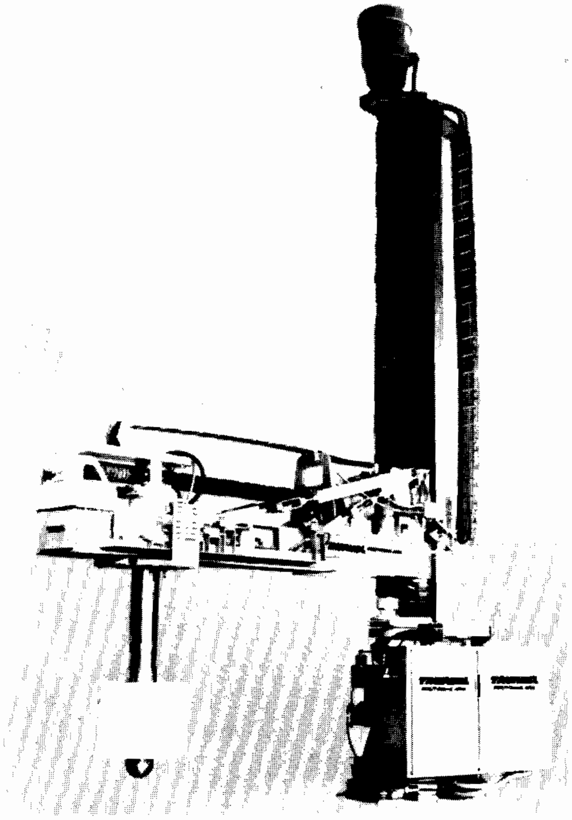


Figure 6–21. A materials handling robot. The Positech Corporation's Probot is a heavy-duty palletizing robot that can lift up to 1300 pounds and is 19 feet high. The robot has 100 inches of reach, 100 inches of lift, and 350 degrees of rotation for its cyclindrical coordinate design. In this picture, it is shown lifting plastic rolls at a factory in Belgium. (Courtesy of Positech Corp., Laurens, Iowa.)

this problem with arbitrary shapes to be fitted into a space is still unsolved mathematically. Interesting games are often made that are variations of the problem with a limited number of different sizes and shapes.

Bin Picking

Another interesting research problem in a materials handling application is called bin picking, which consists of selecting a single object from a bin of objects. Several interesting solutions to this problem have been developed by Professor Robert Kelley at the University of Rhode Island. One solution consists of using a special gripper, which

Figure 6–22. A Cincinnati Milacron HT3 robot stacking boxes in a palletizing operation. A special software function called index makes such operations easy to program. (Courtesy of Cincinnati Milacron.)

can pick up a single part and then move the part in front of a camera for recognition or inspection. A commercial realization is now being developed.

Questions

1. Select a simple manufacturing task of interest, and analyze the automation of the solution using a robotic work cell.
2. Visit a nearby manufacturing facility. Note the current and possible applications of robots.
3. Consider the process of manufacturing paper clips, starting with the raw ore and ending with the final delivery of cases to a distribution warehouse. Would robots be useful in this process? Where?