

1.0 AUTOMATION IN MANUFACTURING

MODULE-I

Automation is the technology by which a process or procedure is accomplished without human assistance. It is implemented using a *program of instructions* combined with a *control system* that executes the instructions. To automate a process, power is required, both to drive the process itself and to operate the program and control system. Although automation can be applied in a wide variety of areas, it is most closely associated with the manufacturing industries.

Automated manufacturing systems operate in the factory on the physical product. They perform operations such as processing, assembly, inspection, or material handling, in some cases accomplishing more than one of these operations in the same system. They are called automated because they perform their operations with a reduced level of human participation compared with the corresponding manual process. In some highly automated systems, there is virtually no human participation. Examples of automated manufacturing systems include:

- automated machine tools that process parts
- transfer lines that perform a series of machining operations
- automated assembly systems
- manufacturing systems that use industrial robots to perform processing or assembly operations
- automatic material handling and storage systems to integrate manufacturing operations
- automatic inspection systems for quality control

Thus, Automation is a technology concerned with the application of mechanical, electronic, and computer-based systems to operate and control production. This technology includes:

- Automatic machine tools to process parts
- Automatic assembly machines
- Industrial robots
- Automatic material handling and storage systems
- Automatic inspection systems for quality control
- Feedback control and computer process control
- Computer systems for planning, data collection, and decision making to support manufacturing activities

1.1 ELEMENTS OF AUTOMATED SYSTEM

An automated system consists of three basic elements:

- (1) *power* to accomplish the process and operate the system.
- (2) a *program of instructions* to direct the process, and
- (3) a *control system* to actuate the instructions.

The relationship amongst these elements is illustrated in Figure 1.1. All systems that qualify as being automated include these three basic elements in one form or another.

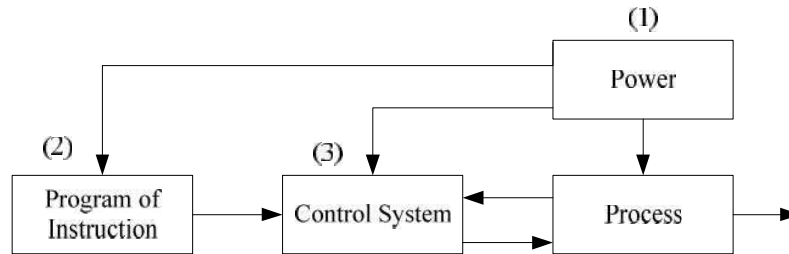


Figure 1.1 Elements of an automated system

(1) Power to accomplish the automated process

An automated system is used to operate some process, and power is required to drive the process as well as the controls. The principal source of power in automated systems is electricity. Electric power has many advantages in automated as well as non-automated processes

- Electrical power is widely available at moderate cost.
- Electrical power can be readily converted to alternative energy forms: mechanical, thermal, light, acoustic, hydraulic, and pneumatic.
- Electrical power at low levels can be used to accomplish functions such as signal, transmission, information processing, and data storage and communication.
- Electrical energy can be stored in long-life batteries for use in locations where an external source of electrical power is not conveniently available.

Power is required in automation for the followings:

- Processing operations
- Loading and unloading the work unit
- Material transport between operations
- Controller unit
- Power to actuate the control signals
- Data acquisition and information processing

(2) Program of Instructions

The actions performed in an automated process are defined by a program of instructions. Each part or product style made in the operation requires one or more processing steps that are unique to that style. These processing steps are performed during a work cycle. A new part is completed during each work cycle (in some manufacturing operations, more than one part is produced during the work cycle; e.g., a plastic injection molding operation may produce multiple parts each cycle using a multiple cavity mold). The particular processing steps for the work cycle are specified in a *work cycle program*.

Work Cycle Programs. In the simplest automated processes, the work cycle consists of essentially one step, which is to maintain a single process parameter at a defined level. However, the system becomes complicated when the process involves a work cycle consisting of multiple steps with more number of process parameters are required to be controlled. Most discrete part manufacturing operations are in this category.

