

Chapter 1

Introduction

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The word *manufacturing* derives from two Latin words, *manus* (hand) and *factus* (make), so that the combination means *made by hand*. This was the way manufacturing was accomplished when the word first appeared in the English language around 1567. Commercial goods of those times were made by hand. The methods were handicraft, accomplished in small shops, and the goods were relatively simple, at least by today's standards. As many years passed, factories came into being, with many workers at a single site, and the work had to be organized using machines rather than handicraft techniques. The products

became more complex, and so did the processes to make them. Workers had to specialize in their tasks. Rather than overseeing the fabrication of the entire product, they were responsible for only a small part of the total work. More up-front planning was required, and more coordination of the operations was needed to keep track of the work flow in the factories. Slowly but surely, the systems of production were being developed.

The systems of production are essential in modern manufacturing. This book is all about these production systems and how they are sometimes automated and computerized.

1.1 PRODUCTION SYSTEMS

A production system is a collection of people, equipment, and procedures organized to perform the manufacturing operations of a company. It consists of two major components as indicated in Figure 1.1:

1. *Facilities.* The physical facilities of the production system include the equipment, the way the equipment is laid out, and the factory in which the equipment is located.
2. *Manufacturing support systems.* These are the procedures used by the company to manage production and to solve the technical and logistics problems encountered in ordering materials, moving the work through the factory, and ensuring that products meet quality standards. Product design and certain business functions are included in the manufacturing support systems.

In modern manufacturing operations, portions of the production system are automated and/or computerized. In addition, production systems include people. People make these systems work. In general, direct labor people (blue-collar workers)

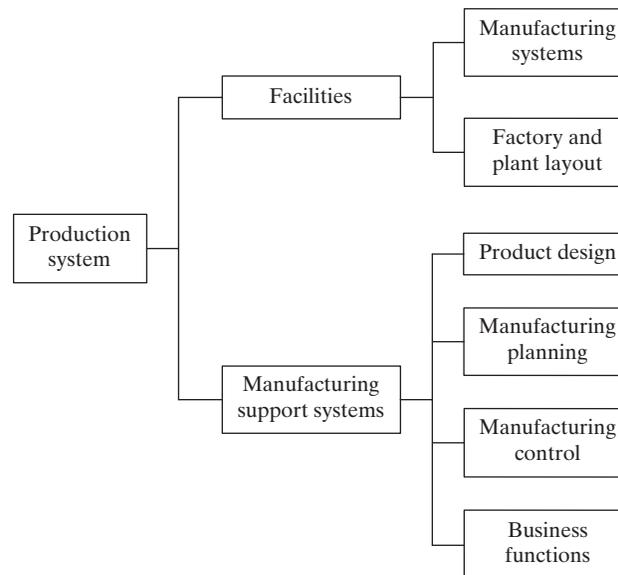


Figure 1.1 The production system consists of facilities and manufacturing support systems.

are responsible for operating the facilities, and professional staff people (white-collar workers) are responsible for the manufacturing support systems.

1.1.1 Facilities

The facilities in the production system consist of the factory, production machines and tooling, material handling equipment, inspection equipment, and computer systems that control the manufacturing operations. Facilities also include the *plant layout*, which is the way the equipment is physically arranged in the factory. The equipment is usually organized into *manufacturing systems*, which are the logical groupings of equipment and workers that accomplish the processing and assembly operations on parts and products made by the factory. Manufacturing systems can be individual work cells consisting of a single production machine and a worker assigned to that machine. More complex manufacturing systems consist of collections of machines and workers, for example, a production line. The manufacturing systems come in direct physical contact with the parts and/or assemblies being made. They “touch” the product.

In terms of human participation in the processes performed by the manufacturing systems, three basic categories can be distinguished, as portrayed in Figure 1.2: (a) manual work systems, (b) worker-machine systems, and (c) automated systems.

Manual Work Systems. A manual work system consists of one or more workers performing one or more tasks without the aid of powered tools. Manual material handling tasks are common activities in manual work systems. Production tasks commonly require the use of hand tools, such as screwdrivers and hammers. When using hand tools, a workholder is often employed to grasp the work part and position it securely for processing. Examples of production-related manual tasks involving the use of hand tools include

- A machinist using a file to round the edges of a rectangular part that has just been milled
- A quality control inspector using a micrometer to measure the diameter of a shaft
- A material handling worker using a dolly to move cartons in a warehouse
- A team of assembly workers putting together a piece of machinery using hand tools.

