Introduction and Overview of Manufacturing

1.1 What is Manufacturing?

The word manufacture is derived from two Latin words: manus (hand) and factus (make); the combination means made by hand. The English word manufacture is several centuries old, and “made by hand” accurately described the manual methods used when the word was first coined. Most modern manufacturing is accomplished by automated and computer-controlled machinery.

1 As a noun, the word manufacture first appeared in English around 1567 A.D. As a verb, it first appeared around 1683 A.D.
Table 1.1 Products representing various technologies, most of which affect nearly all of us.

| Athletic shoes | Fax machine | One-piece molded plastic patio chair |
| Automatic teller machine | Global positioning system | Optical scanner |
| Automatic dishwasher | Hand-held electronic calculator | Personal computer (PC) |
| Automobile | High-density PC diskette | Photocopying machine |
| Ballpoint pen | Home security system | Pull-tab beverage cans |
| Camcorder | Hybrid gas-electric automobile | Quartz crystal wrist watch |
| Cell phone | Industrial robot | Self-propelled mulching lawnmower |
| Compact disc (CD) | Ink-jet color printer | Smart phone |
| Compact disc player | Laptop computer | Supersonic aircraft |
| Compact fluorescent light bulb | LCD and Plasma TVs | Tablet computer |
| Contact lenses | LED lamp | Tennis racket of composite materials |
| Digital camera | Magnetic resonance imaging (MRI) | Video games |
| Digital video disc (DVD) | machine for medical diagnosis | Washing machine and dryer |
| Digital video disc player | Medicines | |
| E-book reader | Microwave oven | |

1.1.1 MANUFACTURING DEFINED

As a field of study in the modern context, manufacturing can be defined in two ways, one technologic and the other economic. Technologically, manufacturing is the application of physical and chemical processes to alter the geometry, properties, and/or appearance of a given starting material to make parts or products; manufacturing also includes assembly of multiple parts to make products. The processes to accomplish manufacturing involve a combination of machinery, tools, power, and labor, as depicted in Figure 1.1(a). Manufacturing is almost always carried out as a sequence of operations. Each operation brings the material closer to the desired final state.

Economically, manufacturing is the transformation of materials into items of greater value by means of one or more processing and/or assembly operations, as depicted in Figure 1.1(b). The key point is that manufacturing adds value to the material by changing its shape or properties, or by combining it with other materials that have been similarly altered. The material has been made more valuable through the manufacturing operations performed on it. When iron ore is converted into steel,
value is added. When sand is transformed into glass, value is added. When petroleum is refined into plastic, value is added. And when plastic is molded into the complex geometry of a patio chair, it is made even more valuable.

Figure 1.2 shows a product on the left and the starting workpiece from which the circular frame of the product was produced on the right. The starting workpiece is a titanium billet, and the product consists of a carbon wafer assembled to the hook that protrudes from the right of the frame. The product is an artificial heart valve costing thousands of dollars, well worth it for patients who need one. In addition, the surgeon who implants it charges several more thousand dollars (call it an “installation fee”). The titanium billet costs a small fraction of the selling price. It measures about 25 mm in diameter. The frame was machined (a material removal process, Section 1.3.1) from the starting billet. Machining time was about 1 hr. Note the added value provided by this operation. Note also the waste in the operation, as depicted in Figure 1.1(a); the finished frame has only about 5% of the mass of the starting workpiece (although the titanium swarf can be recycled).

The words manufacturing and production are often used interchangeably. The author’s view is that production has a broader meaning than manufacturing. To illustrate, one might speak of “crude oil production,” but the phrase “crude oil manufacturing” seems out of place. Yet when used in the context of products such as metal parts or automobiles, either word seems okay.

1.1.2 | MANUFACTURING INDUSTRIES AND PRODUCTS

Manufacturing is an important commercial activity performed by companies that sell products to customers. The type of manufacturing done by a company depends on the kinds of products it makes.

MANUFACTURING INDUSTRIES Industry consists of enterprises and organizations that produce goods and/or provide services. Industries can be classified as primary, secondary, or tertiary. Primary industries cultivate and exploit natural resources, such as agriculture and mining. Secondary industries take the outputs of the primary industries and convert them into consumer and capital goods. Manufacturing is the principal activity in this category, but construction and power utilities are also included. Tertiary industries constitute the service sector of the economy. A list of specific industries in these categories is presented in Table 1.2.

This book is concerned with the secondary industries in Table 1.2, which include the companies engaged in manufacturing. However, the International Standard Industrial Classification (ISIC) used to compile Table 1.2 includes several industries whose production technologies are not covered in this text; for example, beverages, chemicals, and food processing. In this book, manufacturing
Table 1.2 Specific industries in the primary, secondary, and tertiary categories.

<table>
<thead>
<tr>
<th>Primary</th>
<th>Secondary</th>
<th>Tertiary (service)</th>
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<tr>
<td>Agriculture</td>
<td>Aerospace</td>
<td>Banking</td>
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<td>Forestry</td>
<td>Apparel</td>
<td>Communications</td>
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<td>Fishing</td>
<td>Automotive</td>
<td>Education</td>
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<td>Livestock</td>
<td>Basic metals</td>
<td>Entertainment</td>
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<td>Quarries</td>
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<td>Mining</td>
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<td>Petroleum</td>
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<td>Health and medical</td>
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<td>Computers</td>
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<td>Construction</td>
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<td>Consumer appliances</td>
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<td>Electronics</td>
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<td>Equipment</td>
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<td>Fabricated metals</td>
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<td>Food processing</td>
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<td>Glass, ceramics</td>
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<td>Heavy machinery</td>
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<td>Paper</td>
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<td>Petroleum refining</td>
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<td>Pharmaceuticals</td>
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<td>Plastics (shaping)</td>
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<td>Power utilities</td>
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<td>Publishing</td>
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<td>Textiles</td>
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<td>Tire and rubber</td>
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<td>Wood and furniture</td>
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<td>Means production of hardware, which ranges from nuts and bolts to digital computers and military weapons. Plastic and ceramic products are included, but apparel, paper, pharmaceuticals, power utilities, publishing, and wood products are not.</td>
<td></td>
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MANUFACTURED PRODUCTS Final products made by the manufacturing industries can be divided into two major classes: consumer goods and capital goods. Consumer goods are products purchased directly by consumers, such as cars, cell phones, TVs, tires, and tennis rackets. Capital goods are those purchased by companies to produce goods and/or provide services. Examples of capital goods include aircraft, computers, communication equipment, medical apparatus, trucks and buses, railroad locomotives, machine tools, and construction equipment. Most of these capital goods are purchased by the service industries. It was noted in the introduction that manufacturing accounts for about 12% of gross domestic product and services about 75% of GDP in the United States. Yet the manufactured capital goods purchased by the service sector are the enablers of that sector. Without the capital goods, the service industries could not function.

In addition to final products, other manufactured items include the materials, components, tools, and supplies used by the companies that make the final products. Examples of these items include sheet steel, bar stock, metal stampings, machined parts, plastic moldings, cutting tools, dies, molds, and lubricants. Thus, the manufacturing industries consist of a complex infrastructure with various categories and layers of intermediate suppliers that the final consumer never deals with.

This book is generally concerned with discrete items—individual parts and assembled products rather than items produced by continuous processes. A metal stamping is a discrete item, but the sheet-metal coil from which it is made is continuous (almost). Many discrete parts start out as continuous or semicontinuous products, such as extrusions and electrical wire. Long sections made in almost continuous lengths are cut to the desired size. An oil refinery is a better example of a continuous process.

PRODUCTION QUANTITY AND PRODUCT VARIETY The quantity of products made by a factory has an important influence on the way its people, facilities, and procedures are organized. Annual production quantities can be classified into three ranges: (1) low production, quantities in the range of 1–100 units per year; (2) medium production, from 100 to 10,000 units annually; and (3) high production, 10,000 to millions of units. The boundaries between the three ranges are somewhat arbitrary (author’s judgment). Depending on the kinds of products, these boundaries may shift by an order of magnitude or so.
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Production quantity refers to the number of units produced annually of a particular product type. Some plants produce a variety of different product types, each type being made in low or medium quantities. Other plants specialize in high production of only one product type. It is instructive to identify product variety as a parameter distinct from production quantity. Product variety refers to different product designs or types that are produced in the plant. Different products have different shapes and sizes; they perform different functions; they are intended for different markets; some have more components than others; and so forth. The number of different product types made each year can be counted. When the number of product types made in the factory is high, this indicates high product variety.

There is an inverse correlation between product variety and production quantity in terms of factory operations. If a factory’s product variety is high, then its production quantity is likely to be low; but if production quantity is high, then product variety will be low, as depicted in Figure 1.3. Manufacturing plants tend to specialize in a combination of production quantity and product variety that lies somewhere inside the diagonal band in Figure 1.3.

Although product variety has been identified as a quantitative parameter (the number of different product types made by the plant or company), this parameter is much less exact than production quantity because details on how much the designs differ are not captured simply by the number of different designs. Differences between an automobile and an air conditioner are far greater than between an air conditioner and a heat pump. Within each product type, there are differences among specific models.

The extent of the product differences may be small or great, as illustrated in the automotive industry. Each of the U.S. automotive companies produces cars with two or three different nameplates in the same assembly plant, although the body styles and other design features are virtually the same. In different plants, the company builds heavy trucks. The terms “soft” and “hard” might be used to describe these differences in product variety. Soft product variety occurs when there are only small differences among products, such as the differences among car models made on the same production line. In an assembled product, soft variety is characterized by a high proportion of common parts among the models. Hard product variety occurs when the products differ substantially, and there are few common parts, if any. The difference between a car and a truck exemplifies hard variety.

1.1.3 | MANUFACTURING CAPABILITY

A manufacturing plant consists of a set of processes and systems (and people, of course) designed to transform a certain limited range of materials into products of increased value. These three building blocks—materials, processes, and systems—constitute the subject of modern manufacturing. There is a strong interdependence among these factors. A company engaged in manufacturing cannot do everything. It must do only certain things, and it must do those things well.
Manufacturing capability refers to the scope of technical and physical capabilities and limitations of a manufacturing company and each of its plants. Manufacturing capability has three dimensions: (1) technological processing capability, (2) physical size and weight of product, and (3) production capacity.

TECHNOLOGICAL PROCESSING CAPABILITY The technological processing capability of a plant (or company) is its available set of manufacturing processes. Certain plants perform machining operations, others roll steel billets into sheet stock, and others build automobiles. A machine shop cannot roll steel, and a rolling mill cannot build cars. The underlying feature that distinguishes these plants is the processes they can perform. Technological processing capability is closely related to material type. Certain manufacturing processes are suited to certain materials, whereas other processes are suited to other materials. By specializing in a certain process or group of processes, the plant is simultaneously specializing in certain material types. Technological processing capability includes not only the physical processes, but also the expertise possessed by plant personnel in these processing technologies. Companies must concentrate on the design and manufacture of products that are compatible with their technological processing capability.

PHYSICAL PRODUCT LIMITATIONS A second aspect of manufacturing capability is imposed by the physical product. A plant with a given set of processes is limited in terms of the size and weight of the products that can be accommodated. Large, heavy products are difficult to move. To move these products about, the plant must be equipped with cranes of the required load capacity. Smaller parts and products made in large quantities can be moved by conveyor or other means. The limitation on product size and weight extends to the physical capacity of the manufacturing equipment as well. Production machines come in different sizes. Larger machines must be used to process larger parts. The production and material handling equipment must be planned for products that lie within a certain size and weight range.

PRODUCTION CAPACITY A third limitation on a plant’s manufacturing capability is the production quantity that can be produced in a given time period (e.g., month or year). This quantity limitation is commonly called plant capacity, or production capacity, defined as the maximum rate of production output that a plant can achieve under assumed operating conditions. The operating conditions refer to number of shifts per week, hours per shift, direct labor manning levels in the plant, and so on. These factors represent inputs to the manufacturing plant. Given these inputs, how much output can the factory produce?

Plant capacity is usually measured in terms of output units, such as annual tons of steel produced by a steel mill, or number of cars produced by a final assembly plant. In these cases, the outputs are homogeneous, more or less. In cases in which the output units are not homogeneous, other factors may be more appropriate measures, such as available labor hours of productive capacity in a machine shop that produces a variety of parts.

Materials, processes, and systems are the fundamental topics of manufacturing and the three broad subject areas of this book. This introductory chapter provides an overview of these areas before embarking on a detailed coverage in the remaining chapters.

1.2 Materials in Manufacturing

Most engineering materials can be classified into one of three basic categories: (1) Metals, (2) ceramics, and (3) polymers. Their chemistries are different, their mechanical and physical properties are different, and these differences affect the manufacturing processes that can be used to produce products from them. In addition to the three basic categories, there are
(4) **composites**—nonhomogeneous mixtures of the other three basic types rather than a unique category. The classification of the four groups is pictured in Figure 1.4. This section provides a survey of these materials. Chapter 5 covers the four material types in more detail.

### 1.2.1 Metals

Metals used in manufacturing are usually **alloys**, which are composed of two or more elements, with at least one being a metallic element. Metals and alloys can be divided into two basic groups: (1) ferrous and (2) nonferrous.

**FERROUS METALS**  Ferrous metals are based on iron; the group includes steel and cast iron. These metals constitute the most important group commercially, more than three-fourths of the metal tonnage throughout the world. Pure iron has limited commercial use, but when alloyed with carbon, iron has more uses and greater commercial value than any other metal. Alloys of iron and carbon form steel and cast iron.

**Steel** is defined as an iron–carbon alloy containing 0.02%–2.11% carbon. It is the most important category within the ferrous metal group. Its composition often includes other alloying elements as well, such as manganese, chromium, nickel, and molybdenum, to enhance the properties of the metal.
Applications of steel include construction (bridges, I-beams, and nails), transportation (trucks, rails, and rolling stock for railroads), and consumer products (automobiles and appliances).

_Cast iron_ is an alloy of iron and carbon (2%–4%) used in casting (primarily sand casting); silicon is also present in the alloy (in amounts from 0.5% to 3%). Other elements are often added also, to obtain desirable properties in the cast part. Cast iron is available in several different forms, of which gray cast iron is the most common; its applications include blocks and heads for internal combustion engines.

**NONFERROUS METALS** Nonferrous metals include the other metallic elements and their alloys. In almost all cases, the alloys are more important commercially than the pure metals. The nonferrous metals include the pure metals and alloys of aluminum, copper, gold, magnesium, nickel, silver, tin, titanium, zinc, and other metals.

### 1.2.2 CERAMICS

A ceramic is a compound containing metallic (or semimetallic) and nonmetallic elements. Typical nonmetallic elements are oxygen, nitrogen, and carbon. Ceramics include a variety of traditional and modern materials. Traditional ceramics, some of which have been used for thousands of years, include: _clay_, abundantly available, consisting of fine particles of hydrous aluminum silicates and other minerals used in making brick, tile, and pottery; _silica_, the basis for nearly all glass products; and _alumina_ and _silicon carbide_, two abrasive materials used in grinding. Modern ceramics include some of the preceding materials, such as alumina, whose properties are enhanced in various ways through modern processing methods. Newer ceramics include: _carbides_, metal carbides such as tungsten carbide and titanium carbide, which are widely used as cutting tool materials; and _nitrides_, metal and semimetal nitrides such as titanium nitride and boron nitride, used as cutting tools and grinding abrasives.

For processing purposes, ceramics can be divided into crystalline ceramics and glasses. Different processing methods are required for the two types. Crystalline ceramics are formed in various ways from powders and then heated to a temperature below the melting point to achieve bonding between the powders. The glass ceramics (namely, glass) can be melted and cast, and then formed in processes such as traditional glass blowing.

### 1.2.3 POLYMERS

A polymer is a compound formed of repeating structural units called _mers_, whose atoms share electrons to form very large molecules. Polymers usually consist of carbon plus one or more other elements such as hydrogen, nitrogen, oxygen, and chlorine. Polymers are divided into three categories: (1) thermoplastic polymers, (2) thermosetting polymers, and (3) elastomers.

_Thermoplastic polymers_ can be subjected to multiple heating and cooling cycles without substantially altering the molecular structure of the polymer. Common thermoplastics include polyethylene, polystyrene, polyvinylchloride, and nylon. _Thermosetting polymers_ chemically transform (cure) into a rigid structure upon cooling from a heated plastic condition; hence the name thermosetting. Members of this type include phenolics, amino resins, and epoxies. Although the name “thermosetting” is used, some of these polymers cure by mechanisms other than heating. _Elastomers_ are polymers that exhibit significant elastic behavior; hence the name elastomer. They include natural rubber, neoprene, silicone, and polyurethane.

### 1.2.4 COMPOSITES

Composites do not really constitute a separate category of materials; they are mixtures of the other three types. A **composite** is a material consisting of two or more phases that are processed separately...
and then bonded together to achieve properties superior to those of its constituents. The term *phase* refers to a homogeneous mass of material, such as an aggregation of grains of identical unit cell structure in a solid metal. The usual structure of a composite consists of particles or fibers of one phase mixed in a second phase, called the *matrix*.

Composites are found in nature (e.g., wood), and they can be produced synthetically. The synthesized type is of greater interest here, and it includes glass fibers in a polymer matrix, such as fiber-reinforced plastic; polymer fibers of one type in a matrix of a second polymer, such as an epoxy-Kevlar composite; and ceramic in a metal matrix, such as a tungsten carbide in a cobalt binder to form cemented carbide.

Properties of a composite depend on its components, the physical shapes of the components, and the way they are combined to form the final material. Some composites combine high strength with light weight and are suited to applications such as aircraft components, car bodies, boat hulls, tennis rackets, and fishing rods. Other composites are strong, hard, and capable of maintaining these properties at elevated temperatures, for example, cemented carbide cutting tools.

### 1.3 Manufacturing Processes

A *manufacturing process* is a designed procedure that results in physical and/or chemical changes to a starting work material with the intention of increasing the value of that material. A manufacturing process is usually carried out as a *unit operation*, which means it is a single step in the sequence of steps required to transform a starting material into a final part or product. Manufacturing operations can be divided into two basic types: (1) processing operations and (2) assembly operations. A *processing operation* transforms a work material from one state of completion to a more advanced state that is closer to the final desired product. It adds value by changing the geometry, properties, or appearance of the starting material. In general, processing operations are performed on discrete work parts, but certain processing operations are also applicable to assembled items (e.g., painting a spot-welded car body). An *assembly operation* joins two or more components to create a new entity, called an assembly, subassembly, or some other term that refers to the joining process (e.g., a welded assembly is called a *weldment*). A classification of manufacturing processes is presented in Figure 1.5. Some of the basic processes date from antiquity.

#### 1.3.1 PROCESSING OPERATIONS

A processing operation uses energy to alter a work part’s shape, physical properties, or appearance to add value to the material. The forms of energy include mechanical, thermal, electrical, and chemical. The energy is applied in a controlled way by means of machinery and tooling. Human energy may also be required, but the human workers are generally employed to control the machines, oversee the operations, and load and unload parts before and after each cycle of operation. A general model of a processing operation is illustrated in Figure 1.1(a). Material is fed into the process, energy is applied by the machinery and tooling to transform the material, and the completed work part exits the process. Most production operations produce waste or scrap, either as a natural aspect of the process (e.g., removing material as in machining) or in the form of occasional defective pieces. An important objective in manufacturing is to reduce waste in either of these forms.

More than one processing operation is usually required to transform the starting material into final form. The operations are performed in the particular sequence required to achieve the geometry and condition defined by the design specification.

Three categories of processing operations are distinguished: (1) shaping operations, (2) property-enhancing operations, and (3) surface processing operations. *Shaping operations* alter the geometry of the starting work material by various methods. Common shaping processes include casting,
forging, and machining. **Property-enhancing operations** improve its physical properties without changing its shape; heat treatment is the most common example. **Surface processing operations** are performed to clean, treat, coat, or deposit material onto the exterior surface of the work. Common examples of coating are plating and painting. Shaping processes are covered in Parts II through V, corresponding to the four main categories of shaping processes in Figure 1.5. Property-enhancing processes and surface processing operations are covered in Part VI.

**SHAPING PROCESSES** Most shape processing operations apply heat, mechanical force, or a combination of these to effect a change in geometry of the work material. There are various ways to classify the shaping processes. The classification used in this book is based on the state of the starting material, by which there are four categories: (1) **solidification processes**, in which the starting material is a heated liquid or semifluid that cools and solidifies to form the part geometry; (2) **particulate processing**, in which the starting material is a powder, and the powders are formed and heated into the desired geometry; (3) **deformation processes**, in which the starting material is a ductile solid (commonly metal) that is deformed to shape the part; and (4) **material removal processes**, in which the starting material is a solid (ductile or brittle), from which material is removed so that the resulting part has the desired geometry.

In the first category, the starting material is heated sufficiently to transform it into a liquid or highly plastic (semifluid) state. Nearly all materials can be processed in this way. Metals, ceramic
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Section 1.3  |  Manufacturing Processes  |  11

Figure 1.6  Casting and molding processes start with a work material heated to a fluid or semifluid state. The process consists of (1) pouring the fluid into a mold cavity and (2) allowing the fluid to solidify, after which the solid part is removed from the mold.

glasses, and plastics can all be heated to sufficiently high temperatures to convert them into liquids. With the material in a liquid or semifluid form, it can be poured or otherwise forced to flow into a mold cavity and allowed to solidify, thus taking a solid shape that is the same as the cavity. Most processes that operate this way are called casting or molding. Casting is the name used for metals, and molding is the common term used for plastics. This category of shaping process is depicted in Figure 1.6. Figures 8.6, 8.8, and 8.14 show three castings, and a collection of plastic molded parts is displayed in Figure 10.20.

In particulate processing, the starting materials are powders of metals or ceramics. Although these two materials are quite different, the processes to shape them in particulate processing are quite similar. The common technique in powder metallurgy involves pressing and sintering, illustrated in Figure 1.7, in which the powders are first squeezed into a die cavity under high pressure and then heated to bond the individual particles together. Examples of parts produced by powder metallurgy are shown in Figure 12.1.

In the deformation processes, the starting work part is shaped by the application of forces that exceed the yield strength of the material. For the material to be formed in this way, it must be sufficiently ductile to avoid fracture during deformation. To increase ductility (and for other reasons), the work material is often heated before forming to a temperature below the melting point. Deformation processes are associated most closely with metalworking and include operations such as forging and extrusion, shown in Figure 1.8. Figure 15.18 shows a forging operation performed by a drop hammer.
Also included within the deformation processes category is sheet metalworking, which involves bending, forming, and shearing operations performed on starting blanks and strips of sheet metal. Several sheet metal parts, called stampings because they are made on a stamping press, are illustrated in Figure 16.30.

Material removal processes are operations that remove excess material from the starting workpiece so that the resulting shape is the desired geometry. The most important processes in this category are machining operations such as turning, drilling, and milling, shown in Figure 1.9. These cutting operations are most commonly applied to solid metals, performed using cutting tools that are harder and stronger than the work metal. Grinding is another common material removal process. Other processes in this category are known as nontraditional processes because they use lasers, electron beams, chemical erosion, electric discharges, and electrochemical energy to remove material rather than cutting or grinding tools.

It is desirable to minimize waste and scrap in converting a starting work part into its subsequent geometry. Certain shaping processes are more efficient than others in terms of material conservation. Material removal processes (e.g., machining) tend to be wasteful of material, simply by the way they work. The material removed from the starting shape is waste, at least in terms of the unit operation. Other processes, such as certain casting and molding operations, often convert close to 100% of the starting material into final product. Manufacturing processes that transform nearly all of the starting material into product and require no subsequent machining to achieve final part geometry are called net shape processes. Other processes require minimum machining to produce the final shape and are called near net shape processes.

![Figure 1.8](image_url) Common deformation processes: (a) forging, in which two halves of a die squeeze the work part, causing it to assume the shape of the die cavity; (b) extrusion, in which a billet is forced to flow through a die orifice, thus taking the cross-sectional shape of the orifice.

![Figure 1.9](image_url) Common machining operations: (a) turning, in which a single-point cutting tool removes metal from a rotating workpiece to reduce its diameter; (b) drilling, in which a rotating drill bit is fed into the work to create a round hole; and (c) milling, in which a work part is fed past a rotating cutter with multiple edges.
PROPERTY-ENHANCING PROCESSES The second major type of part processing is performed to improve mechanical or physical properties of the work material. These processes do not alter the shape of the part, except unintentionally in some cases. The most important property-enhancing processes involve heat treatments, which include various annealing and strengthening processes for metals and glasses. Sintering of powdered metals is also a heat treatment that strengthens a pressed powder metal work part. Its counterpart in ceramics is called firing.

SURFACE PROCESSING Surface processing operations include (1) cleaning, (2) surface treatments, and (3) coating and thin film deposition processes. Cleaning includes both chemical and mechanical processes to remove dirt, oil, and other contaminants from the surface. Surface treatments include mechanical working such as shot peening and sand blasting, and physical processes such as diffusion and ion implantation. Coating and thin film deposition processes apply a coating of material to the exterior surface of the work part. Common coating processes include electroplating, anodizing of aluminum, organic coating (call it painting), and porcelain enameling. Thin film deposition processes include physical vapor deposition and chemical vapor deposition to form extremely thin coatings of various substances.

1.3.2 | ASSEMBLY OPERATIONS

The second basic type of manufacturing operation is assembly, in which two or more separate parts are joined to form a new entity. Components of the new entity are connected either permanently or semipermanently. Permanent joining processes include welding, brazing, soldering, and adhesive bonding. They form a joint between components that cannot be easily disconnected. Certain mechanical assembly methods are available to fasten together two (or more) parts in a joint that can be conveniently disassembled. The use of screws, bolts, and other threaded fasteners are important traditional methods in this category. Other mechanical assembly techniques form a more permanent connection; these include rivets, press fitting, and expansion fits. Joining and assembly processes are discussed in Chapters 25 through 28.

1.3.3 | PRODUCTION MACHINES AND TOOLING

Manufacturing operations are accomplished using machinery and tooling (and people). The extensive use of machinery in manufacturing began with the Industrial Revolution. It was at that time that metal cutting machines started to be developed and widely used. These were called machine tools—power-driven machines used to operate cutting tools previously operated by hand. Modern machine tools are described by the same basic definition, except that the power is electrical rather than water or steam, and the level of precision and automation is much greater today. Machine tools are among the most versatile of all production machines. They are used to make not only parts for consumer products, but also components for other production machines. Both in a historic and a reproductive sense, the machine tool is the mother of all machinery.

Other production machines include presses for stamping operations, forge hammers for forging, rolling mills for rolling sheet metal, welding machines for welding, and placement machines for assembling electronic components to printed circuit boards. The name of the equipment usually follows from the name of the process.

Production equipment can be general purpose or special purpose. General purpose equipment is more flexible and adaptable to a variety of jobs. It is commercially available for any manufacturing company to invest in. Special purpose equipment is usually designed to produce a specific part or product in very large quantities. The economics of mass production justify large investments in special purpose machinery to achieve high efficiencies and short cycle times. This is not the only reason for special purpose equipment, but it is the dominant one. Another reason may be because
Table 1.3 Production equipment and tooling used in various manufacturing processes.

<table>
<thead>
<tr>
<th>Process</th>
<th>Equipment</th>
<th>Special tooling (function)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casting</td>
<td>Mold (cavity for molten metal)</td>
<td></td>
</tr>
<tr>
<td>Molding</td>
<td>Molding machine</td>
<td>Mold (cavity for hot polymer)</td>
</tr>
<tr>
<td>Rolling</td>
<td>Rolling mill</td>
<td>Roll (reduce work thickness)</td>
</tr>
<tr>
<td>Forging</td>
<td>Forge hammer or press</td>
<td>Die (squeeze work to shape)</td>
</tr>
<tr>
<td>Extrusion</td>
<td>Press</td>
<td>Extrusion die (reduce cross section)</td>
</tr>
<tr>
<td>Stamping</td>
<td>Press</td>
<td>Die (shearing, forming sheet metal)</td>
</tr>
<tr>
<td>Machining</td>
<td>Machine tool</td>
<td>Cutting tool (material removal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fixture (hold work part)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jig (hold part and guide tool)</td>
</tr>
<tr>
<td>Grinding</td>
<td>Grinding machine</td>
<td>Grinding wheel (material removal)</td>
</tr>
<tr>
<td>Welding</td>
<td>Welding machine</td>
<td>Electrode (fusion of work metal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fixture (hold parts during welding)</td>
</tr>
</tbody>
</table>

*Various types of casting setups and equipment (Chapter 8).

the process is unique and commercial equipment is not available. Some companies with unique processing requirements develop their own special purpose equipment.

Production machinery usually requires tooling that customizes the equipment for the particular part or product. In many cases, the tooling must be designed specifically for the part or product configuration. When used with general purpose equipment, it is designed to be exchanged. For each work part type, the tooling is fastened to the machine and the production run is made. When the run is completed, the tooling is changed for the next work part type. When used with special purpose machines, the tooling is often designed as an integral part of the machine. Because the special purpose machine is likely being used for mass production, the tooling may never need changing except for replacement of worn components or for repair of worn surfaces.

The type of tooling depends on the type of process. Table 1.3 lists examples of special tooling used in various operations. Details are provided in the chapters that discuss these processes.

1.4 Production Systems

To operate effectively, a manufacturing firm must have systems that allow it to efficiently accomplish its type of production. Production systems consist of people, equipment, and procedures designed for the combination of materials and processes that constitute a firm’s manufacturing operations. Production systems can be divided into two categories: (1) production facilities and (2) manufacturing support systems, as shown in Figure 1.10.2 Production facilities consist of the factory, physical equipment, and the arrangement of equipment in the factory. Manufacturing support systems are the procedures used by the company to manage production and solve the technical and logistics problems encountered in ordering materials, moving work through the factory, and ensuring that products meet quality standards. Both categories include people. People make these systems work. In general, direct labor workers are responsible for operating the manufacturing equipment; and professional staff workers are responsible for manufacturing support.

2 This diagram also indicates the major topic areas covered in this book.
1.4.1 PRODUCTION FACILITIES

Production facilities consist of the factory and the production, material handling, and other equipment in the factory. The equipment comes in direct physical contact with the parts and/or assemblies as they are being made. The facilities “touch” the product. Facilities also include the way the equipment is arranged in the factory, called the plant layout. The equipment is usually organized into logical groupings; in this book they are called manufacturing systems, such as an automated production line, or a machine cell consisting of an industrial robot and a machine tool.

A manufacturing company attempts to design its manufacturing systems and organize its factories to serve the particular mission of each plant in the most efficient way. Over the years, certain types of production facilities have come to be recognized as the most appropriate way to organize for a given combination of product variety and production quantity, as discussed in Section 1.1.2. Different types of facilities are required for each of the three ranges of annual production quantities.

LOW-QUANTITY PRODUCTION In the low-quantity range (1–100 units per year), the term job shop is often used to describe the type of production facility. A job shop makes low quantities of specialized and customized products. The products are typically complex, such as a prototype aircraft and special machinery. The equipment in a job shop is general purpose, and the labor force is highly skilled.

A job shop must be designed for maximum flexibility to deal with the wide product variations encountered (hard product variety). If the product is large and heavy, and therefore difficult to move, it typically remains in a single location during its fabrication or assembly. Workers and processing equipment are brought to the product, rather than moving the product to the equipment. This type of layout is referred to as a fixed-position layout, shown in Figure 1.11(a). In a pure situation, the product remains in a single location during its entire production. Examples of such products include ships, large aircraft, locomotives, and heavy machinery. In actual practice, these items are usually built in large modules at single locations, and then the completed modules are brought together for final assembly using large-capacity cranes.

The individual components of these large products are often made in factories in which the equipment is arranged according to function or type. This arrangement is called a process layout. The lathes are in one department, the milling machines are in another department, and so on, as in Figure 1.11(b). Different parts, each requiring a different operation sequence, are routed through the departments in the particular order needed for their processing, usually in batches. The process layout is noted for its flexibility; it can accommodate a great variety of operation sequences for different part configurations. Its disadvantage is that the machinery and methods to produce a part are not designed for high efficiency.
MEDIUM-QUANTITY PRODUCTION  In the medium-quantity range (100–10,000 units annually), two different types of facility are distinguished, depending on product variety. When product variety is hard, the usual approach is batch production, in which a batch of one product is made, after which the manufacturing equipment is changed over to produce a batch of the next product, and so on. The production rate of the equipment is greater than the demand rate for any single product type, and so the same equipment can be shared among multiple products. The changeover between production runs takes time—time to change tooling and set up the machinery. This setup time is lost production time, and this is a disadvantage of batch manufacturing. Batch production is commonly used for make-to-stock situations, in which items are manufactured to replenish inventory that has been gradually depleted by demand. The equipment is usually arranged in a process layout, as in Figure 1.11(b).

An alternative approach to medium-range production is possible if product variety is soft. In this case, extensive changeovers between one product style and the next may not be necessary. It is often possible to configure the manufacturing system so that groups of similar products can be made on the same equipment without significant lost time because of setup. The processing or assembly of different parts or products is accomplished in cells consisting of several workstations or machines. The term cellular manufacturing is often associated with this type of production. Each cell is designed to produce a limited variety of part configurations; that is, the cell specializes in the production of a given set of similar parts, according to the principles of group technology (Section 35.5). The layout is called a cellular layout, depicted in Figure 1.11(c).

HIGH-PRODUCTION  The high-quantity range (10,000 to millions of units per year) is referred to as mass production. The situation is characterized by a high demand rate for the product, and the manufacturing system is dedicated to the production of that single item. Two categories of mass production can be distinguished: quantity production and flow line production. Quantity production
Section 1.5 | Manufacturing Economics

involves the mass production of single parts on single pieces of equipment. It typically involves standard machines (e.g., stamping presses) equipped with special tooling (e.g., dies and material handling devices), in effect dedicating the equipment to the production of one part type. Typical layouts used in quantity production are the process layout and cellular layout (if several machines are involved).

**Flow line production** involves multiple pieces of equipment or workstations arranged in sequence, and the work units are physically moved through the sequence to complete the product. The workstations and equipment are designed specifically for the product to maximize efficiency. The layout is called a *product layout*, and the workstations are arranged into one long line, as in Figure 1.11(d), or into a series of connected line segments. The work is usually moved between stations by mechanized conveyor. At each station, a small amount of the total work is completed on each unit of product.

The most familiar example of flow line production is the assembly line, associated with products such as cars and household appliances. The pure case of flow line production occurs when there is no variation in the products made on the line. Every product is identical, and the line is referred to as a *single-model production line*. To successfully market a given product, it is often beneficial to introduce feature and model variations so that individual customers can choose the exact merchandise that appeals to them. From a production viewpoint, the feature differences represent a case of soft product variety. The term *mixed-model production line* applies to these situations in which there is soft variety in the products made on the line. Modern automobile assembly is an example. Cars coming off the assembly line have variations in options and trim representing different models and in many cases different nameplates of the same basic car design.

1.4.2 | MANUFACTURING SUPPORT SYSTEMS

To operate its 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 functions are often carried out in the firm by people organized into departments such as the following:

- **Manufacturing engineering.** The manufacturing engineering department is responsible for planning the manufacturing processes—deciding what processes should be used to make the parts and assemble the products. This department is also involved in designing and ordering the machine tools and other equipment used by the operating departments to accomplish processing and assembly.

- **Production planning and control.** This department is responsible for solving the logistics problem in manufacturing—ordering materials and purchased parts, scheduling production, and making sure that the operating departments have the necessary capacity to meet the production schedules.

- **Quality control.** Producing high-quality products should be a top priority of any manufacturing firm in today’s competitive environment. It means designing and building products that conform to specifications and satisfy or exceed customer expectations. Much of this effort is the responsibility of the QC department.

1.5 | Manufacturing Economics

In Section 1.1.1, manufacturing was defined as a transformation process that adds value to a starting work material. In Section 1.1.2, it was noted that manufacturing is a commercial activity performed by companies that sell products to customers. It is appropriate to consider some of the
economic aspects of manufacturing, and that is the purpose of this section. The coverage consists of (1) production cycle time analysis and (2) manufacturing cost models.

1.5.1 | PRODUCTION CYCLE TIME ANALYSIS

“Time is money,” as the saying goes. The total time to make a product is one of the components that determine its total cost and the price that can be charged for it. The total time is the sum of all of the individual cycle times of the unit operations needed to manufacture the product. As defined in Section 1.3, a unit operation is a single step in the sequence of steps required to make the final product. The cycle time of a unit operation is defined as the time that one work unit spends being processed or assembled. It is the time interval between when one work unit begins the operation and the next unit begins. A typical production cycle time consists of the actual processing time plus the work handling time, for example, loading and unloading the part in the machine. In some processes, such as machining, time is also required to periodically change the tooling used in the operation when it wears out. In equation form,

\[ T_c = T_o + T_h + T_t \]  \hspace{1cm} (1.1)

where \( T_c \) = cycle time of the unit operation, min/pc; \( T_o \) = actual processing time in the operation, min/pc; \( T_h \) = work part handling time, min/pc; and \( T_t \) = tool handling time if that applies in the operation, min/pc. As indicated, the tool handling time usually occurs periodically, not every cycle, so the time per workpiece must be determined by dividing the actual time associated with changing the tool by the number of pieces between tool changes. It should be mentioned that many production operations do not include a tool change, so that term is omitted from Equation (1.1) in those cases.

Batch and job shop production are common types of manufacturing. The time to produce a batch of parts in a unit operation consists of the time to set up for the batch plus the actual run time. This can be summarized as follows:

\[ T_b = T_{su} + QT_c \]  \hspace{1cm} (1.2)

where \( T_b \) = total time to complete the batch, min/batch; \( T_{su} \) = setup time, min/batch; \( Q \) = batch quantity, number of pieces (pc); and \( T_c \) = cycle time as defined in Equation (1.1), min/pc. To obtain a realistic value of the average production time per piece, the setup time is spread over the batch quantity, as follows:

\[ T_p = \frac{T_{su}}{Q} + T_c = \frac{T_{su} + QT_c}{Q} = \frac{T_b}{Q} \]  \hspace{1cm} (1.3)

where \( T_p \) = average production time per piece, min/pc; and the other terms are defined above.

If the batch size is one part, then Equations (1.2) and (1.3) are still applicable, and \( Q = 1 \). In high production (mass production), these equations can also be used, but the value of \( Q \) is so large that the setup time loses significance: As \( Q \rightarrow \infty \), \( T_{su}/Q \rightarrow 0 \).

The average production time per piece in Equation (1.3) can be used to determine the actual average production rate in the operation:

\[ R_p = \frac{60}{T_p} \]  \hspace{1cm} (1.4)

where \( R_p \) = average hourly production rate, pc/hr. This production rate includes the effect of setup time. During the production run (after the machine is set up), the production rate is the reciprocal of the cycle time:

\[ R_c = \frac{60}{T_c} \]  \hspace{1cm} (1.5)
where $R_c = \text{hourly cycle rate, cycles/hr or pc/hr}$. These equations indicate that the cycle rate will always be larger than the actual production rate unless the setup time is zero ($R_c \geq R_p$).

1.5.2 | MANUFACTURING COST MODELS

The cycle time analysis can be used to estimate the costs of production, which include not only the cost of time but also materials and overhead. The cost of time consists of labor and equipment costs, which are applied to the average production time per piece as cost rates (e.g., $$/hr or $$/min). Thus, the cost model for production cost per piece can be stated as follows:

$$C_{pc} = C_m + C_o T_p + C_t$$  \hspace{1cm} (1.6)

where $C_{pc} = \text{cost per piece, } $$/pc$; $C_m = \text{starting material cost, } $$/pc$; $C_o = \text{cost rate of operating the work cell, } $$/min$; $T_p = \text{average production time per piece, min/pc}$; and $C_t = \text{cost of tooling used in the unit operation, } $$/pc$. If applicable in the particular manufacturing process, the cost of tooling $C_t$ must be determined by dividing the actual cost of the tooling by the number of pieces produced by that tooling. The cost rate $C_o$ consists of labor and equipment costs:

$$C_o = C_L + C_{eq}$$  \hspace{1cm} (1.7)

where $C_L = \text{cost rate of labor, } $$/min$; and $C_{eq} = \text{cost rate of equipment in the work cell, } $$/min$.

Equation (1.6) implies that the piece is produced in one unit operation, but as noted in the technological definition of manufacturing in Section 1.1.1, manufacturing is almost always carried out as a sequence of operations. The cost equation can be amended to reflect this reality by summing up the costs of each unit operation:

$$C_{pc} = C_m + \sum_{i=1}^{n_o} C_{oi} T_{pi} + \sum_{i=1}^{n_o} C_{ti}$$  \hspace{1cm} (1.8)

where $n_o = \text{the number of unit operations in the manufacturing sequence for the part or product}$; and the subscript $i$ is used to identify the costs and times associated with each operation, $i = 1, 2, \ldots, n_o$. There are sometimes additional costs that must be included in certain processes, such as the cost of heating energy in casting and welding.

**OVERHEAD COSTS** The two cost rates, $C_L$ and $C_{eq}$, include overhead costs, which consist of all of the expenses of operating the company other than material, labor, and equipment. Overhead costs can be divided into two categories: (1) factory overhead and (2) corporate overhead. Factory overhead consists of the costs of running the factory excluding materials, direct labor, and equipment. This overhead category includes plant supervision, maintenance, insurance, heat and light, and so forth. A worker who operates a piece of equipment may earn an hourly wage of $15/hr, but when fringe benefits and other overhead costs are figured in, the worker may cost the company $30/hr. Corporate overhead consists of company expenses not related to the factory, such as sales, marketing, accounting, legal, engineering, research and development, office space, utilities, and health benefits. These functions are required in the company, but they are not directly related.

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3 Health benefits, if available from the company, are fringe benefits that apply to all regular employees, and so they would be included in the direct labor overhead in the factory as well as the corporate offices.
to the cost of manufacturing. On the other hand, for pricing the product, they must be added in, or else the company will lose money on every product it sells.

J. Black [1] offers some estimates of the typical costs associated with manufacturing a product, presented in Figure 1.12. Several observations are worth noting. First, total manufacturing costs constitute only 40% of the product’s selling price. Corporate overhead expenses (engineering, research and development, administration, sales, marketing, etc.) add up to more than the manufacturing cost. Second, parts and materials are 50% of total manufacturing cost, so that is about 20% of selling price. Third, direct labor is only about 12% of manufacturing cost, so that is less than 5% of selling price. Factory overhead, which includes plant and machinery, depreciation, and energy at 26% and indirect labor at 12%, adds up to more than three times direct labor cost.

The issue of overhead costs can become quite complicated. A more complete treatment can be found in [4] and most introductory accounting textbooks. The approach in this book is simply to include an appropriate overhead expense in the labor and equipment cost rates. For example, the labor cost rate is

$$C_L = \frac{R_H}{60} \left(1 + R_{LOH}\right)$$  \hspace{1cm} (1.9)

where $C_L$ = labor cost rate, $$/\text{min}; R_H = \text{worker’s hourly wage rate, }$/\text{hr}; \text{ and } R_{LOH} = \text{labor overhead rate, }\%$.

**EQUIPMENT COST RATE** The cost of production equipment used in the factory is a fixed cost, meaning that it remains constant for any level of production output. It is a capital investment that is made in the hope that it will pay for itself by producing a revenue stream that ultimately exceeds its cost. The company puts up the money to purchase the equipment as an initial cost, and then the equipment pays back over a certain number of years until it is replaced or disposed of. This is different from direct labor and material costs, which are variable costs, meaning they are paid for as they are used. Direct labor cost is a cost per time ($$/\text{min}), and material cost is a cost per piece ($$/\text{pc}).

In order to determine an equipment cost rate, the initial cost plus installation cost of the equipment must be amortized over the number of minutes it is used during its lifetime. The equipment cost rate is defined by the following:

$$C_{eq} = \frac{IC}{60NH} \left(1 + R_{OH}\right)$$  \hspace{1cm} (1.10)

where $C_{eq} = \text{equipment cost rate, }$/\text{min}; IC = \text{initial cost of the equipment, }$; N = \text{anticipated number of years of service}; H = \text{annual number of hours of operation, hr/yr}; \text{ and } R_{OH} = \text{applicable overhead rate for the equipment, }\%$. 
Example 1.1
Equipment Cost Rate

A production machine is purchased for an initial cost plus installation of $500,000. Its anticipated life = 7 yr. The machine is planned for a two-shift operation, 8 hr per shift, 5 days per week, 50 weeks per year. The applicable overhead rate on this type of equipment = 35%. Determine the equipment cost rate.

Solution: The number of hours of operation per year \( H = 50(2)(5)(8) = 4000 \) hr/yr. Using Equation (1.10),
\[
C_{eq} = \frac{500,000}{60(7)(4000)}(1 + 0.35) = \$0.402/\text{min} = \$24.11/\text{hr}
\]

Example 1.2
Cycle Time and Cost per Piece

The production machine in Example 1.1 is used to produce a batch of parts that each has a starting material cost of $2.35. