

Introduction to DeGarmo's Materials and Processes in Manufacturing

1.1 Materials, Manufacturing, and the Standard of Living

Manufacturing is critical to a country's economic welfare and standard of living because the standard of living in any society is determined, primarily, by the *goods* and *services* that are available to its people. Manufacturing companies contribute about 20% of the GNP, employ about 18% of the workforce, and account for 40% of the exports of the United States. In most cases, materials are utilized in the form of manufactured goods. **Manufacturing** and **assembly** represent the organized activities that convert raw materials into salable goods. The manufactured goods are typically divided into two classes: producer goods and consumer goods. **Producer goods** are those goods manufactured for other companies to use to manufacture either producer or consumer goods. **Consumer goods** are those purchased directly by the consumer or the general public. For example, someone has to build the machine tool (a lathe) that produces (using machining processes) the large rolls that are sold to the rolling mill factory to be used to roll the sheets of steel that are then formed (using dies) into body panels of your car. Similarly, many service industries depend heavily on the use of manufactured products, just as the agricultural industry is heavily dependent on the use of large farming machines for efficient production.

Processes convert materials from one form to another adding value to them. The more efficiently materials can be produced and converted into the desired products that function with the prescribed quality, the greater will be the companies' productivity and the better will be the standard of living of the employees.

The history of mankind has been linked to our ability to work with tools and materials, beginning with the Stone Age and ranging through the eras of copper and bronze, the Iron Age,

and recently the age of steel. Although ferrous materials still dominate the manufacturing world, we have entered the age of tailor-made plastics, composite materials, light-weight and high-performance metallic alloys, new exotic alloys, and hybrid materials.

A good example of this progression is shown in **Figure 1.1**. The goal of the manufacturer of any product or service is to continually improve. For a given product or service, this improvement process usually follows an S-shaped curve, as shown in Figure 1.1a, often called a product life-cycle curve. After the initial invention/creation and development, a period of rapid growth in performance occurs, with relatively few resources required. However, each improvement becomes progressively more difficult. For a significant gain, more money and time and innovation are required. Finally, the product or service enters the maturity phase, during which additional performance gains become very costly.

For example, in the automobile tire industry, Figure 1.1b shows the evolution of radial tire performance from its birth in 1946 to the present. Growth in performance is actually the superposition of many different improvements in material, processes, and design.

These innovations, known as **sustaining technology**, serve to continually bring more value to the consumer of existing products and services. In general, sustaining manufacturing technology is the backbone of American industry and the ever-increasing productivity metric.

Although materials are no longer used only in their natural state, there is obviously an absolute limit to the amounts of many materials available here on earth. Therefore, as the variety of man-made materials continues to increase, resources must be used efficiently and recycled whenever possible. Of course, recycling only postpones the exhaustion date.

Like materials, processes have also proliferated greatly in the past 50 years, with new processes being developed to handle the new materials more efficiently and with less waste. A good example

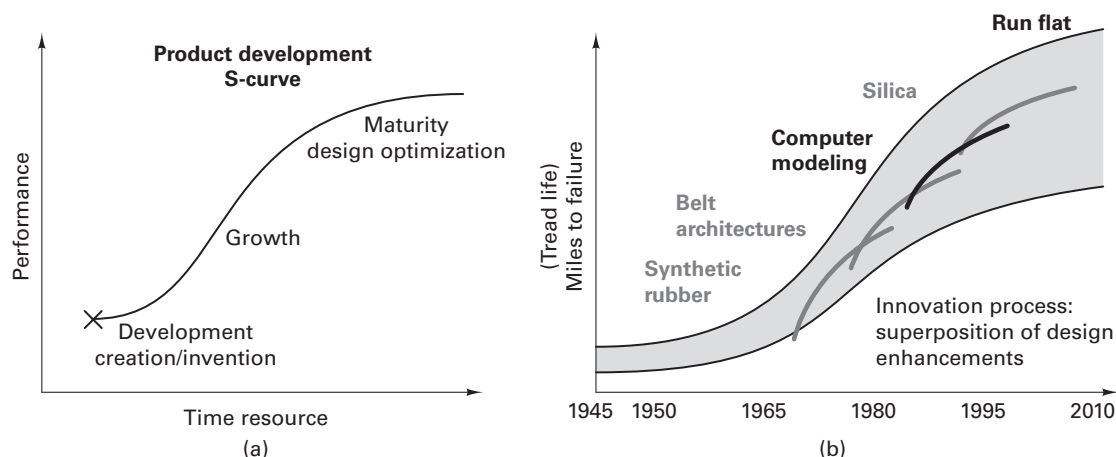


FIGURE 1.1 (a) A product development curve usually has an “S”-shape. (b) Example of the S-curve for the radial tire. (Courtesy of Bart Thomas, Michelin.)

is the laser, invented around 1960, which now finds many uses in machining, measurement, inspection, heat treating, welding, additive manufacturing, surgery, and many more. New developments in manufacturing technology often account for improvements in productivity. Even when the technology is proprietary, the competition often gains access to it, usually quite quickly.

Starting with the product design, materials, labor, and equipment are interactive factors in manufacturing that must be combined properly (integrated) to achieve low cost, superior quality, and on-time delivery. **Figure 1.2** shows a breakdown of costs for a product (like a car). Typically about 40% of the selling price of a product is the **manufacturing cost**. Because the selling price determines how much the customer is willing to pay, maintaining the profit often depends on reducing manufacturing cost. The internal customers who really make the product are called direct labor. They are usually the targets of automation, but typically they account for only about 10% of the manufacturing cost, even though they are the main element in increasing productivity.

Referring again to the total expenses shown in Figure 1.2 (selling price less profit), about 68% of dollars are spent on people, but only 5% to 10% on director labor, the breakdown for the rest being about 15% for engineers and 25% for marketing, sales, and general management people. The average labor cost

in manufacturing in the United States is \$10 to \$25 per hour for hourly workers. Reductions in direct labor will have only marginal effects on the total people costs. The optimal combination of factors for producing a small quantity of a given product may be very inefficient for a larger quantity of the same product. Consequently, a systems approach, taking all the factors into account, must be used. This requires a sound and broad understanding on the part of the decision makers on the value of materials, processes, and equipment to the company, and their customers, accompanied by an understanding of the manufacturing systems (MSs). Materials, processes, and manufacturing systems are what this book is all about.

1.2 Manufacturing and Production Systems

Manufacturing is the economic term for making goods and services available to satisfy human wants. Manufacturing implies creating value by applying useful mental or physical labor.

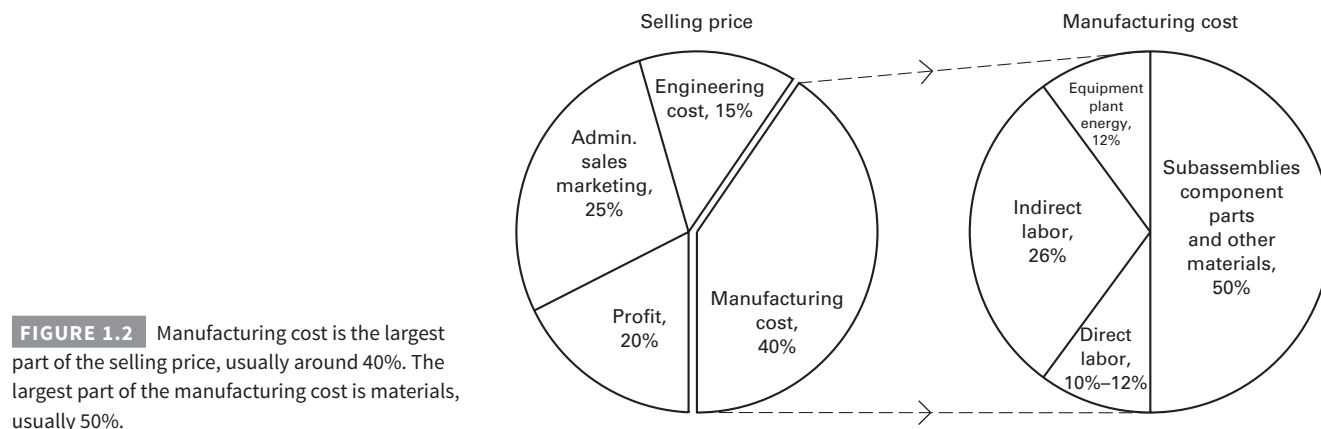


FIGURE 1.2 Manufacturing cost is the largest part of the selling price, usually around 40%. The largest part of the manufacturing cost is materials, usually 50%.

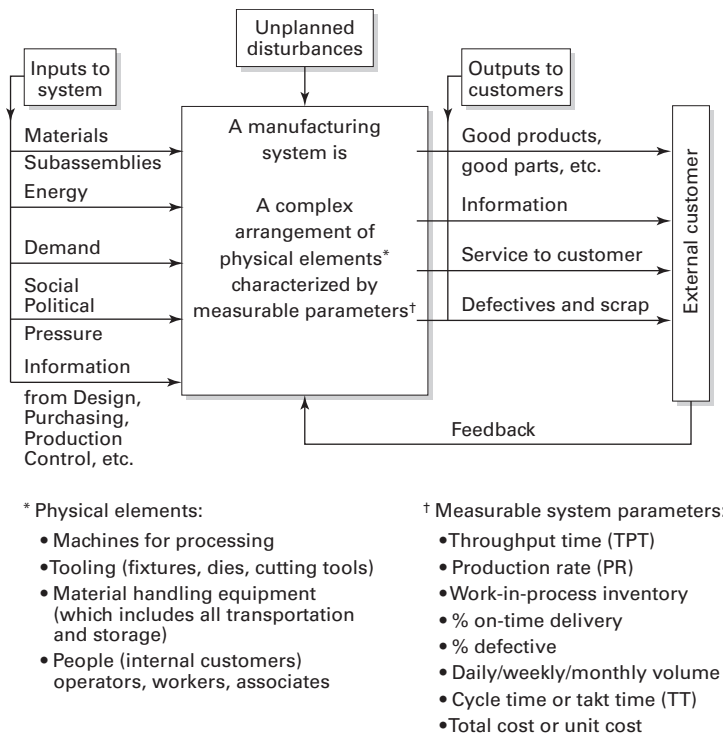


FIGURE 1.3 Here is our definition of a manufacturing system with its inputs and outputs. (Black 1991/McGraw-Hill.)

The *manufacturing processes* are arranged in the factory to form a *manufacturing system*. The manufacturing system is a complex arrangement of physical elements characterized by measurable parameters. The manufacturing system takes inputs and produces products for the external customer, as shown in **Figure 1.3**.

The inputs to the manufacturing system include materials, information, and energy. The system is a complex set of elements that includes machines (or machine tools), people, material-handling equipment, and tooling. Workers are the internal customers. They process materials within the system, which gain value as the material progresses from process to machine. Manufacturing system outputs may be finished or semifinished goods. Semifinished goods serve as inputs to some other process at other locations. Manufacturing systems are dynamic, meaning that they must be designed to adapt constantly to change. Many of the inputs cannot be fully controlled by management, and the effect of disturbances must be counteracted by manipulating the controllable inputs or the system itself. Controlling the input material availability and/or predicting demand fluctuations may be difficult. A national economic decline or recession can cause shifts in the business environment that can seriously change any of these inputs. In manufacturing systems, not all inputs are fully controllable. To understand how manufacturing systems work and be able to design manufacturing systems, computer modeling (simulation) and analysis are used. However, modeling and analysis are difficult because

1. In the absence of a system design, the manufacturing systems can be very complex, be difficult to define, and have conflicting goals.

2. The data or information may be difficult to secure, inaccurate, conflicting, missing, or even too abundant to digest and analyze.
3. Relationships may be awkward to express in analytical terms, and interactions may be nonlinear; thus, many analytical tools cannot be applied with accuracy. System size may inhibit analysis.
4. Systems are always dynamic and change during analysis. The environment can change the system, and vice versa.
5. All systems analyses are subject to errors of omission (missing information) and commission (extra information). Some of these are related to breakdowns or delays in feedback elements.

Because of these difficulties, digital simulation has become an important technique for manufacturing systems modeling and analysis as well as for manufacturing system design.

The entire company is often referred to as the enterprise or the production system. The production system services the manufacturing system, as shown in **Figure 1.4**. In this book, a production system will refer to the total company and will include within it the manufacturing system. The production system includes the manufacturing system plus all the other functional areas of the plant for information, design, analysis, and control. These subsystems are connected by various means to each other to produce either goods or services or both.

Goods refer to material things. **Services** are nonmaterial things that we buy to satisfy our wants, needs, or desires. Service production systems include transportation, banking, finance, savings and loan, insurance, utilities, health care, education, communication, entertainment, sporting events, and

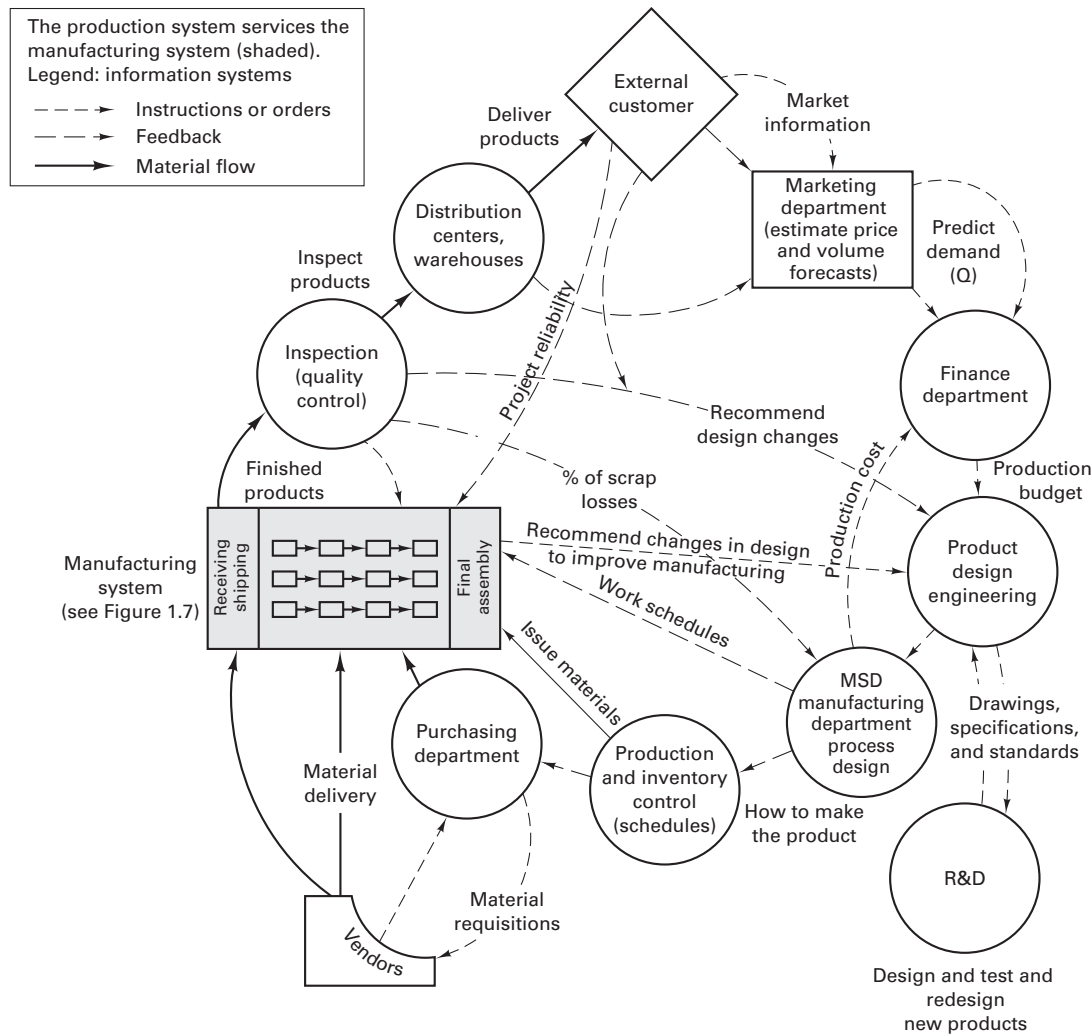


FIGURE 1.4 The production system includes and services the manufacturing system. The functional departments are connected by formal and informal information systems, designed to service the manufacturing that produces the goods.

so forth. They are useful labors that do not directly produce a product. Manufacturing has the responsibility for designing processes (sequences of operations and processes) and systems to create (make or manufacture) the product as designed. The system must exhibit flexibility to meet customer demand (volumes and mixes of products) as well as changes in product design.

As shown in **Table 1.1**, production terms have a definite rank of importance, somewhat like rank in the army. Confusing *system* with *section* is similar to mistaking a colonel for a corporal. In either case, knowledge of rank is necessary. The terms tend to overlap because of the inconsistencies of popular usage.

An obvious problem exists here in the terminology of manufacturing and production. The same term can refer to different things. For example, *drill* can refer to the machine tool that does these kinds of operations; the operation itself, which can be done on many different kinds of machines; or the cutting tool, which exists in many different forms. It is therefore important to use modifiers whenever possible: “Use the *radial drill press* to drill a hole using a 1-in.-diameter spade drill.” The emphasis

of this book will be directed toward the understanding of the processes, machines, and tools required for manufacturing and how they interact with the materials being processed. In the last chapters of the book, an introduction to systems aspects is presented.

Production System—the Enterprise

The highest-ranking term in the hierarchy is **production system**. A production system includes people, money, equipment, materials and supplies, markets, management, and the manufacturing system. In fact, all aspects of commerce (manufacturing, sales, advertising, profit, and distribution) are involved. **Table 1.2** provides a partial list of production systems. Another term for them is “industries” as in the “aerospace industry.”

Much of the information given for manufacturing systems is relevant to the service system. Most require a service production system for proper product sales. This is particularly true in

TABLE 1.1 Production Terms for Manufacturing Production Systems

Term	Meaning	Examples
Production system; the enterprise	All aspects of workers, machines, and information, considered collectively, needed to manufacture parts or products; integration of all units of the system is critical.	Company that makes engines, assembly plant, glassmaking factory, foundry; sometimes called the enterprise or the business.
Manufacturing system (sequence of operations, collection of processes) or factory	The collection of manufacturing processes and operations resulting in specific end products; an arrangement or layout of many processes, material-handling equipment, and operators.	Rolling steel plates, manufacturing of automobiles, series of connected operations or processes, a job shop, a flow shop, a continuous process.
Machine or machine tool or manufacturing process	A specific piece of equipment designed to accomplish specific processes, often called a <i>machine tool</i> ; machine tools linked together to make a manufacturing system.	Spot welding, milling machine, lathe, drill press, forge, drop hammer, die caster, punch press, grinder, etc.
Job (sometimes called a <i>station</i> ; a collection of tasks)	A collection of operations done on machines or a collection of tasks performed by one worker at one location on the assembly line.	Operation of machines, inspection, final assembly; e.g., forklift driver has the job of moving materials.
Operation (sometimes called a <i>process</i>)	A specific action or treatment, often done on a machine, the collection of which makes up the job of a worker.	Drill, ream, bend, solder, turn, face, mill extrude, inspect, load.
Tools or tooling	Refers to the implements used to hold, cut, shape, or deform the work materials; called <i>cutting tools</i> if referring to machining; can refer to <i>jigs</i> and <i>fixtures</i> in workholding and <i>punches</i> and <i>dies</i> in metal forming.	Grinding wheel, drill bit, end milling cutter, die, mold, clamp, three-jaw chuck, fixture.

TABLE 1.2 Partial List of Production Systems for Producer and Consumer Goods

Aerospace and airplanes	Foods (canned, dairy, meats, etc.)
Appliances	Footwear
Automotive (cars, trucks, vans, wagons, etc.)	Furniture
Beverages	Glass
Building supplies (hardware)	Hospital suppliers
Cement and asphalt	Leather and fur goods
Ceramics	Machines
Chemicals and allied industries	Marine engineering
Clothing (garments)	Metals (steel, aluminum, etc.)
Construction	Natural resources (oil, coal, forest, pulp and paper)
Construction materials (brick, block, panels)	Publishing and printing (books, CDs, newspapers)
Drugs, soaps, cosmetics	Restaurants
Electrical and microelectronics	Retail (food, department stores, etc.)
Energy (power, gas, electric)	Ship building
Engineering	Textiles
Equipment and machinery (agricultural, construction and electrical products, electronics, household products, industrial machine tools, office equipment, computers, power generators)	Tire and rubber Tobacco Transportation vehicles (railroad, airline, truck, bus) Vehicles (bikes, cycles, ATVs, snowmobiles)

industries, such as the food (restaurant) industry, in which customer service is as important as quality and on-time delivery. **Table 1.3** provides a short list of service industries.

TABLE 1.3 Types of Service Industries

Advertising and marketing
Communication (telephone, computer networks)
Education
Entertainment (radio, TV, movies, plays)
Equipment and furniture rental
Financial (banks, investment companies, loan companies)
Health care
Insurance
Transportation and car rental
Travel (hotel, motel, cruise lines)

Manufacturing Systems

A collection of operations and processes used to obtain a desired product(s) or component(s) is called a **manufacturing system**. The manufacturing system design is therefore the arrangement of the manufacturing processes in the factory. Control of a system applies to overall control of the whole, not merely of the individual processes or equipment. The entire manufacturing system must be controlled to schedule and control the factory—all its inputs, inventory levels, product quality, output rates, and so forth.

Manufacturing Processes

A **manufacturing process** converts unfinished materials to finished products, often using machines or machine tools. For example, injection molding, die casting, progressive stamping, milling, arc welding, painting, assembling, testing, pasteurizing, homogenizing, and annealing are commonly called processes

or manufacturing processes. The term *process* can also refer to a sequence of steps, processes, or operations for production of goods and services, as shown in **Figure 1.5**, which shows the processes to manufacture an Olympic-type medal.

A **machine tool** is an assembly of related mechanisms on a frame or bed that together produce a desired result. Generally, motors, controls, and auxiliary devices are included. Cutting tools and workholding devices are considered separately.

A machine tool may do a single process (e.g., cutoff saw) or multiple processes, or it may manufacture an entire component. Machine sizes vary from a tabletop drill press to a 1000-ton forging press.

Job and Station

In the classical manufacturing system, a **job** is the total of the work or duties a worker performs. A **station** is a location or area where a production worker performs tasks or a job.

A job is a group of related operations and tasks performed at one station or series of stations in cells. For example, the job at a final assembly station may consist of four tasks:

1. Attach carburetor
2. Connect gas line
3. Connect vacuum line
4. Connect accelerator rod

The job of an operator of a turret lathe (a semiautomatic machine tool) may include the following operations and tasks: load, start, index and stop, unload, and inspect. The operator's job may also include setting up the machine (i.e., getting ready for manufacturing). Other machine operations include drilling, reaming, facing, turning, chamfering, and knurling. The operator can run more than one machine or service at more than one station.

The terms *job* and *station* have been carried over to unmanned machines. A job is a group of related operations generally performed at one station, and a station is a position or location in a machine (or process) where specific operations are performed. A simple machine may have only one station. Complex machines can be composed of many stations. The job at a station often includes many simultaneous operations, such as "drill all five holes" by multiple spindle drills. In the planning of a job, a process plan is often developed (by the engineer) to describe how a component is made using a sequence of operations. The engineer begins with a part drawing and selects the raw material. Follow in **Figure 1.6** the sequence of machining operations that transforms the cylinder in a pinion shaft.

Operation

An **operation** is a distinct action performed to produce a desired result or effect. Typical manual machine operations are loading and unloading. Operations can be divided into suboperational elements. For example, loading is made up of picking up a part, placing part in jig, and closing jig. However, suboperational elements will not be discussed here.

Operations categorized by function are

1. *Materials handling and transporting*: change in the location or position of the product.
2. *Processing*: change in volume and quality, including assembly and disassembly; can include packaging.
3. *Packaging*: special processing; may be temporary or permanent for shipping.
4. *Inspecting and testing*: comparison to the standard or check of process behavior.
5. *Storing*: time lapses without further operations.

These basic operations may occur more than once in some processes, or they may sometimes be omitted. *Remember, it is the manufacturing processes that add value and quality to the materials.* Defective processes produce poor quality or scrap. Other operations may be necessary but do not, in general, add value, whereas operations performed by machine tools that do material processing usually do add value.

Treatments

Treatments operate continuously on the workpiece. They usually alter or modify the product-in-process without tool contact. Heat treating, curing, galvanizing, plating, finishing, (chemical) cleaning, and painting are examples of treatments. Treatments usually add value to the part.

These processes are difficult to include in manufacturing cells because they often have long cycle times, are hazardous to the workers' health, or are unpleasant to be around because of high heat or chemicals. They are often done in large tanks or furnaces or rooms. The cycle time for these processes may dictate the cycle times for the entire system. These operations also tend to be material specific. Many manufactured products are given decorative and protective surface treatments that control the finished appearance. A customer may not buy a new vehicle because it has a visible defect in the chrome bumper, although this defect will not alter the operation of the car.

Tools, Tooling, and Workholders

The lowest mechanism in the production term rank is the **tool**. Tools are used to hold, cut, shape, or form the unfinished product. Common hand tools include the saw, hammer, screwdriver, chisel, punch, sandpaper, drill, clamp, file, torch, and grindstone.

Basically, mechanized versions of such hand tools are called cutting tools. Some examples of tools for cutting are drill bits, reamers, single-point turning tools, milling cutters, saw blades, broaches, and grinding wheels. Noncutting tools for forming include extrusion dies, punches, and molds.

Tools also include workholders, jigs, and fixtures. These tools and cutting tools are generally referred to as the **tooling**, which usually must be considered (purchased) separate from machine tools. Cutting tools wear and fail and must be periodically replaced before parts are ruined. The workholding devices must be able to locate and secure the workpieces during processing in a repeatable, mistake-proof way.

How an olympic medal is made using the CAD/CAM process

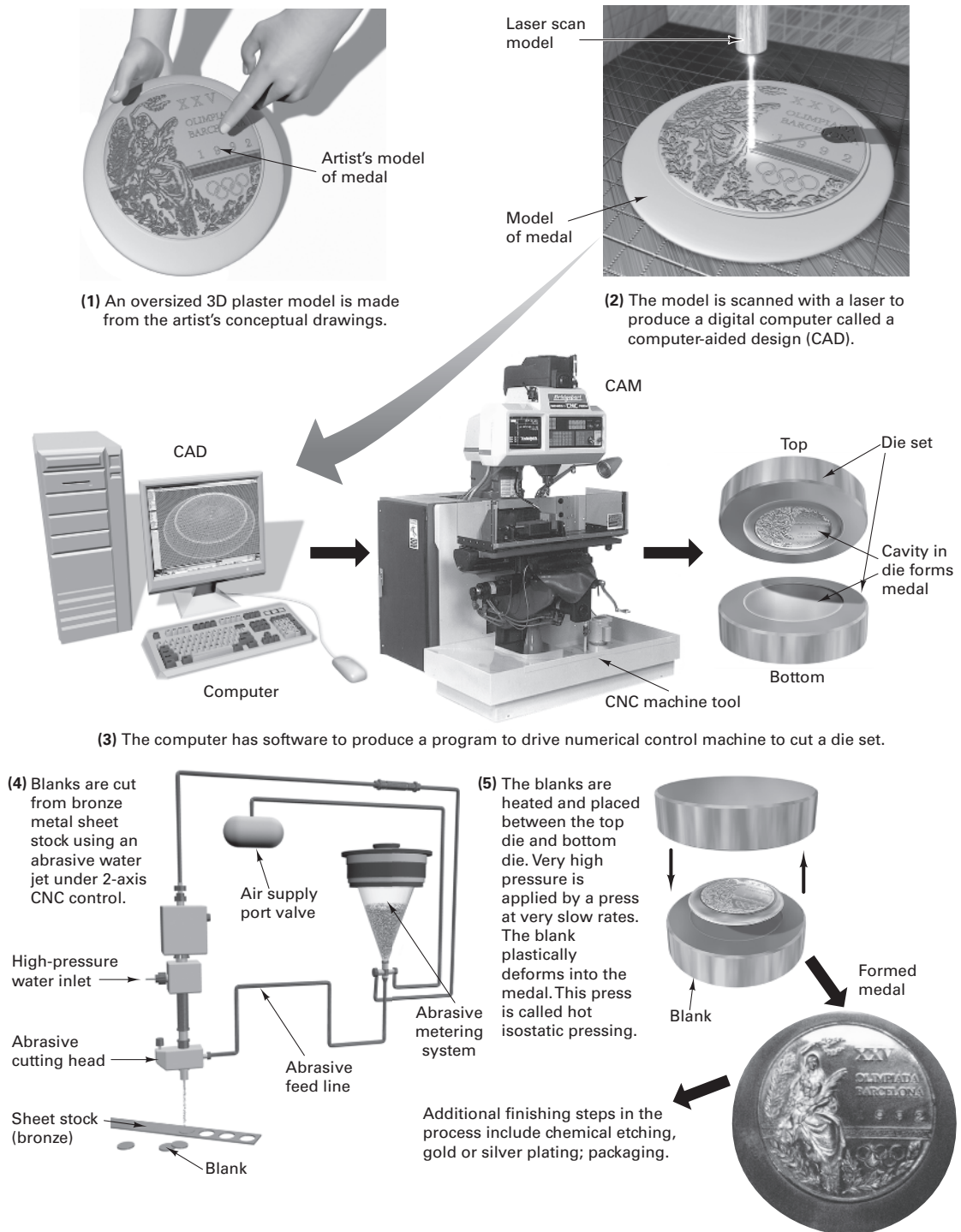


FIGURE 1.5 The manufacturing process for making Olympic medals has many steps or operations, beginning with design and including die making. (Courtesy of J. T. Black.)

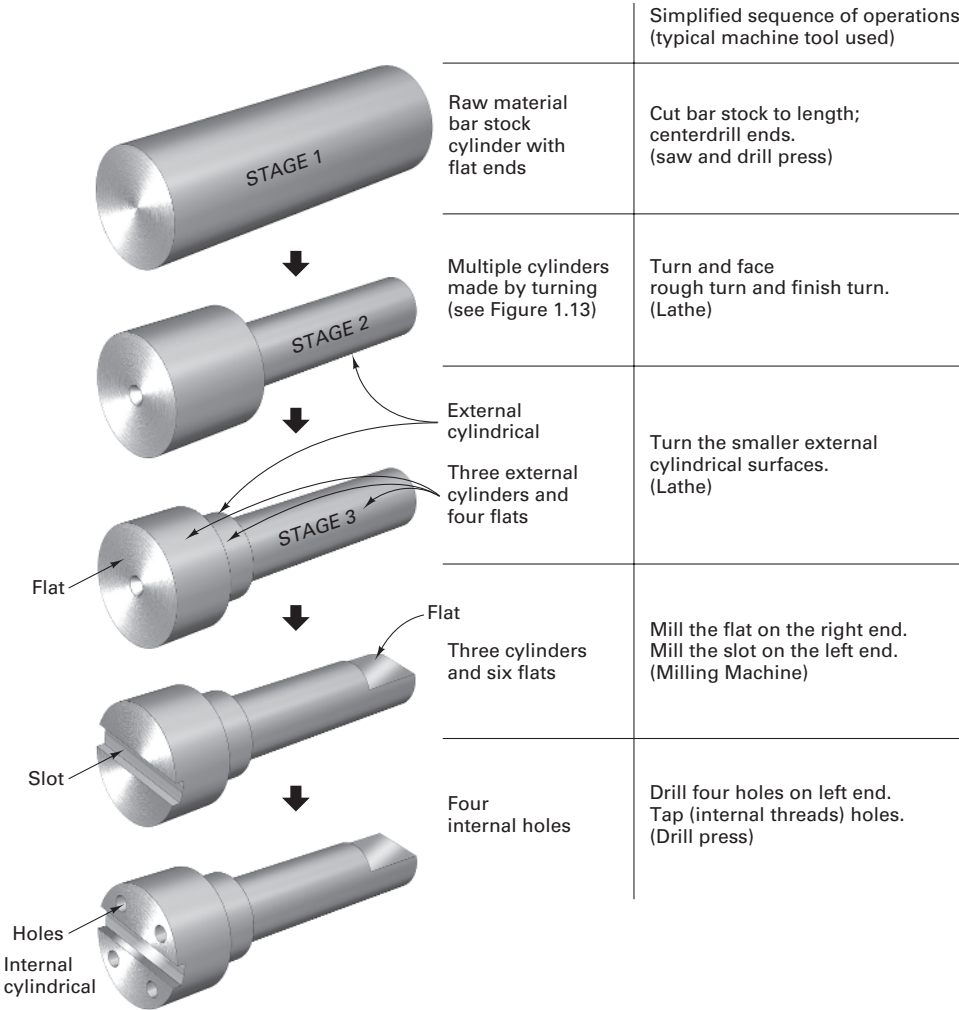


FIGURE 1.6 The component called a pinion shaft is manufactured by a “sequence of operations” to produce various geometric surfaces. The engineer determines the sequence and selects the processes and tooling needed to make the component.

Tooling for Measurement and Inspection

Measuring tools and instruments are also important for manufacturing. Common examples of measuring tools are rulers, calipers, micrometers, and gages. Precision devices that use laser optics or vision systems coupled with sophisticated electronics are becoming commonplace. Vision systems and coordinate measuring machines are becoming critical elements for achieving superior quality.

Integrating Inspection into the Process

The integration of the **inspection** process into the manufacturing process or the manufacturing system is a critical step toward building products of superior quality. An example will help. Compare an electric typewriter with a computer that does word

processing. The electric typewriter is flexible. It types whatever words are wanted in whatever order. It types a specific font and type size. The computer can do all of this but can also, through its software, change font or type size, set italics; set bold, dark type; vary the spacing to justify the right margin; plus many other functions. It checks immediately for incorrect spelling and other defects like repeated words. The software system provides a signal to the hardware to flash the word so that the operator will know something is wrong and can make an immediate correction. If the system were designed to prevent the typist from typing repeated words, then this would be a *poka-yoke*, a term meaning defect prevention. Defect prevention is better than immediate defect detection and correction. Ultimately, the system should be able to forecast the probability of a defect, correcting the problem at the source. This means that the typist would have to be removed from the process loop, perhaps by having the system type out what it is told (convert oral to written directly). Poka-yoke devices and source inspection techniques

are keys to designing manufacturing systems that produce superior-quality products at low cost.

Products and Fabrications

In manufacturing, material things (goods) are made to satisfy human wants. **Products** result from manufacturing, which also includes conversion processes such as refining, smelting, and mining.

Products can be manufactured by fabricating or by processing. **Fabricating** is the manufacture of a product from pieces such as parts, components, or assemblies. Individual products or parts can also be fabricated. Separable discrete items such as tires, nails, spoons, screws, refrigerators, or hinges are fabricated.

Processing is also used to refer to the manufacture of a product by continuous means, or by a continuous series of operations, for a specific purpose. Continuous items such as steel strip, beverages, breakfast foods, tubing, chemicals, and petroleum are “processed.” Many processed products are marketed as discrete items, such as bottles of beer, bolts of cloth, spools of wire, and sacks of flour.

Separable discrete products, both piece parts and assemblies, are fabricated in a plant, factory, or mill, for instance, a textile or rolling mill. Products that flow (liquids, gases, grains, or powders) are processed in a *plant* or *refinery*. The *continuous-process industries* such as petroleum and chemical plants are sometimes called processing industries or flow industries.

To a lesser extent, the terms *fabricating industries* and *manufacturing industries* are used when referring to fabricators or manufacturers of large products composed of many parts, such as a car, a plane, or a tractor. Manufacturing often includes continuous-process treatments such as electroplating, heating, demagnetizing, and extrusion forming.

Construction or building is making goods by means other than manufacturing or processing in factories. Construction is a form of project manufacturing of useful goods like houses, highways, and buildings. The public may not consider construction as manufacturing because the work is not usually done in a plant or factory, but it can be. Companies can now build a custom house of any design in a factory, truck it to the building site, and assemble it on a foundation in two or three weeks.

Agriculture, fisheries, and commercial fishing produce real goods from useful labor. Lumbering is similar to both agriculture and mining in some respects, and mining should be considered processing. Processes that convert the raw materials from agriculture, fishing, lumbering, and mining into other usable and consumable products are also forms of manufacturing.

Workpiece and Its Configuration

In the manufacturing of goods, the primary objective is to produce a component having a desired geometry, size, and finish. Every component has a shape that is bounded by various types of surfaces of certain sizes that are spaced and arranged relative to each other. Consequently, a component is manufactured

by producing the surfaces that bound the shape. Surfaces may be:

1. Plane or flat
2. Cylindrical (external or internal)
3. Conical (external or internal)
4. Irregular (curved or warped)

Figure 1.6 illustrates how a shape can be analyzed and broken up into these basic bounding surfaces. Parts are manufactured by using a set or sequence of processes that will (1) remove portions of a rough block of material (bar stock, casting, forging) to produce and leave the desired bounding surface; (2) add portions of material (welding, additive manufacturing); or (3) cause material to form into a stable configuration that has the required bounding surfaces (casting, forging). Consequently, in designing an object, the designer specifies the shape, size, and arrangement of the bounding surface. The part design must be analyzed to determine what materials will provide the desired properties, including mating to other components, and what processes can best be employed to obtain the end product at the most reasonable cost. This is often the job of the engineer.

Roles of Engineers in Manufacturing

Many engineers have as their function the designing of products. The products are brought into reality through the processing or fabrication of materials. In this capacity, designers are a key factor in the material selection and manufacturing procedure. A **design engineer**, better than any other person, should know what the design is to accomplish, what assumptions can be made about service loads and requirements, what service environment the product must withstand, and what appearance the final product is to have. To meet these requirements, the material(s) to be used must be selected and specified. In most cases, to utilize the material and to enable the product to have the desired form, the designer knows that certain manufacturing processes will have to be employed. In many instances, the selection of a specific material may dictate what processing must be used. On the other hand, when certain processes must be used, the design may have to be modified for the process to be utilized effectively and economically. Certain dimensional sizes can dictate the processing, and some processes require certain sizes for the parts going into them. In converting the design into reality, many decisions must be made. In most instances, they can be made most effectively at the design stage. It is thus apparent that design engineers are a vital factor in the manufacturing process, and it is indeed a blessing to the company if they can *design for manufacturing*, that is, design the product so that it can be manufactured and/or assembled economically (i.e., at low unit cost). Design for manufacturing uses the knowledge of manufacturing processes, and so the design and manufacturing engineers should work together to integrate design and manufacturing activities.

Manufacturing engineers select and coordinate specific processes and equipment to be used or supervise and manage their use. Some design special tooling so that standard machines can be utilized in producing specific products. These engineers must have a broad knowledge of manufacturing processes and material behavior so that desired operations can be done effectively and efficiently

without overloading or damaging machines and without adversely affecting the materials being processed. Although it is not obvious, the most hostile environment the material may ever encounter in its lifetime is the processing environment.

Industrial engineers and **lean engineers** are responsible for manufacturing systems design (or layout) of factories. They must take into account the interrelationships of the factory design and the properties of the materials that the machines are going to process as well as the interreaction of the materials and processes. The choice of machines and equipment used in manufacturing and their arrangement in the factory are key design tasks.

The **lean engineer** has expertise in cell design, setup reduction (tool design), integrated quality control devices (poka-yokes and decouplers) and reliability (maintenance of machines and people) for the lean production system. See Chapters 42 and 43 for a discussion of cell design and lean engineering.

Materials engineers devote their major efforts in developing new and better materials. They, too, must be concerned with how these materials can be processed and with the effects that the processing will have on the properties of the materials. Although their roles may be quite different, it is apparent that a large proportion of engineers must concern themselves with the interrelationships of materials and manufacturing processes.

As an example of the close interrelationship of design, materials selection, and the selection and use of manufacturing processes, consider the common desk stapler. Suppose that this item is sold at the retail store for \$20. The wholesale outlet sold the stapler for \$16, and the manufacturer probably received about \$10 for it. Staplers typically consist of 10 to 12 parts and some rivets and pins. Thus, the manufacturer had to produce and assemble the 10 parts for about \$1 per part. Only by giving a great deal of attention to design, selection of materials, selection of processes, selection of equipment used for manufacturing (tooling), and utilization of personnel could such a result be achieved.

The stapler is a relatively simple product, yet the problems involved in its manufacture are typical of those that manufacturing industries must deal with. The elements of design, materials, and processes are all closely related, each having its effect on the performance of the device and the other elements. For example, suppose the designer calls for the component that holds the staples to be a metal part. Will it be a machined part rather than a formed part? Entirely different processes and materials need to be specified depending on the choice. Or, if a part is to be changed from metal to plastic, then a whole new set of fundamentally different materials and processes would need to come into play. Such changes would also have a significant impact on cost as well as the service (useful life) of the product.

Changing World Competition

In recent years, major changes in the world of goods manufacturing have taken place. Three of these are:

1. Worldwide competition for global products and their manufacture.
2. High-tech manufacturing advanced technology, computerization.
3. New manufacturing systems designs, strategies, and management.

Worldwide (global) competition is a fact of manufacturing life, and it will get stronger in the future. The goods you buy today may have been made anywhere in the world. For many U.S. companies, suppliers in China, India, and Mexico are not uncommon.

The second aspect, advanced manufacturing technology, usually refers to new machine tools or processes controlled by computers. Additive manufacturing and hybrid manufacturing are examples of new computer-controlled processes. Companies that produce additive manufacturing machine tools, though small, can have an enormous impact on factory productivity. Improved processes lead to better components and more durable goods. However, the new technology is often purchased from companies that have developed the technology, so this approach is important but may not provide a unique competitive advantage if your competitors can also buy the technology, provided that they have the capital. Some companies develop their own unique process technology and try to keep it proprietary as long as they can.

The third change and perhaps the real key to success in manufacturing is to implement lean manufacturing system design that can deliver, on time to the customer, super-quality goods at the lowest possible cost in a flexible way. Lean production is an effort to reduce waste and improve markedly the methodology by which goods are produced rather than simply upgrading the manufacturing process technology.

Manufacturing system design is discussed extensively in this book, and it is strongly recommended that students examine this material closely after they have gained a working knowledge of materials and processes. The next section provides a brief discussion of manufacturing system designs (factory designs).

Manufacturing System Designs

Five designs can be identified: the job shop, the flow shop, the linked-cell shop, the project shop, and the continuous process (see **Figure 1.7**). The continuous process deals with liquids and/or gases (such as an oil refinery) rather than solids or discrete parts and is used mostly by the chemical engineer.

The most common of these layouts is the **job shop**, characterized by large varieties of components, general-purpose machines, and a functional layout (**Figure 1.8**). This means that machines are collected by function (all lathes together, all mills together, and all grinding machines together), and the parts are routed around the shop in small lots to the various machines. The layout of the factory shows the multiple paths through the shop. The material is moved from machine to machine in carts or containers (called the lot or batch).

Flow shops are characterized by larger volumes of the same part or assembly, special-purpose machines and equipment, less variety, less flexibility, and more mechanization. Flow shop layouts are typically either continuous or interrupted and can be for manufacturing or assembly, as shown in **Figure 1.9**. If continuous, a production line is built that basically runs one large-volume complex item in great quantity and nothing else. The common light bulb is made this way. A transfer line producing an engine block is another typical example. If interrupted,

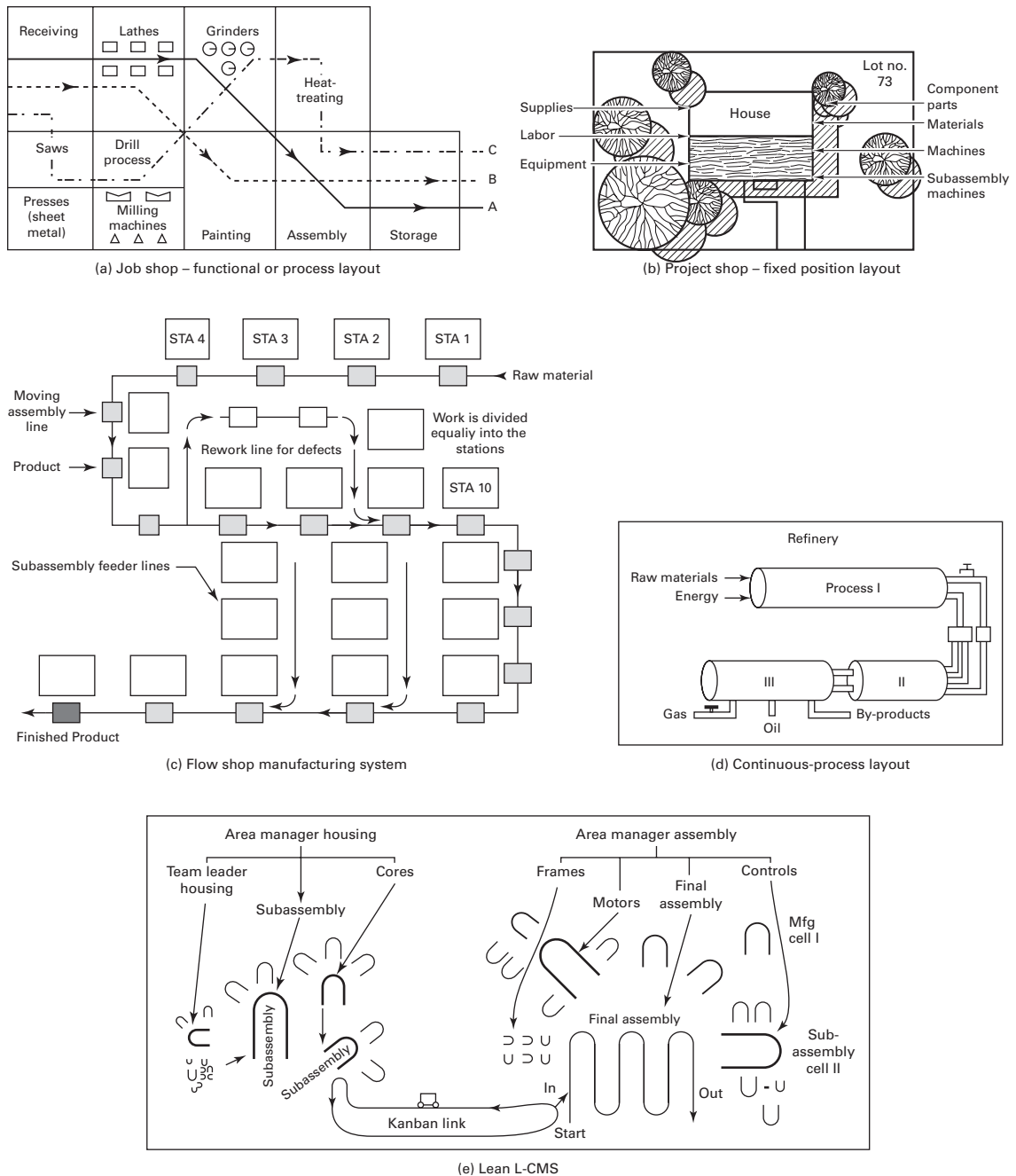


FIGURE 1.7 Schematic layouts of factory designs: (a) functional or job shop, (b) fixed location or project shop, (c) flow shop or assembly line, (d) continuous process, and (e) linked-cell design.

the line manufactures large lots but is periodically “changed over” to run a similar but different component.

The **linked-cell manufacturing system (L-CMS)** is composed of manufacturing and subassembly cells connected to final assembly (linked) using a unique form of inventory and information control called *kanban*. The L-CMS is used in lean

production systems where manufacturing processes and subassemblies are restructured into U-shaped cells so that they can operate on a one-piece-flow basis, like final assembly.

As shown in **Figure 1.10**, the lean production factory is laid out (designed) very differently than the mass production system. More than 70% of all manufacturing industries

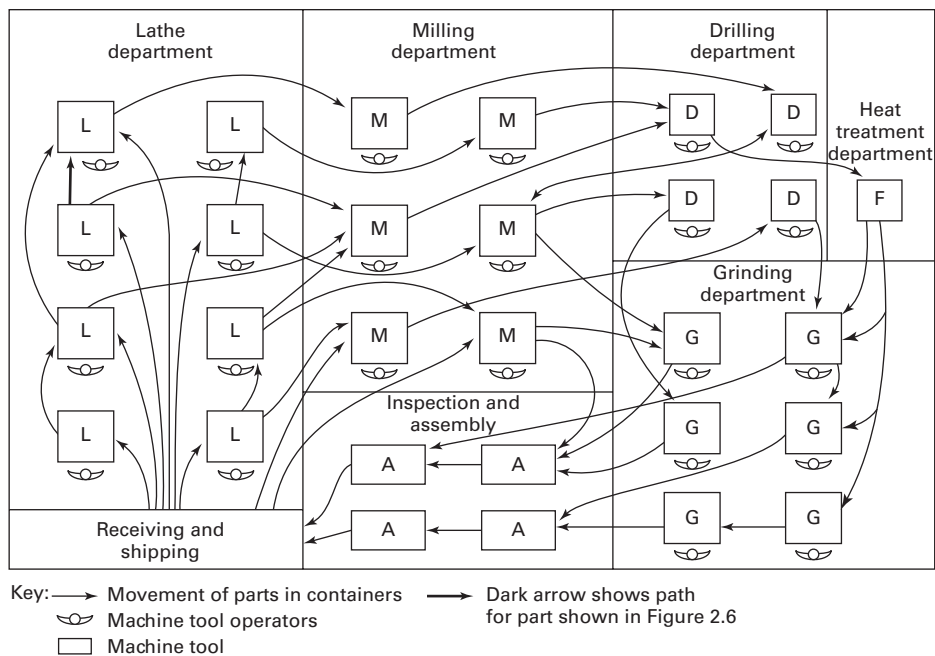


FIGURE 1.8 Schematic layout of a job shop where processes are gathered functionally into areas or departments. Each square block represents a manufacturing process or machine tool, which sometimes called the “spaghetti design.”

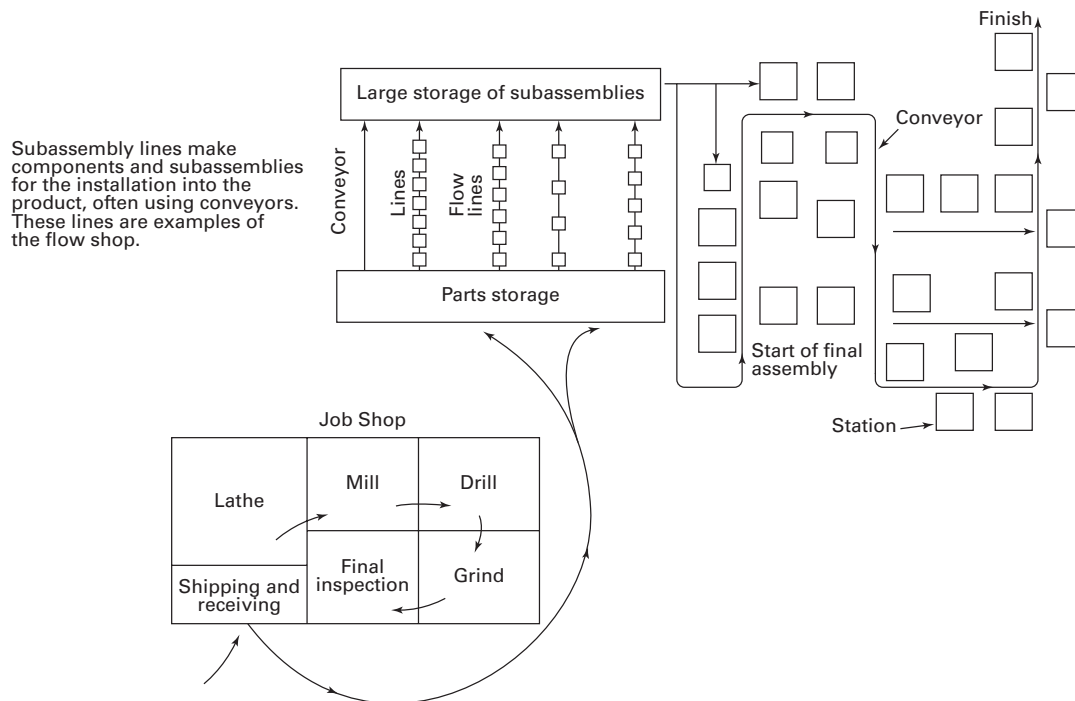


FIGURE 1.9 Flow shops and lines are common in the mass production system. Final assembly is usually a moving assembly line. The product travels through stations in a specific amount of time. The work needed to assemble the product is distributed into the stations, called division of labor. The moving assembly line for cars is an example of the flow shop.

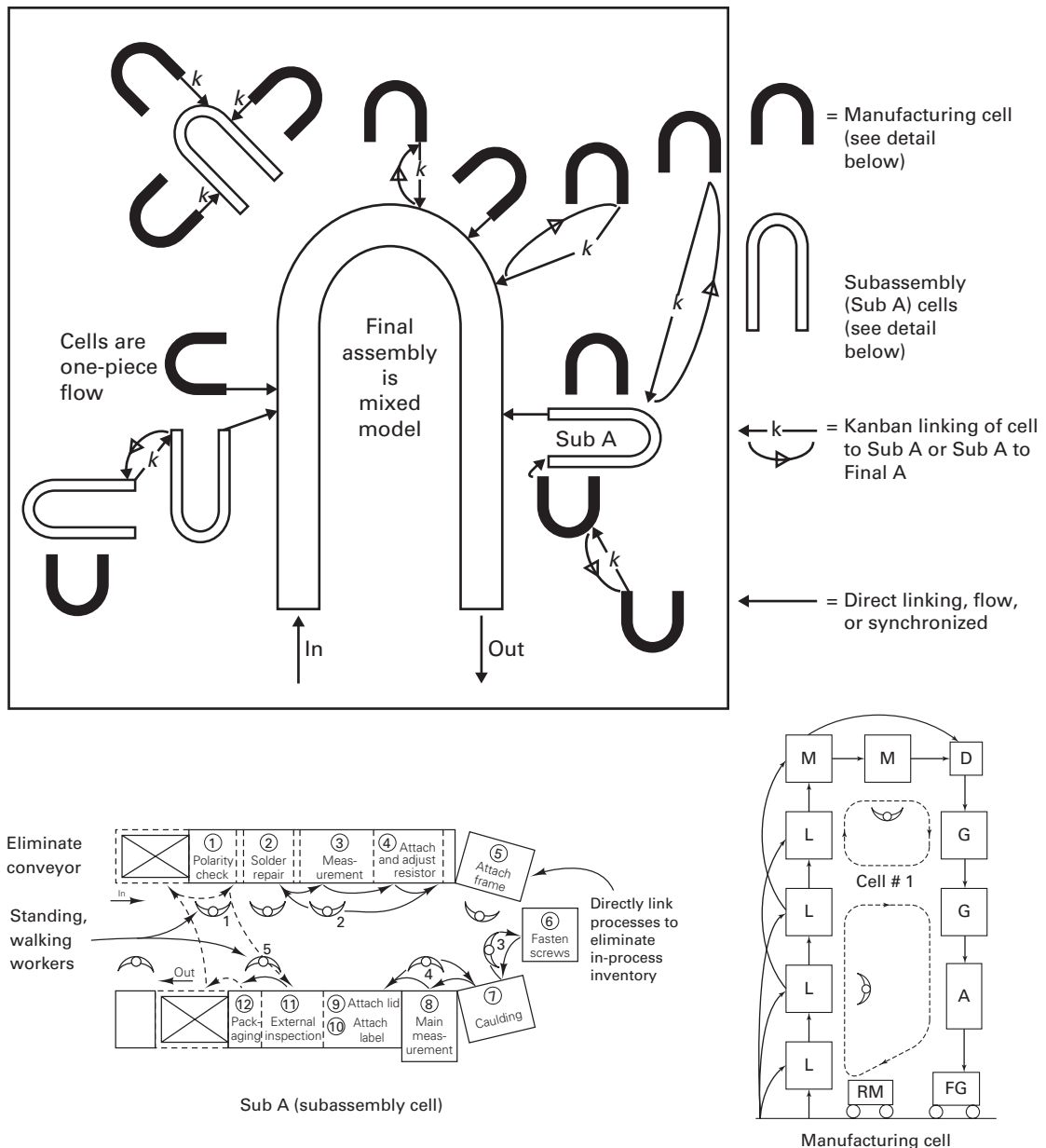


FIGURE 1.10 The linked-cell manufacturing system for lean production has subassembly and manufacturing cells connected to final assembly by kanban links. The traditional subassembly lines can be redesigned into U-shaped cells as part of the conversion of mass production to lean production.

have adopted lean production. Hundreds of manufacturing companies have dismantled their conveyor-based flow lines and replaced them with U-shaped subassembly cells, providing flexibility while eliminating the need for line balancing. Chapters 42 and 43 discuss subassembly cells and manufacturing cells.

The **project shop** is characterized by the immobility of the item being manufactured. In the construction industry, bridges and roads are good examples. In the manufacture of goods, large airplanes, ships, large machine tools, and locomotives are manufactured in project shops. It is necessary that the workers,

machines, and materials come to the site. The number of end items is not very large, and therefore the lot sizes of the components going into the end item are not large. Thus, the job shop usually supplies parts and subassemblies to the project shop in small lots.

Continuous processes are used to manufacture liquids, oils, gases, and powders. These manufacturing systems are usually large plants producing goods for other producers or mass-producing canned or bottled goods for consumers. The manufacturing engineer in these factories is often a chemical engineer.

Naturally, there are many hybrid forms of these manufacturing systems, but the job shop is a very common system. Because of its design, the job shop has been shown to be the least cost-efficient of all the systems. Component parts in a typical job shop spend only 5% of their time in machines and the rest of the time waiting or being moved from one functional area to the next. Once the part is on the machine, it is actually being processed (i.e., having value added to it by the changing of its shape) only about 30% to 40% of the time. The rest of the time parts are being loaded, unloaded, inspected, and so on. The advent of **numerical control** machines increased the percentage of time that the machine is making chips because tool movements are programmed and the machines can automatically change tools or load or unload parts.

However, there are a number of trends that are forcing manufacturing management to consider means by which the job shop system itself can be redesigned to improve its overall efficiency. These trends have forced manufacturing companies to convert their batch-oriented job shops into L-C manufacturing systems, with the manufacturing and subassembly cells structured around specific products.

A technique called Value Stream Mapping (VSM) is widely employed as a means to examine the product flow and the associated information flow. In a value stream map, all of the steps or processes required to bring a product (or a family of products) from raw material to finished goods (to the customer) are outlined. Both value-adding and non-value-adding steps are recorded. The map is used to describe the current state of the manufacturing process, after analysis a future or improved state is developed, often a manufacturing cell as shown in Figure 1.10. VSM is discussed more extensively in Chapter 43.

Another way to identify families of products with a similar set of manufacturing processes is called group technology. **Group technology (GT)** can be used to restructure the factory floor. GT is a concept whereby similar parts are grouped together into part families. Parts of similar size and shape can often be processed through a similar set of processes. A part family based on manufacturing would have the same set or sequences of manufacturing processes. The machine tools needed to process the part family are gathered into a cell. Thus, with GT, job shops can be restructured into cells, each cell specializing in a particular family of parts. The parts are handled less, machine setup time is shorter, in-process inventory is lower, and the time needed for parts to get through the manufacturing system (called the throughput time) is greatly reduced.

Basic Manufacturing Processes

It is the manufacturing processes that create or add value to a product. The manufacturing processes can be classified as:

- Casting, foundry, or molding processes
- Forming or metalworking processes
- Machining (material removal) processes
- Nano, micro, and nontraditional processes
- Joining and assembly
- Surface treatments (finishing)

- Additive manufacturing or 3D printing
- Heat treating
- Other

These classifications are not mutually exclusive. For example, some finishing processes involve a small amount of metal removal or metal forming. A laser can be used for joining metal removal, heat treating, or additive manufacturing. Occasionally, we have a process such as shearing, which is really metal cutting but is viewed as a (sheet) metal-forming process. Assembly may involve processes other than joining. The categories of process types are far from perfect.

Casting and molding processes are widely used to produce parts that often require other follow-up processes, such as **machining**. Casting uses molten metal to fill a cavity. The metal retains the desired shape of the mold cavity after solidification. An important advantage of casting and molding is that, in a single step, materials can be converted from a crude form into a desired shape. In most cases, a secondary advantage is that excess or scrap material can easily be recycled. **Figure 1.11** illustrates schematically some of the basic steps in the *lost-wax or investment casting process*, one of many processes used in the foundry industry.

Casting processes are commonly classified into two types: permanent mold (a mold can be used repeatedly) or nonpermanent mold (a new mold must be prepared for each casting made). Molding processes for plastics and composites are included in the chapters on forming processes.

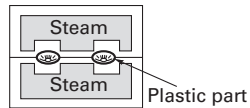
Forming and shearing operations typically utilize material (metal or plastics) that has been previously cast or molded. In many cases, the materials pass through a series of forming or shearing operations, so the form of the material for a specific operation may be the result of all the prior operations. The basic purpose of forming and shearing is to modify the shape and size and/or physical properties of the material.

Metal-forming and shearing operations are done both “hot” and “cold,” a reference to the temperature of the material at the time it is being processed with respect to the temperature at which this material can recrystallize (i.e., grow new grain structure). **Figure 1.12** shows the process by which the fender of a car is made using a series of metal-forming processes.

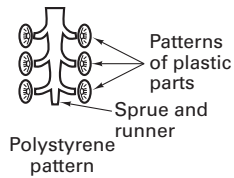
Metal cutting, machining, or metal removal processes refer to the removal of certain selected areas from a part to obtain a desired shape or finish. Chips are formed by interaction of a cutting tool with the material being machined. **Figure 1.13** shows a chip being formed by a single-point cutting tool in a machine tool called a lathe. The manufacturing engineer may be called on to specify the cutting parameters such as cutting speed, feed, or depth of cut. The engineer may also have to select the cutting tools for the job.

Cutting tools used to perform the basic turning on the lathe are shown in Figure 1.13. The cutting tools are mounted in machine tools, which provide the required movements of the tool with respect to the work (or vice versa) to accomplish the process desired. In recent years, many new machining processes have been developed.

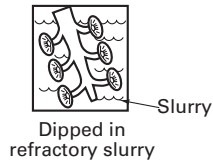
The seven basic machining processes are shaping, drilling, turning, milling, sawing, broaching, and abrasive machining. Each of these basic processes is extensively discussed.



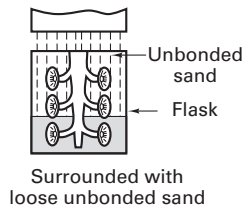
To make the foam parts, metal molds are used. Beads of polystyrene are heated and expanded in the mold to get parts.



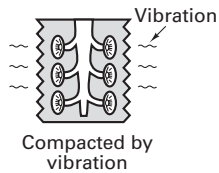
A pattern containing a sprue, runners, risers, and parts is made from single or multiple pieces of foamed polystyrene plastic.



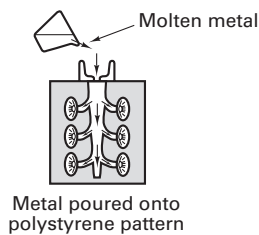
The polystyrene pattern is dipped in a ceramic slurry, which wets the surface and forms a coating about 0.005 in. thick.



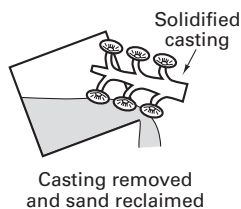
The coated pattern is placed in a flask and surrounded with loose, unbonded sand.



The flask is vibrated so that the loose sand is compacted around the pattern.



During the pouring of molten metal, the hot metal vaporizes the pattern and fills the resulting cavity.



The solidified casting is removed from flask and the loose sand reclaimed.

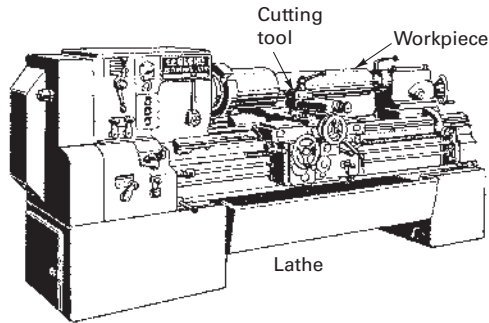
FIGURE 1.11 Schematic of the lost-foam casting process.

Historically, eight basic types of machine tools have been developed to accomplish the basic processes. These machine tools are called shapers (and planers), drill presses, lathes, boring machines, milling machines, saws, broaches, and grinders. Today, most machine tools are capable of performing more than one of the basic machining processes. Shortly after numerical control was invented in the mid-1950s, machining centers were

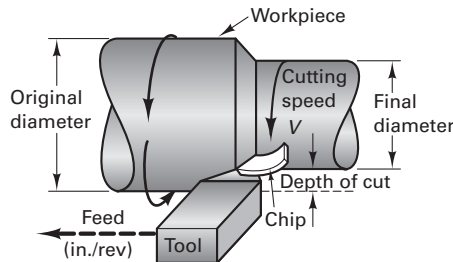
developed that could combine many of the basic processes, plus other related processes, into a single machine tool with a single workpiece setup.

Aside from the chip-making processes, there are processes wherein metal is removed by chemical, electrical, electrochemical, or thermal sources. Generally speaking, these nontraditional processes have evolved to fill a specific need when conventional

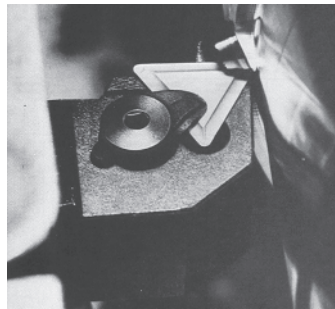
The machining process (turning on a lathe)



The workpiece is mounted in a workholding device in a machine tool (lathe) and is cut (machined) with a cutting tool.



The workpiece is rotated while the tool is fed at some feed rate (inches per revolution). The desired cutting speed V determines the rpm of the workpiece. This process is called turning.



The cutting tool interacts with the workpiece to form a chip by a shearing process. The tool shown here is an indexable carbide insert tool with a chip-breaking groove.

FIGURE 1.13 Single-point metal-cutting process (turning) produces a chip while creating a new surface on the workpiece. (Courtesy of J. T. Black.)



FIGURE 1.14 High-strength aluminum antenna bracket for a space satellite produced by additive manufacturing. The part is approximately 40 cm (16 in.) in length and weighs less than 1 kg (2.2 lbs). (Courtesy of EOS GmbH.)

all but welding is used in the sequence of operations to produce a computer. Starting in the upper left corner, microelectronic fabrication methods produce entire integrated circuits (ICs) of solid-state (no moving parts) components, with wiring and connections, on a single piece of semiconductor material, usually single-crystalline silicon. Arrays of ICs are produced on thin, round disks of semiconductor material called wafers. Once the semiconductor on the wafer has been fabricated, the finished wafer is cut up into individual ICs or chips. Next, at level 2, these chips are individually housed with connectors or leads making up “dies” that are placed into “packages” using adhesives. The packages provide protection from the elements and a connection between the die and another subassembly called the printed circuit boards (PCBs). At level 3, IC packages, along with other discrete components (e.g., resistors, capacitors, etc.), are soldered onto PCBs and then assembled with even larger circuits on PCBs. This is sometimes referred to as electronic assembly. Electronic packages at this level are called cards or printed

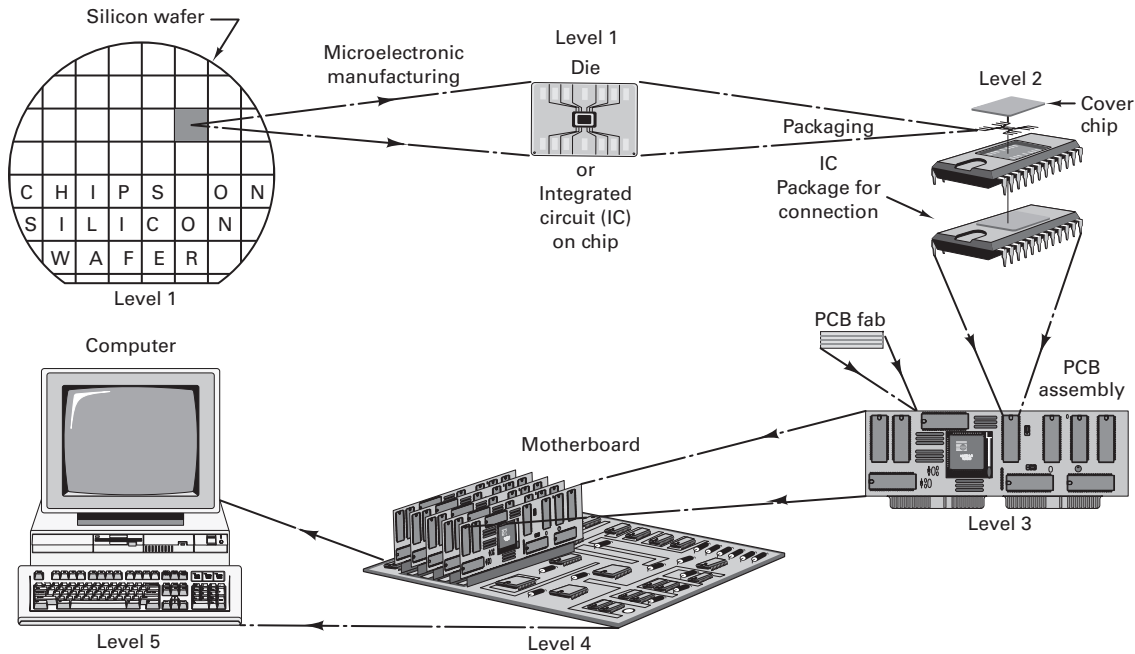


FIGURE 1.15 How an electronic product is made.

wiring assemblies. Next, series of cards are combined on a back-panel PCB, also known as a motherboard or simply a board. This level of packaging is sometimes referred to as card-on-board packaging. Ultimately, card-on-board assemblies are put into housings using mechanical fasteners and snap fitting and finally integrated with power supplies and other electronic peripherals through the use of cables to produce final commercial products.

Finishing processes are yet another class of processes typically employed for cleaning, removing burrs left by machining, or providing protective and/or decorative surfaces on workpieces. Surface treatments include chemical and mechanical cleaning, deburring, painting, plating, buffing, galvanizing, and anodizing.