Worker-Machine Systems. In a worker-machine system, a human worker operates powered equipment, such as a machine tool or other production machine. This is one of the most widely used manufacturing systems. Worker-machine systems include

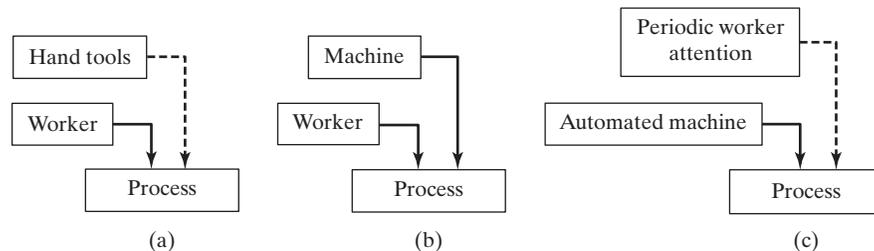


Figure 1.2 Three categories of manufacturing systems: (a) manual work system, (b) worker-machine system, and (c) fully automated system.

combinations of one or more workers and one or more pieces of equipment. The workers and machines are combined to take advantage of their relative strengths and attributes, which are listed in Table 1.1. Examples of worker-machine systems include the following:

- A machinist operating an engine lathe to fabricate a part for a product
- A fitter and an industrial robot working together in an arc-welding work cell
- A crew of workers operating a rolling mill that converts hot steel slabs into flat plates
- A production line in which the products are moved by mechanized conveyor and the workers at some of the stations use power tools to accomplish their processing or assembly tasks.

Automated Systems. An automated system is one in which a process is performed by a machine without the direct participation of a human worker. Automation is implemented using a program of instructions combined with a control system that executes the instructions. Power is required to drive the process and to operate the program and control system (these terms are defined more completely in Chapter 4).

There is not always a clear distinction between worker-machine systems and automated systems, because many worker-machine systems operate with some degree of automation. Two levels of automation can be identified: semiautomated and fully automated. A *semiautomated machine* performs a portion of the work cycle under some form of program control, and a human worker tends to the machine for the remainder of the cycle, by loading and unloading it, or by performing some other task each cycle. A *fully automated machine* is distinguished from its semiautomated counterpart by its capacity to operate for an extended period of time with no human attention. Extended period of time means longer than one work cycle; a worker is not required to be present during each cycle. Instead, the worker may need to tend the machine every tenth cycle, or every hundredth cycle. An example of this type of operation is found in many injection molding plants, where the molding machines run on automatic cycles, but periodically the molded parts at the machine must be collected by a worker. Figure 1.2(c) depicts a fully automated system. The semiautomated system is best portrayed by Figure 1.2(b).

In certain fully automated processes, one or more workers are required to be present to continuously monitor the operation, and make sure that it performs according to the intended specifications. Examples of these kinds of automated processes include complex

TABLE 1.1 Relative Strengths and Attributes of Humans and Machines

| Humans | Machines |
|---|---------------------------------------|
| Sense unexpected stimuli | Perform repetitive tasks consistently |
| Develop new solutions to problems | Store large amounts of data |
| Cope with abstract problems | Retrieve data from memory reliably |
| Adapt to change | Perform multiple tasks simultaneously |
| Generalize from observations | Apply high forces and power |
| Learn from experience | Perform simple computations quickly |
| Make decisions based on incomplete data | Make routine decisions quickly |

chemical processes, oil refineries, and nuclear power plants. The workers do not actively participate in the process except to make occasional adjustments in the equipment settings, perform periodic maintenance, and spring into action if something goes wrong.

1.1.2 Manufacturing Support Systems

To operate the production facilities efficiently, a company must organize itself to design the processes and equipment, plan and control the production orders, and satisfy product quality requirements. These functions are accomplished by manufacturing support systems—people and procedures by which a company manages its production operations. Most of these support systems do not directly contact the product, but they plan and control its progress through the factory.

Manufacturing support involves a sequence of activities, as depicted in Figure 1.3. The activities consist of four functions that include much information flow and data processing: (1) business functions, (2) product design, (3) manufacturing planning, and (4) manufacturing control.

Business Functions. The business functions are the principal means by which the company communicates with the customer. They are, therefore, the beginning and the end of the information-processing sequence. Included in this category are sales and marketing, sales forecasting, order entry, and customer billing.

The order to produce a product typically originates from the customer and proceeds into the company through the sales department of the firm. The production order will be in one of the following forms: (1) an order to manufacture an item to the customer’s specifications, (2) a customer order to buy one or more of the manufacturer’s proprietary products, or (3) an internal company order based on a forecast of future demand for a proprietary product.

Product Design. If the product is manufactured to customer design, the design has been provided by the customer, and the manufacturer’s product design department is not involved. If the product is to be produced to customer specifications, the manufacturer’s product design department may be contracted to do the design work for the product as well as to manufacture it.

If the product is proprietary, the manufacturing firm is responsible for its development and design. The sequence of events that initiates a new product design often originates in the sales department; the direction of information flow is indicated in Figure 1.3. The departments of the firm that are organized to accomplish product design might include research and development, design engineering, and perhaps a prototype shop.

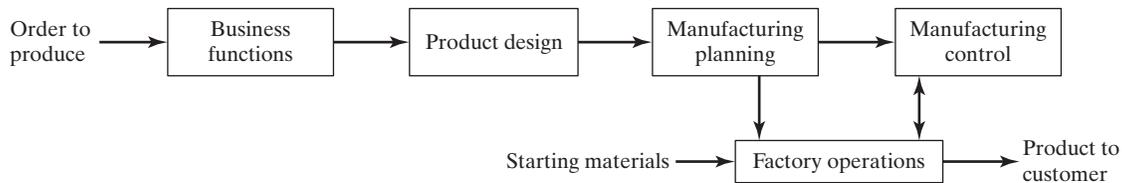


Figure 1.3 Sequence of information-processing activities in a typical manufacturing firm.

Manufacturing Planning. The information and documentation that constitute the product design flows into the manufacturing planning function. The information-processing activities in manufacturing planning include process planning, master scheduling, material requirements planning, and capacity planning.

Process planning consists of determining the sequence of individual processing and assembly operations needed to produce the part. The manufacturing engineering department is responsible for planning the processes and related technical details such as tooling. Manufacturing planning includes logistics issues, commonly known as production planning. The authorization to produce the product must be translated into the **master production schedule**, which is a listing of the products to be made, the dates on which they are to be delivered, and the quantities of each. Based on this master schedule, the individual components and subassemblies that make up each product must be scheduled. Raw materials must be purchased or requisitioned from storage, parts must be ordered from suppliers, and all of these items must be planned so they are available when needed. The computations for this planning are made by **material requirements planning**. In addition, the master schedule must not list more quantities of products than the factory is capable of producing each month with its given number of machines and manpower. **Capacity planning** is concerned with determining the human and equipment resources of the firm and checking to make sure that the production plan is feasible.

Manufacturing Control. Manufacturing control is concerned with managing and controlling the physical operations in the factory to implement the manufacturing plans. The flow of information is from planning to control as indicated in Figure 1.3. Information also flows back and forth between manufacturing control and the factory operations. Included in this function are shop floor control, inventory control, and quality control.

Shop floor control deals with the problem of monitoring the progress of the product as it is being processed, assembled, moved, and inspected in the factory. Shop floor control is concerned with inventory in the sense that the materials being processed in the factory are work-in-process inventory. Thus, shop floor control and inventory control overlap to some extent. **Inventory control** attempts to strike a proper balance between the risk of too little inventory (with possible stock-outs of materials) and the carrying cost of too much inventory. It deals with such issues as deciding the right quantities of materials to order and when to reorder a given item when stock is low. The function of **quality control** is to ensure that the quality of the product and its components meet the standards specified by the product designer. To accomplish its mission, quality control depends on inspection activities performed in the factory at various times during the manufacture of the product. Also, raw materials and component parts from outside sources are sometimes inspected when they are received, and final inspection and testing of the finished product is performed to ensure functional quality and appearance. Quality control also includes data collection and problem-solving approaches to address process problems related to quality, such as statistical process control (SPC) and Six Sigma.

1.2 AUTOMATION IN PRODUCTION SYSTEMS

Some components of the firm's production system are likely to be automated, whereas others will be operated manually or clerically. The automated elements of the production system can be separated into two categories: (1) automation of the manufacturing

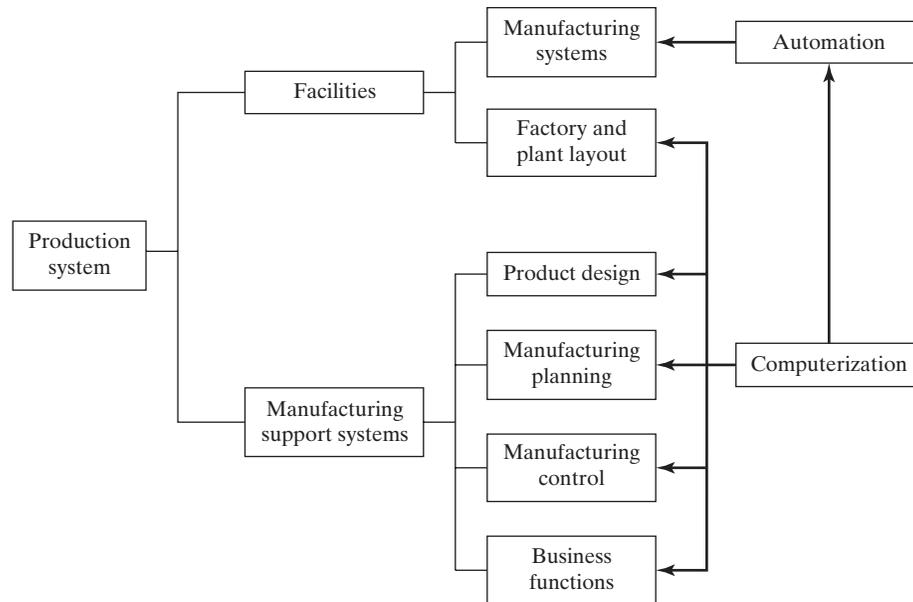


Figure 1.4 Opportunities for automation and computerization in a production system.

systems in the factory, and (2) computerization of the manufacturing support systems. In modern production systems, the two categories are closely related, because the automated manufacturing systems on the factory floor are themselves usually implemented by computer systems that are integrated with the manufacturing support systems and management information system operating at the plant and enterprise levels. The two categories of automation are shown in Figure 1.4 as an overlay on Figure 1.1.

1.2.1 Automated Manufacturing Systems

Automated manufacturing systems operate in the factory on the physical product. They perform operations such as processing, assembly, inspection, and material handling, in many 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.

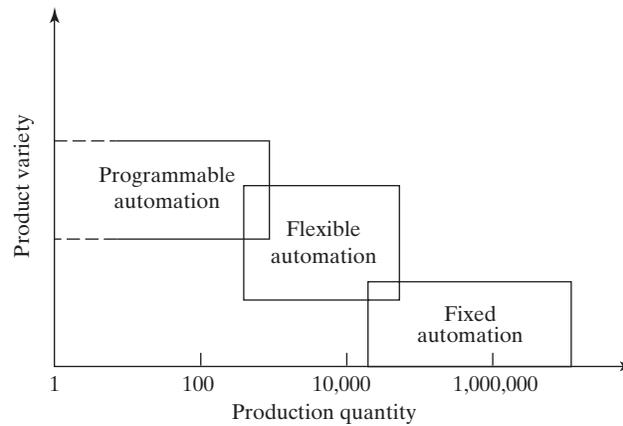


Figure 1.5 Three types of automation relative to production quantity and product variety.

Automated manufacturing systems can be classified into three basic types: (1) fixed automation, (2) programmable automation, and (3) flexible automation. They generally operate as fully automated systems although semiautomated systems are common in programmable automation. The relative positions of the three types of automation for different production volumes and product varieties are depicted in Figure 1.5.

Fixed Automation. Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration. Each operation in the sequence is usually simple, involving perhaps a plain linear or rotational motion or an uncomplicated combination of the two, such as feeding a rotating spindle. It is the integration and coordination of many such operations in one piece of equipment that makes the system complex. Typical features of fixed automation are (1) high initial investment for custom-engineered equipment, (2) high production rates, and (3) inflexibility of the equipment to accommodate product variety.

The economic justification for fixed automation is found in products that are made in very large quantities and at high production rates. The high initial cost of the equipment can be spread over a very large number of units, thus minimizing the unit cost relative to alternative methods of production. Examples of fixed automation include machining transfer lines and automated assembly machines.

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 they can be read and interpreted by the system. New programs can be prepared and entered into the equipment to produce new products. Some of the features that characterize programmable automation include (1) high investment in general-purpose equipment, (2) lower production rates than fixed automation, (3) flexibility to deal with variations and changes in product configuration, and (4) high suitability for batch production.

Programmable automated systems 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 item, the system must be reprogrammed with the set of machine instructions that correspond to the new item. The physical setup of the machine must also be changed: Tools must be loaded, fixtures must be attached to the machine table, and any required machine settings must be entered. This changeover takes time. Consequently, the typical cycle for a given batch includes a period during which the setup and reprogramming take place, followed by a period in which the parts are produced. Examples of programmable automation include numerically controlled (NC) machine tools, industrial robots, and programmable logic controllers.

Flexible Automation. Flexible automation is an extension of programmable automation. A flexible automated system is capable of producing a variety of parts or products with virtually no time lost for changeovers from one design to the next. There is no lost production time while reprogramming the system and altering the physical setup (tooling, fixtures, machine settings). Accordingly, the system can produce various mixes and schedules of parts or products instead of requiring that they be made in batches. What makes flexible automation possible is that the differences between parts processed by the system are not significant, so the amount of changeover between designs is minimal. Features of flexible automation include (1) high investment for a custom-engineered system, (2) continuous production of variable mixtures of parts or products, (3) medium production rates, and (4) flexibility to deal with product design variations. Examples of flexible automation are flexible manufacturing systems that perform machining processes.

1.2.2 Computerized Manufacturing Support Systems

Automation of the manufacturing support systems is aimed at reducing the amount of manual and clerical effort in product design, manufacturing planning and control, and the business functions of the firm. Nearly all modern manufacturing support systems are implemented using computers. Indeed, computer technology is used to implement automation of the manufacturing systems in the factory as well. **Computer-integrated manufacturing** (CIM) denotes the pervasive use of computer systems to design the products, plan the production, control the operations, and perform the various information-processing functions needed in a manufacturing firm. True CIM involves integrating all of these functions in one system that operates throughout the enterprise. Other terms are used to identify specific elements of the CIM system; for example, *computer-aided design* (CAD) supports the product design function. *Computer-aided manufacturing* (CAM) is used for functions related to manufacturing engineering, such as process planning and numerical control part programming. Some computer systems perform both CAD and CAM, and so the term *CAD/CAM* is used to indicate the integration of the two into one system.

Computer-integrated manufacturing involves the information-processing activities that provide the data and knowledge required to successfully produce the product. These activities are accomplished to implement the four basic manufacturing support functions identified earlier: (1) business functions, (2) product design, (3) manufacturing planning, and (4) manufacturing control.

1.2.3 Reasons for Automating

Companies undertake projects in automation and computer-integrated manufacturing for good reasons, some of which are the following:

1. *Increase labor productivity.* Automating a manufacturing operation invariably increases production rate and labor productivity. This means greater output per hour of labor input.
2. *Reduce labor cost.* Increasing labor cost has been, and continues to be, the trend in the world's industrialized societies. Consequently, higher investment in automation has become economically justifiable to replace manual operations. Machines are increasingly being substituted for human labor to reduce unit product cost.
3. *Mitigate the effects of labor shortages.* There is a general shortage of labor in many advanced nations, and this has stimulated the development of automated operations as a substitute for labor.
4. *Reduce or eliminate routine manual and clerical tasks.* An argument can be put forth that there is social value in automating operations that are routine, boring, fatiguing, and possibly irksome. Automating such tasks improves the general level of working conditions.
5. *Improve worker safety.* Automating a given operation and transferring the worker from active participation in the process to a monitoring role, or removing the worker from the operation altogether, makes the work 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 (OSHA) in 1970. This has provided an impetus for automation.
6. *Improve product quality.* Automation not only results in higher production rates than manual operation, it also performs the manufacturing process with greater consistency and conformity to quality specifications.
7. *Reduce manufacturing lead time.* Automation helps reduce the elapsed time between customer order and product delivery, providing a competitive advantage to the manufacturer for future orders. By reducing manufacturing lead time, the manufacturer also reduces work-in-process inventory.
8. *Accomplish processes that cannot be done manually.* Certain operations cannot be accomplished without the aid of a machine. These processes require precision, miniaturization, or complexity of geometry that cannot be achieved manually. Examples include certain integrated circuit fabrication operations, rapid prototyping processes based on computer graphics (CAD) models, and the machining of complex, mathematically defined surfaces using computer numerical control. These processes can only be realized by computer-controlled systems.
9. *Avoid the high cost of not automating.* There is a significant competitive advantage gained in automating a manufacturing plant. The advantage cannot always be demonstrated on a company's project authorization form. The benefits of automation often show up in unexpected and intangible ways, such as in 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.