Process parameters are inputs to the process such as temperature setting of a furnace, coordinate axis value in a positioning system, valve opened or closed in a fluid flow system, and motor on or off. Process parameters are distinguished from *process variables*, which are outputs from the process; for example, the actual temperature of the furnace, the actual position of the axis, the actual flow rate of the fluid in the pipe, and the rotational speed of the motor. As our list of examples suggests, the changes in process parameter values may be continuous (gradual changes during the processing step; for example, gradually increasing temperature during a heat treatment cycle) or discrete (stepwise changes; for example, on/off).

The work cycle may include manual steps, where the operator performs certain activities during the work cycle and the automated system performs the rest. A common example is the loading and unloading of parts by the operator to and from a numerical control machine between machining cycles where the machine performs the cutting operation under part program control. Initiation of the cutting operation of each cycle is triggered by the operator activating a "start" button after the part has been loaded.

Decision-Making in the Programmed Work Cycle. In automated work cycles the only two features are (1) the number and sequence of processing steps and (2) the process parameter changes in each step. Each work cycle consists of the same steps and associated process parameter changes with no variation from one cycle to the next. The program of instructions is repeated each work cycle without deviation. In fact, many automated manufacturing operations require decisions to be made during the programmed work cycle to cope with variations in the cycle. In many cases, the variations are routine elements of the cycle, and the corresponding instructions for dealing with them are incorporated into the regular part program. These cases include:

- *Operator interaction.* Although the program of instructions is intended to be carried out without human interaction, the controller unit may require input data from a human operator in order to function.
- *Different part or product styles processed by the System.* In this instance, the automated system is programmed to perform different work cycles on different part or product styles.
- *Variations in the starting work units.* In many manufacturing operations the starting work units are not consistent. A good example is a sand casting as the starting work unit in a machining operation. The dimensional variations in the raw castings sometimes necessitate an extra machining pass to bring the machined dimension to the specified value. The part program must be coded to allow for the additional pass when necessary.

In all of these examples, the routine variations can be accommodated in the regular *work* cycle program. The program can be designed to respond to sensor or operator inputs by executing the appropriate subroutine corresponding to the input. In other cases, the variations in the work cycle are not routine at all. They are infrequent and unexpected, such as the failure of an equipment component. In these instances, the program must include contingency procedures or modifications in the sequence to cope with conditions that lie outside the normal routine.

(3) Control System

The control element of the automated system executes the program of instructions. The control system causes the process to accomplish its defined function which is to carry out some manufacturing operation. The controls in an automated system can be either closed loop

or open loop. A *closed loop control system*, also known as a *feedback control system* is one in which the output variable is compared with an input parameter, and any difference between the two is used to drive the output into agreement with the input. As shown in Figure 1.2, a closed loop control system consists of six basic elements: (1) input parameter, (2) process, (3) output variable, (4) feedback sensor, (5) controller and (6) actuator.

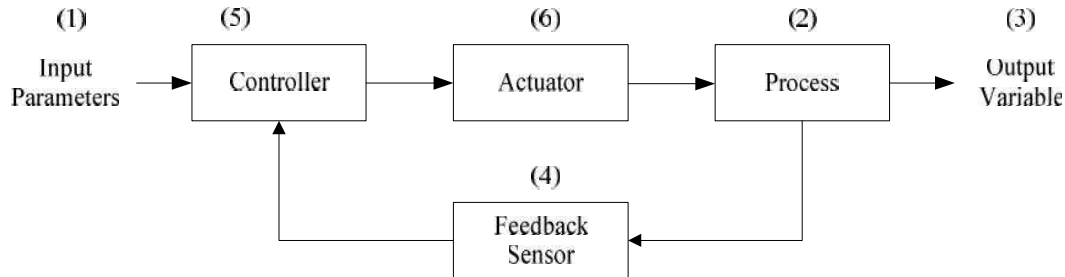


Figure 1.2 A feedback control system

The *input parameter* often referred to as the *set point*, represents the desired value of the output. The *process* is the operation or function being controlled. In particular, it is the *output variable* that is being controlled in the loop. A *sensor* is used to measure the output variable and close the loop between input and output. Sensors perform the feedback function in a closed loop control system. The controller compares the output with the input and makes the required adjustment in the process to reduce the difference between them. The adjustment is accomplished using one or more *actuators*, which are the hardware devices that physically carry out the control actions, such as an electric motor or a flow valve. The model in Figure 2 shows only one loop, however, most industrial processes require multiple loops, one for each process variable that must be controlled

In contrast to the closed loop control system, an *open loop control system* operates without the feedback loop, as in Figure 1.3. In this case, the controls operate without measuring the output variable so no comparison is made between the actual value of the output and the desired input parameter. The controller relies on an accurate model of the effect of its actuator on the process variable. With an open loop system, there is always the risk that the actuator will not have the intended effect on the process, and that is the disadvantage of an open loop system. Its advantage is that it is generally simpler and less expensive than a closed loop system. Open loop systems are usually appropriate when the following conditions apply: (1) The actions performed by the control system are simple, (2) the actuating function is very reliable, and (3) any reaction forces opposing the actuation are small enough to have no effect on the actuation. If these characteristics are not applicable, then a closed loop control system may be more appropriate.

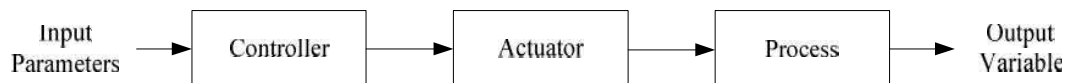


Figure 1.3 An open loop control system

1.3 ADVANCED AUTOMATION FUNCTIONS

In addition to executing work cycle programs, an automated system may be capable of executing advanced functions that are not specific to a particular work unit. In general, the functions are concerned with enhancing the performance and safety of the equipment. Advanced automation functions include the following: (1) safety monitoring, (2) maintenance and repair diagnostics, and (3) error detection and recovery.

Advanced automation functions are made possible by special subroutines included in the program of instructions. In some cases, the functions provide information only and do not involve any physical actions by the control system. An example of this case includes reporting a list of preventive maintenance tasks that should be accomplished. Any actions taken on the basis of this report are decided by the human operators and managers of the system and not by the system itself. In other cases, the program of instructions must be physically executed by means of the control system using available actuators. A simple example of this case is a safety monitoring system that sounds an alarm when a human worker gets dangerously close to the automated system.

(1) Safety Monitoring

One of the significant reasons for automating a manufacturing operation is to remove worker(s) from a hazardous working environment. An automated system is often installed to perform a potentially dangerous operation that would otherwise be accomplished manually by human workers. However, even in automated systems workers are still needed to service the system at periodic time intervals. If not full-time. Accordingly, it is important that the automated system be designed to operate safely when workers are in attendance. In addition it is essential that the automated system carry out its process in a way that is not self-destructive. Thus there are two reasons for providing an automated system with a safety monitoring capability: (1) to protect human workers in the vicinity of the system and (2) to protect the equipment associated with the system. It should be mentioned that a given safety monitoring system is limited in its ability to respond to hazardous conditions by the possible irregularities that have been foreseen by the system designer. If the designer has not anticipated a particular hazard, and consequently has not provided the system with the sensing capability to detect that hazard, then the safety monitoring system cannot recognize the event if and when it occurs.

(2) Maintenance and Repair Diagnostics

Modern automated production systems are becoming increasingly complex and sophisticated, thus complicating the problem of maintaining and repairing them. *Maintenance and repair diagnostics* refers to the capabilities of an automated system to assist in the identification of the source of potential or actual malfunctions and failures of the system. Three modes of operation are typical of a modern maintenance and repair diagnostics subsystem.

- *Status monitoring*: In the status monitoring mode, the diagnostic subsystem monitors and records the status of key sensors and parameters of the system during normal operation. On request, the diagnostics subsystem can display any of these values and provide an interpretation of current system status, perhaps warning of an imminent failure.
- *Failure diagnostics*: The failure diagnostics mode is invoked when a malfunction or failure occurs. Its purpose is to interpret the current values of the monitored values and to analyze the recorded values preceding the failure so that the cause of the failure can be identified.
- *Recommendation of repair procedure*: The subsystem provides a recommended procedure to the repair crew as to the steps that should be taken to effect repairs.

Methods for developing the recommendations are sometimes based on the use of expert systems in which the collective judgments of many repair experts are pooled and incorporated into a computer program that uses artificial intelligence techniques.

Status monitoring serves two important functions in machine diagnostics: (1) providing information for diagnosing a current failure and (2) providing data to predict a future malfunction or failure. First, when a failure of the equipment has occurred, it is usually difficult for the repair crew to determine the reason for the failure and what steps should be taken to make repairs. It is often helpful to reconstruct the events leading up to the failure. The computer is programmed to monitor and record the variables and to draw logical inferences from their values about the reason for the malfunction. This diagnosis helps the repair personnel make the necessary repairs and replace the appropriate components.

This is especially helpful in electronic repairs where it is often difficult to determine on the basis of visual inspection which components have failed. The second function of status monitoring is to identify signs of an impending failure, so that the affected components can be replaced before failure actually causes the system to go down. These part replacements can be made during the night shift or other time when the process is not operating with the result that the system experiences no loss of regular operation.

(3) Error Detection and recovery

In the operation of any automated system, there are hardware malfunctions and unexpected events that occur during operation. These events can result in costly delays and loss of production until the problem has been corrected and regular operation is restored. Traditionally equipment malfunctions are corrected by human workers, perhaps with the aid of maintenance and repair diagnostics subroutine. With the increased use of computer control for manufacturing processes, there is a trend toward using the control computer not only to diagnose the malfunctions but also to automatically take the necessary corrective action to restore the system to normal operation. The term *error detection and recovery* is used when the computer performs these functions,

Error Detection: As indicated by the term error detection and recovery consists of two steps: (1) error detection and (2) error recovery. The *error defection* step uses the automated system's available sensor systems to determine when a deviation or malfunction has occurred, correctly interpret the sensor signal(s), and classify-the error. Design of the error detection subsystem must begin with the classification of the possible errors that can occur during system operation. The errors in a manufacturing process tend to be very application specific. They must be anticipated in advance in order to select sensors that will enable their detection

In analyzing a given production operation, the possible errors can be classified into one of three general categories:

- (1) random errors,
- (2) systematic errors, and
- (3) aberrations,

Random errors occur as a result of the normal stochastic nature of the process. These errors occur when the process is in statistical control. Large variations in part dimensions, even when the production process is in statistical control, can cause problems in downstream operations. By detecting these deviations on a part-by-part basis, corrective action can be taken in subsequent operations.

Systematic errors are those that result from some assignable cause such as a change in raw material properties or a drift in an equipment setting. These errors usually cause the product to deviate from specifications so as to be unacceptable in quality terms.

The third type of error *aberrations*, results from either an equipment failure or a human mistake. Examples of equipment failures include fracture of a mechanical shear pin, bursts in a hydraulic line, rupture of a pressure vessel, and sudden failure of a cutting tool. Examples of human mistakes include errors in the control program, improper fixture setups, and substitution of the wrong raw materials,

The two main design problems in error detection are: (1) to anticipate all of the possible errors that can occur in a given process and (2) to specify the appropriate sensor systems and associated interpretive software so that the system is capable of recognizing each error. Solving the first problem requires a systematic evaluation of the possibilities under each of the three error classifications. If the error has not been anticipated, then the error detection subsystem cannot correctly detect and identify it.

Error recovery: It is concerned with applying the necessary corrective action to overcome the error and bring the system back to normal operation. The problem of designing an error recovery system focuses on devising appropriate strategies and procedures that will either correct or compensate for the variety of errors that can occur in the process. Generally, a specific recovery strategy and procedure must be designed for each different error. The types of strategies can be classified as follows:

1. *Make adjustments at the end of the current work cycle.* When the current work cycle is completed, the part program branches to a corrective action subroutine specifically designed for the error detected, executes the subroutine, and then returns to the work cycle program. This action reflects a low level of urgency and is most commonly associated with random errors in the process.
2. *Make adjustments during the current cycle.* This generally indicates a higher level of urgency than the preceding type. In this case, the action to correct or compensate for the detected error is initiated as soon as the error is detected. However, it must be possible to accomplish the designated corrective action while the work cycle is still being executed.
3. *Stop the process to invoke corrective action.* In this case, the deviation or malfunction requires that the execution of the work cycle be suspended during corrective action. It is assumed that the system is capable of automatically recovering from the error without human assistance. At the end of the corrective action, the regular work cycle is continued.
4. *Stop the process and call for help.* In this case, the error requiring stoppage of the process that cannot be resolved through automated recovery procedures. This situation arises because: (1) the automated cell is not enabled to correct the problem or (2) the error cannot be classified into the predefined list of errors. In either case, human assistance is required to correct the problem and restore the system to fully automated operation.

Error detection and recovery requires an interrupt system. When an error in the process is sensed and identified, an interrupt in the current program execution is invoked to branch to the appropriate recovery subroutine. This is done either at the end of the current cycle (type 1 above) or immediately (types 2, 3, and 4). At the completion of the recovery procedure, program execution reverts back to normal operation.

1.4 LEVELS OF AUTOMATION

The concept of automated systems can be applied to various levels of factory operations. One normally associates automation with the individual production machines. However, the production machine itself is made up of subsystems that may themselves be automated.

For example, a modern numerical control (NC) machine tool is an automated system. However, the NC machine itself is composed of multiple control systems. Similarly, a NC machine is often part of a larger manufacturing system, and the larger system may itself be automated. Thus there are various levels of automation is depicted in Figure 1.4.

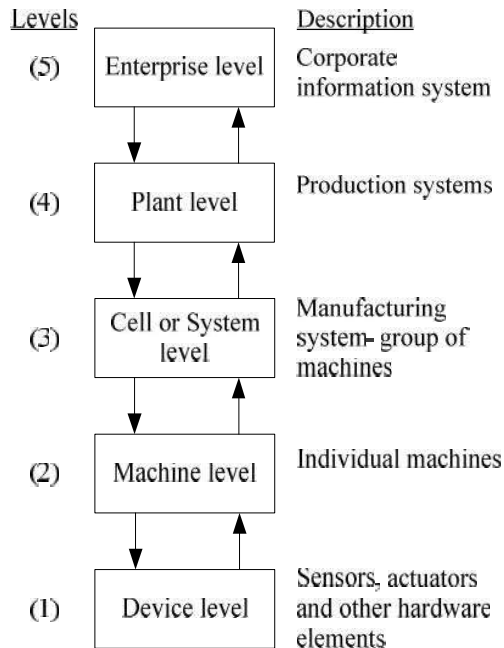


Figure 1.4 Level of automation

1. *Device level.* This is the lowest level in automation hierarchy. It includes the actuators, sensors, and other hardware components that comprise the machine level. The devices are combined into the individual control loops of the machine; for example, the feedback control loop for one axis of a CNC machine or one joint of an industrial robot.
2. *Machine level.* Hardware at the device level is assembled into individual machines. Examples include CNC machine tools and similar production equipment, industrial robots, powered conveyors, and automated guided vehicles. Control functions at this level include performing the sequence of steps in the program of instructions in the correct order and making sure that each step is properly executed.
3. *Cell or system level.* This is the manufacturing cell or system level, which operates under instructions from the plant level. A manufacturing cell or system is a group of machines or workstations connected and supported by a material handling system, computer and other equipment appropriate to the manufacturing process. Production lines are included in this level. Likely functions include part dispatching and machine loading, coordination among machines and material handling system, and collecting and evaluating inspection data.

4. *Plant level.* This is the factory or production systems level. It receives instructions from the corporate information system and translates them into operational plans for production. Likely functions include: order processing, process planning, inventory control, purchasing, material requirements planning, shop floor control, and quality control.
5. *Enterprise level.* This is the highest level consisting of the corporate information system. It is concerned with all of the functions necessary to manage the company: marketing and sales, accounting, design, research, aggregate planning, and master production scheduling.

1.5 TYPES OF AUTOMATION

Automated production systems are classified into three basic types:

1. Fixed automation
2. Programmable automation
3. Flexible automation

Fixed automation

Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration. The operations in the sequence are usually simple. It is the integration and coordination of many such operations into one piece of equipment that makes the system complex. The typical features of fixed automation are:

- High initial investment for custom-engineered equipment
- High production rates
- Relatively inflexible in accommodating product changes

The economic justification for fixed automation is found in products with very high demand rates and volumes. The high initial cost of the equipment can be spread over a very large number of units, thus making the unit cost attractive compared to alternative methods of production.

Programmable automation

In programmable automation, the production equipment is designed with the capability to change the sequence of operations to accommodate different product configurations. The operation sequence is controlled by a program, which is a set of instructions coded so that the system can read and interpret them. New programs can be prepared and entered into the equipment to produce new products. Some of the features that characterize programmable automation include:

- High investment in general-purpose equipment
- Low production rates relative to fixed automation
- Flexibility to deal with changes in product configuration
- Most suitable for batch production

Automated production systems that are programmable are used in low and medium-volume production. The parts or products are typically made in batches. To produce each new batch of a different product, the system must be reprogrammed with the set of machine instructions that correspond to the new product. The physical setup of the machine must also be changed over: Tools must be loaded, fixtures must be attached to the machine table, and the required machine settings must be entered. This changeover procedure takes time. Consequently, the

typical cycle for a given product includes a period during which the setup and reprogramming takes place, followed by a period in which the batch is produced.

Flexible automation

Flexible automation is an extension of programmable automation. The concept of flexible automation has developed only over the last 15 to 20 years, and the principles are still evolving. A flexible automated system is one that is capable of producing a variety of products (or parts) with virtually no time lost for changeovers from one product to the next. There is no production time lost while reprogramming the system and altering the physical setup (tooling, fixtures and machine settings). Consequently, the system can produce various combinations and schedules of products, instead of requiring that they be made in separate batches. The features of flexible automation can be summarized as follows:

- High investment for a custom-engineered system
- Continuous production of variable mixtures of products
- Medium production rates
- Flexibility to deal with product design variations

The essential features that distinguish flexible automation from programmable automation are (1) the capacity to change part programs with no lost production time, and (2) the capability to change over the physical setup, again with no lost production time. These features allow the automated production system to continue production without the downtime between batches that is characteristic of programmable automation. Changing the part programs is generally accomplished by preparing the programs offline on a computer system and electronically transmitting the programs to the automated production system. Therefore, the time required to do the programming for the next job does not interrupt production on the current job. Changing the physical setup between parts is accomplished by making the changeover offline and then moving it into place simultaneously as the next part comes into position for processing. The use of pallet fixtures that hold the parts and transfer into position at the workplace is one way of implementing this approach. For these approaches to be successful, the variety of parts that can be made on a flexible automated production system is usually more limited than a system controlled by programmable automation.

The relative positions of the three types of automation for different production volumes and product varieties are depicted in Figure 1.5.

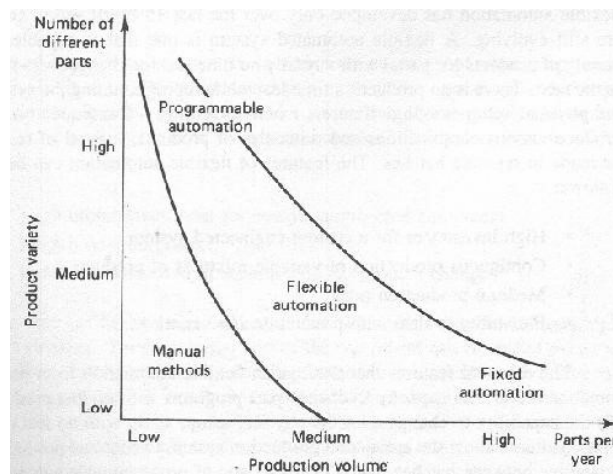


Figure 1.5 Types of automation as a function of volume of production verses product variety

1.6 REASONS FOR AUTOMATING

The important reasons for automating include the following:

1. *Increased productivity:* Automation of manufacturing operations holds the promise of increasing the productivity of labor. This means greater output per hour of labor input. Higher production rates (output per hour) are achieved with automation than with the corresponding manual operations.
2. *High cost of labor:* The trend in the industrialized societies of the world has been toward ever-increasing labor costs. As a result, higher investment in automated equipment has become economically justifiable to replace manual operations. The high cost of labor is forcing business leaders to substitute machines for human labor. Because machines can produce at higher rates of output, the use of automation results in a lower cost per unit of product.
3. *Labor shortages:* In many advanced nations there has been a general shortage of labor. Labor shortages also stimulate the development of automation as a substitute for labor.
4. *Trend of labor toward the service sector:* This trend has been especially prevalent in the advanced countries. First around 1986, the proportion of the work force employed in manufacturing stands at about 20%. In 1947, this percentage was 30%. By the year 2000, some estimates put the figure as low as 2%, certainly, automation of production jobs has caused some of this shift. The growth of government employment at the federal, state, and local levels has consumed a certain share of the labor market which might otherwise have gone into manufacturing. Also, there has been a tendency for people to view factory work as tedious, demeaning, and dirty. This view has caused them to seek employment in the service sector of the economy.
5. *Safety:* By automating the operation and transferring the operator from an active participation to a supervisory role, work is made safer. The safety and physical well-being of the worker has become a national objective with the enactment of the Occupational Safety and Health Act of 1970 (OSHA). It has also provided an impetus for automation.
6. *High cost of raw materials:* The high cost of raw materials in manufacturing results in the need for greater efficiency in using these materials. The reduction of scrap is one of the benefits of automation.
7. *Improved product quality:* Automated operations not only produce parts at faster rates than do their manual counterparts, but they produce parts with greater consistency and conformity to quality specifications.
8. *Reduced manufacturing lead time:* For reasons that we shall examine in subsequent chapters, automation allows the manufacturer to reduce the time between customer order and product delivery. This gives the manufacturer a competitive advantage in promoting good customer service.
9. *Reduction of in-process inventory:* Holding large inventories of work-in-process represents a significant cost to the manufacturer because it ties up capital. In-process

inventory is of no value. It serves none of the purposes of raw materials stock or finished product inventory. Accordingly, it is to the manufacturer's advantage to reduce work-in-progress to a minimum. Automation tends to accomplish this goal by reducing the time a workpart spends in the factory.

10. *High cost of not automating*: A significant competitive advantage is gained by automating a manufacturing plant. The advantage cannot easily be demonstrated on a company's project authorization form. The benefits of automation often show up in intangible and unexpected ways, such as improved quality, higher sales, better labor relations, and better company image. Companies that do not automate are likely to find themselves at a competitive disadvantage with their customers, their employees, and the general public.

All of these factors act together to make production automation a feasible and attractive alternative to manual methods of manufacture.

1.7 TYPES OF PRODUCTION

Another way of classifying production activity is according to the quantity of product made. In this classification, there are three types of production:

1. Job shop production
 2. Batch production
 3. Mass production
1. *Job shop production*: The distinguishing feature of job shop production is low volume. The manufacturing lot sizes are small, often one of a kind. Job shop production is commonly used to meet specific customer orders, and there is a great variety in the type of work the plant must do. Therefore, the production equipment must be flexible and general purpose to allow for this variety of work. Also, the skill level of job shop workers must be relatively high so that they can perform a range of different work assignments. Examples of products manufactured in a job shop include space vehicles, aircraft, machine tools, special tools and equipment, and prototypes of future products. Construction work and shipbuilding are not normally identified with the job shop category, even though the quantities are in the appropriate range. Although these two activities involve the transformation of raw materials into finished products, the work is not performed in a factory.
 2. *Batch production*: This category involves the manufacture of medium-sized lots of the same item or product. The lots may be produced only once, or they may be produced at regular intervals. The purpose of batch production is often to satisfy continuous customer demand for an item. However, the plant is capable of a production rate that exceeds the demand rate. Therefore, the shop produces to build up an inventory of the item. Then it changes over to other orders. When the stock of the first item becomes depleted, production is repeated to build up the inventory again. The manufacturing equipment used in batch production is general-purpose but designed for higher rates of production. Examples of items made in batch-type shops include industrial equipment, furniture, textbooks, and component parts for many assembled consumer products (household appliances, lawn mowers, etc.). Batch production plants include machine shops, casting