Heat treatment is the heating and cooling of a metal for the specific purpose of altering its metallurgical and mechanical properties. Because changing and controlling these properties is so important in the processing and performance of metals, heat treatment is a very important manufacturing process. Each type of metal reacts differently to heat treatment. Consequently, a designer should know not only how a selected metal can be altered by heat treatment but also, equally important, *how a selected metal will react, favorably or unfavorably, to any heating or cooling that may be incidental to the manufacturing processes.*

Other Manufacturing Operations

In addition to the processes already described, there are many other fundamental manufacturing operations that must be considered. Inspection determines whether the desired objectives stated by the designer in the specifications have been achieved. This activity provides feedback to design and manufacturing with regard to the process capability. Essential to this inspection function are measurement activities. In the factory,

measurements by attributes or variables (Chapter 10) inspect the outcomes from the process and determine how they compare to the specifications. The many aspects of quality control are presented in Chapter 12. Chapter 11 covers testing, where a product is tried by actual function or operation or by subsection to external effects. Although a test is a form of inspection, it is often not viewed that way. In manufacturing, parts and materials are inspected for conformance to the dimensional and physical specifications, while testing may simulate the environmental or usage demands to be made on a product after it is placed in service. Complex processes may require many tests and inspections. Testing includes life-cycle tests, destructive tests, nondestructive testing to check for processing defects, wind-tunnel tests, road tests, and overload tests.

Transportation of goods in the factory is often referred to as *material handling* or *conveyance* of the goods and refers to the transporting of unfinished goods (work-in-process) in the plant and supplies to and from, between, and during manufacturing operations. Loading, positioning, and unloading are also material-handling operations. Transportation, by truck or train, is material handling between factories. Proper manufacturing system design and mechanization can reduce material handling in countless ways.

Automatic material handling is a critical part of continuous automatic manufacturing. The word *automation* is derived from automatic material handling. Material handling, a fundamental operation done by people and by conveyors and loaders, often includes positioning the workpiece within the machine by indexing, shuttle bars, slides, and clamps. In recent years, wire-guided automated guided vehicles (AGVs) and automatic storage and retrieval systems (AS/RSs) have been developed in an attempt to replace forklift trucks on the factory floor. Another form of material handling, the mechanized removal of waste (chips,

trimming, and cutoffs), can be more difficult than handling the product. Chip removal must be done before a tangle of scrap chips damages tooling or creates defective workpieces.

Most texts on manufacturing processes do not mention **packaging**, yet the packaging is often the first thing the customer sees. Also, packaging often maintains the product's quality between completion and use. (The term *packaging* is also used in electronics manufacturing to refer to placing micro-electronic chips in containers for mounting on circuit boards.) Packaging can also prepare the product for delivery to the user. It varies from filling ampules with antibiotics to steel-strapping aluminum ingots into palletized loads. A product may require several packaging operations. For example, Hershey Kisses are (1) individually wrapped in foil, (2) placed in bags, (3) put into boxes, and (4) placed in shipping cartons.

Weighing, filling, sealing, and labeling are packaging operations that are highly automated in many industries. When possible, the cartons or wrappings are formed from material on rolls in the packaging machine. Packaging is a specialty combining elements of product design (styling), material handling, and quality control. Some packages cost more than their contents (e.g., cosmetics and razor blades).

During **storage**, nothing happens intentionally to the product or part except the passage of time. Part or product deterioration on the shelf is called **shelf life**, meaning that items can rust, age, rot, spoil, embrittle, corrode, creep, and otherwise change in state or structure, while supposedly nothing is happening to them. Storage is detrimental, wasting the company's time and money. The best strategy is to keep the product moving with as little storage as possible. Storage during processing must be *eliminated*, not automated or computerized. Companies should avoid investing heavily in large automated systems that do not alter the bottom line. Have the outputs improved with respect to the inputs, or has storage simply increased the costs (indirectly) without improving either the quality or the throughput time?

By not storing a product, the company avoids having to (1) remember where the product is stored, (2) retrieve it, (3) worry about its deteriorating, or (4) pay storage (including labor) costs. Storage is the biggest waste of all and should be eliminated at every opportunity.

Understanding Your Process Technology

Understanding the process technology of the company is very important for everyone in the company. Manufacturing technology affects the design of the product and the manufacturing system, the way in which the manufacturing system can be controlled, the types of people employed, and the materials that can be processed. **Table 1.4** outlines the factors that characterize a process technology. Take a process you are familiar with and think about these factors. One valid criticism of American companies is that their managers seem to have an aversion to understanding their companies' manufacturing technologies. Failure to understand the company business (i.e., its fundamental process technology) can lead to the failure of the company.

The way to overcome technological aversion is to run the process and study the technology. Only someone who has run

TABLE 1.4 Characterizing a Process Technology

Mechanics (statics and dynamics of the process)
How does the process work?
What are the process mechanics (statics, dynamics, friction)?
What physically happens, and what makes it happen? (Understand the physics.)
Economics or costs
What are the tooling costs, the engineering costs?
Which costs are short term, which long term?
What are the setup costs?
Time spans
How long does it take to set up the process initially?
What is the throughput time?
How can these times be shortened?
How long does it take to run a part once it is set up (cycle time)?
What process parameters affect the cycle time?
Constraints
What are the process limits?
What cannot be done?
What constrains this process (sizes, speeds, forces, volumes, power, cost)?
What is very hard to do within an acceptable time/cost frame?
Uncertainties, process reliability, and safety
What can go wrong?
How can this machine fail?
What do people worry about with this process?
Is this a reliable, safe, and stable process?
Skills
What operator skills are critical?
What is not done automatically?
How long does it take to learn to do this process?
Flexibility
Can this process be adapted easily for new parts of a new design or material?
How does the process react to changes in part design and demand?
What changes are easy to do?
Process capability
What are the accuracy and precision of the process?
What tolerances does the process meet? (What is the process capability?)
How repeatable are those tolerances?

a drill press can understand the sensitive relationship between feed rate and drill torque and thrust. All processes have these "know-how" features. Those who run the processes must be part of the decision-making for the factory. The CEO who takes a vacation working on the plant floor and learning the processes will be well on the way to being the head of a successful company.

Product Life Cycle and Life-Cycle Cost

Manufacturing systems are dynamic and change with time. There is a general, traditional relationship between a product's life cycle and the kind of manufacturing system used to make the product. **Figure 1.16** simplifies the **product life cycle** into these steps, again using an S-shaped curve.

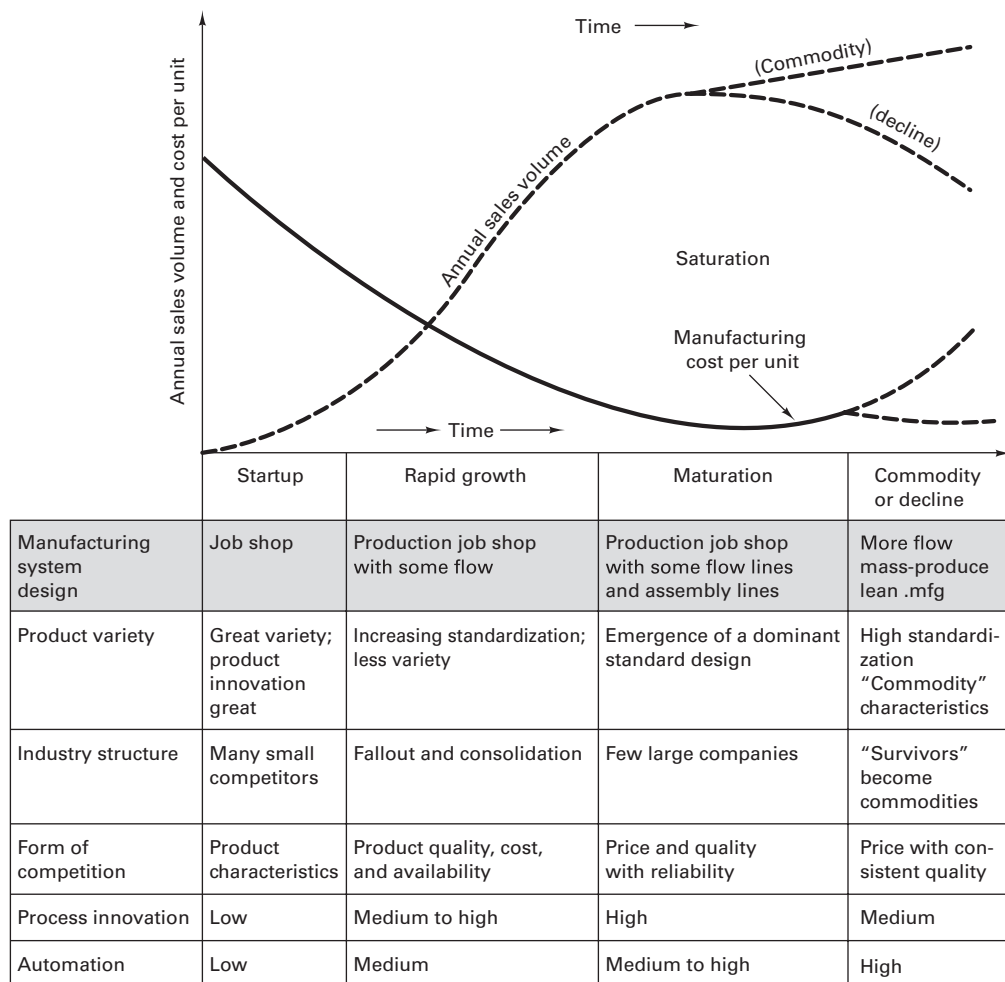


FIGURE 1.16 Product life-cycle costs change with the classic manufacturing system designs.

1. **Startup.** New product or new company, low volume, small company.
2. **Rapid growth.** Products become standardized and volume increases rapidly. Company's ability to meet demand stresses its capacity.
3. **Maturation.** Standard designs emerge. Process development is very important.
4. **Commodity.** Long-life, standard-of-the-industry type of product.
5. **Decline.** Product is slowly replaced by improved products.

The maturation of a product in the marketplace generally leads to fewer competitors, with competition based more on price and on-time delivery than on unique product features. As the competitive focus shifts during the different stages of the product life cycle, the requirements placed on manufacturing—cost, quality, flexibility, and delivery dependability—also change. The stage of the product life cycle affects the product design stability, the length of the product development cycle, the frequency of engineering change orders, and the commonality of

components—all of which have implications for manufacturing process technology.

During the design phase of the product, much of the cost of manufacturing and assembly is determined. Assembly of the product is inherently integrative as it focuses on groups of parts and the supply chain.

It is crucial to achieve this integration during the design phase because about 70% of the life-cycle cost of a product is determined when it is designed. Design choices determine materials; fabrication methods; assembly methods; and, to a lesser degree, material-handling options, inspection techniques, and other aspects of the production system. Manufacturing engineers and internal customers can influence only a small part of the overall cost if they are presented with a finished design that does not reflect their concerns. Therefore, all aspects of production should be included if product designs are to result in real functional integration.

Life-cycle costs include the costs of all the materials, manufacture, use, repair, and disposal of a product. Early design decisions determine about 60% of the cost, and all activities up to the start of full-scale development determine about 75%. Later

decisions can make only minor changes to the ultimate total unless the design of the manufacturing system is changed.

In short, the concept of product life cycle provides a framework for thinking about the product's evolution through time and the kind of market segments that are likely to develop at various times. Analysis of life-cycle costs shows that the design of the manufacturing system determines the cost per unit, which generally decreases over time with process improvements and increased volumes.

The L-CMS design discussed in Chapters 42 and 43 (known as lean production or the **Toyota Production System [TPS]**) has transformed the automobile industry and many other industries to be able to make a large variety of products in small volumes with very short throughput times. Thousands of companies have implemented lean manufacturing to reduce waste, decrease cost per unit significantly while maintaining flexibility, and improve quality. This is a new business model affecting product development, design, purchasing, marketing, customer service, and all other aspects of the company.

Low-cost manufacturing does not just happen. There is a close, interdependent relationship between the design of a product, the selection of materials, the selection of processes and equipment, the design of the processes, and tooling selection and design. Each of these steps must be carefully considered, planned, and coordinated before manufacturing starts.

Some of the steps involved in getting the product from the original idea stage to daily manufacturing are discussed in more detail in Chapter 9. The steps are closely related to each other. For example, the design of the tooling is dependent on the design of the parts to be produced. It is often possible to simplify the tooling if certain changes are made in the design of the parts or the design of the manufacturing systems. Similarly, the material selection will affect the design of the tooling or the processes selected. Can the design be altered so that it can be produced with tooling already on hand and thus avoid the purchase of new equipment? Close coordination of all the various phases of design and manufacture is essential if economy is to result.

With the advent of computers and computer-controlled machines, the integration of the design function and the manufacturing function through the computer is a reality. This is

usually called CAD/CAM (computer-aided manufacturing). The key is a common database from which detailed drawings can be made for the designer and the manufacturer and from which programs can be generated to make all the tooling. In addition, extensive computer-aided testing and inspection of the manufactured parts is taking place. There is no doubt that this trend will continue at ever-accelerating rates as computers become cheaper and smarter, but at this time, the computers necessary to accomplish complete computer-integrated manufacturing (CIM) are expensive and the software very complex. Implementing CIM requires a lot of manpower as well.

Comparisons of Manufacturing System Design

When designing a manufacturing system, two customers must be taken into consideration: the external customer who buys the product and the internal customer who makes the product. The external customer is likely to be global and demand greater variety with superior quality and reliability. The internal customer is often empowered to make critical decisions about how to make the products. The Toyota Motor Company is making vehicles in 25 countries. Their truck plant in Indiana has the capacity to make 150,000 vehicles per year (creating 2300 jobs), using the TPS. An appreciation of the complexity of the manufacturing system design problem is shown in **Figure 1.17**, where the choices between the system designs are reflected against the number of different products, or parts being made in the system, often called *variety*. Clearly, there are many choices regarding which method (or system) to use to make the goods. A manufacturer never really knows how large or diverse a market will be. If a diverse and specialized market emerges, a company with a focused flow-line system may be too inflexible to meet the varying demand. If a large but homogeneous market develops, a manufacturer with a flexible system may find production costs too high and the flexibility unexploitable.

Another general relationship between manufacturing system designs and production volumes is shown in **Figure 1.18**.

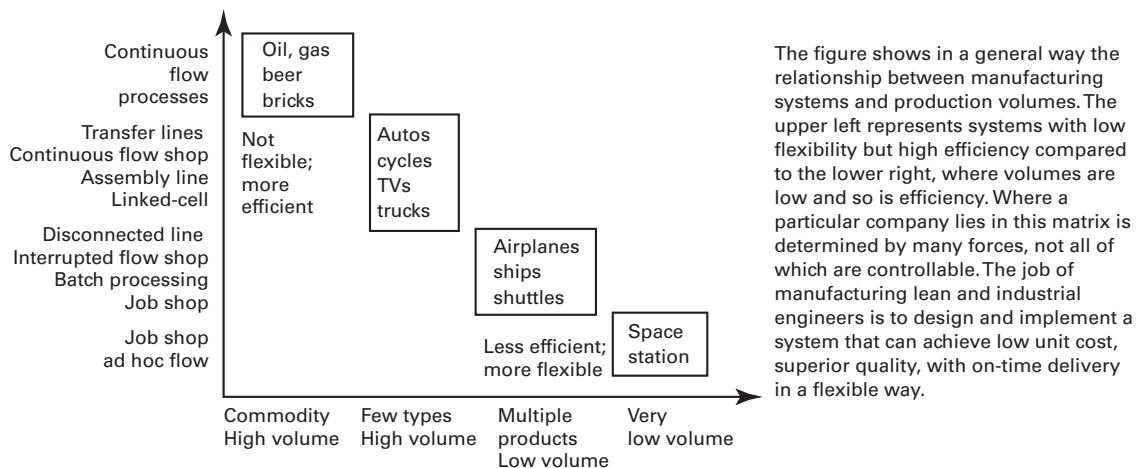
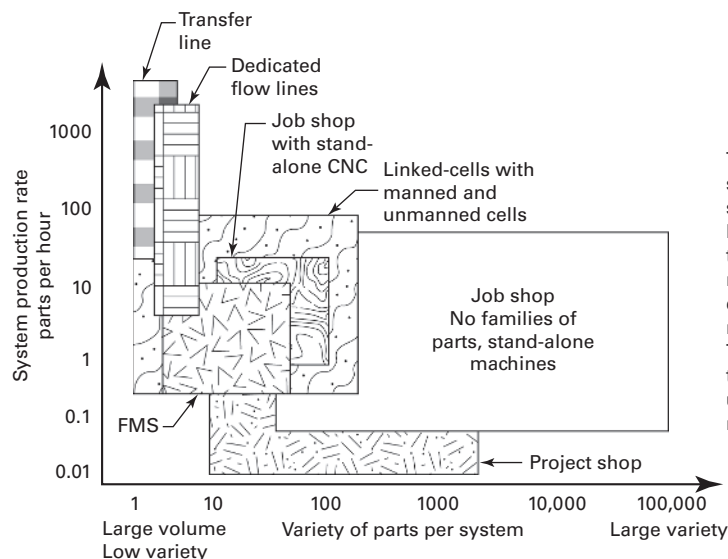


FIGURE 1.17 This figure shows in a general way the relationship between manufacturing systems and production volumes.



This part variety-production rate matrix shows examples of particular manufacturing system designs. This matrix was developed by Black based on real factory data. Notice there is a large amount of overlap in the middle of the matrix, so the manufacturing engineer has many choices regarding which method or system to use to make the goods. This book will show the connection between the process and the manufacturing system used to produce the products, turning raw materials into finished goods.

FIGURE 1.18 Different manufacturing system designs produce goods at different production rates.

New Manufacturing Systems

The manufacturing process technology described in this chapter is available worldwide. Many countries have about the same level of process development when it comes to manufacturing technology. Much of the technology existing in the world today was developed in the United States, Germany, France, and Japan. More recently Taiwan, Korea, and China have made great inroads into American markets, particularly in the automotive and electronics industries. Many companies have developed and promoted a different kind of manufacturing system design. This new manufacturing system, called lean production or lean manufacturing, will take its place with the American Armory System and the Ford System for mass production. This new manufacturing system, developed by the Toyota Motor Company, has been successfully adopted by many American companies.

For lean production to work, units with no defects (100% good) must flow rhythmically to subsequent processes without interruption. To accomplish this, an integrated quality control program has to be developed. The responsibility for quality has been given to manufacturing and the internal customer. All the employees are inspectors and are empowered to make it right the first time. There is a companywide attitude toward constant

quality improvement. Make quality easy to see, stop the line when something goes wrong, and inspect things 100% if necessary to prevent defects from occurring. The results of this system are astonishing in terms of quality, low cost, and on-time delivery of goods to the customer.

The most important factor in economical and successful manufacturing is the manner in which the resources—labor, materials, and capital—are organized and managed so as to provide effective coordination, responsibility, and control. Part of the success of lean production can be attributed to a different management approach. This approach is characterized by a holistic attitude (i.e., respect) toward people.

The real secret of successful manufacturing lies in designing a manufacturing system in which everyone who works in the system understands how the system works, how the flow of goods is controlled, with the decision-making placed at the correct level. The engineers also must possess a broad fundamental knowledge of design, metallurgy, processing, economics, accounting, and human relations. In the manufacturing game, low-cost mass production is the result of teamwork within an integrated manufacturing/production system. This is the key to producing superior quality at less cost with on-time delivery by a flexible system.

Review Questions

1. What role does manufacturing play relative to the standard of living of a country?
2. Aren't all goods really consumer goods, depending on how you define the customer? Discuss.
3. The Subway sandwich shop is an example of a job shop, a flow shop, or a project shop, which?
4. How does a system differ from a process? From a machine tool? From a job? From an operation?
5. Is a cutting tool the same thing as a machine tool? Discuss.
6. What are the major classifications of basic manufacturing processes?

7. Casting is often used to produce a complex-shaped part to be made from a hard-to-machine metal. How else could the part be made?
8. In the lost-wax casting process, what happens to the foam?
9. In making a gold medal, what do we mean by a “relief image” cut into the die?
10. How is a railroad station like a station on an assembly line?
11. Because no work is being done on a part when it is in storage, it does not cost you anything. True or false? Explain.
12. What forming processes are used to make a paper clip?
13. What is tooling in a manufacturing system?
14. It is acknowledged that chip-type machining is basically an inefficient process. Yet it is probably used more than any other to produce desired shapes. Why?
15. Compare Figures 1.1 and 1.16. What are the stages of the product life cycle for a computer?
16. In a modern safety razor with three or four blades that sells for \$1, what do you think the cost of the blades might be?
17. List three purposes of packaging operations.
18. *Assembly* is defined as “the putting together of all the different parts to make a complete machine.” Think of (and describe) an assembly process. Is making a club sandwich an assembly process? What about carving a turkey? Is this an assembly process?
19. What are the physical elements in a manufacturing system?
20. In the production system, who usually figures out how to make the product?
21. In Figure 1.8, what do the lines connecting the processes represent?
22. Characterize the process of squeezing toothpaste from a tube (extrusion of toothpaste) using Table 1.4 as a guideline. See the index for help on extrusion.
23. It has been said that low-cost products are more likely to be more carefully designed than high-priced items. Do you think this is true? Why or why not?
24. Proprietary processes are closely held or guarded company secrets. The chemical makeup of a lubricant for an extrusion process is a good example. Give another example of a proprietary process.
25. If the rolls for the cold-rolling mill that produces the sheet metal used in your car cost \$300,000 to \$400,000, how is it that your car can still cost less than \$20,000?
26. Make a list of service systems, giving an example of each.
27. What is the fundamental difference between a service system and a manufacturing system?
28. In the process of buying a calf, raising it to a cow, and disassembling it into “cuts” of meat for sale, where is the “value added”?
29. What kind of process is powder metallurgy: casting or forming?
30. In view of Figure 1.2, who really determines the selling price per unit?
31. What costs make up manufacturing costs (sometimes called factory costs)?
32. What are the major phases of a product life cycle?
33. How many different manufacturing systems might be used to make a component with annual projected sales of 16,000 parts per year with 10–12 different models (varieties)?
34. In general, as the annual volume for a product increases, the unit cost decreases. Explain.

Problems

1. The Toyota truck plant in Indiana produces 150,000 trucks per year. The plant runs one eight-hour shift and makes 400 trucks per day. About 1300 people work on the final assembly line. Each truck has about 20 direct labor hours per car in it.
 - a. Assuming the truck sells for \$26,000 and workers earn \$50 per hour in wages and benefits, what percentage of the cost of the truck is in direct labor?
 - b. What is the production rate of the final assembly line?
2. A company is considering making automobile bumpers from aluminum instead of from steel. List some of the factors **it would** have to consider in arriving at its decision.
3. Many companies are critically examining the relationship of product design to manufacturing and assembly. Why do they call this concurrent engineering?
4. We can analogize your university to a manufacturing system that produces graduates. Assuming that it takes 4 years to get a college degree and that each course really adds value to the student’s knowledge base, what percentage of the 4 years is “value adding” (percentage of time in class plus two hours of preparation for each hour in class)?
5. What kind of manufacturing system (design) is your university?
6. What are the major process steps in the assembly of a subway sandwich?
7. What is the relationship between Figures 1.2 and 1.4?
8. Recently, National Geographic magazine asked the US Librarian of Congress to compile a list of the 10 most meaningful advances in history—inventions and innovations of significance to modern life. The “Top Ten Innovations” list

that was compiled included: (1) Printing press, (2) Light bulb, (3) Airplane, (4) Personal computer, (5) Vaccines, (6) Automobile, (7) Clock, (8) Telephone, (9) Refrigeration, and (10) Camera.

- a. Select one of the items from the list and discuss the materials or materials advances that enabled its creation.
- b. For the same item selected in Part 1, discuss the manufacturing processes, or process advances, that enabled its creation.
- c. If new items were to be added to the list over the next 10 to 20 years, what do you think they would be?
- d. For items suggested in Part 3, what materials or process advances would have been instrumental in their development and use?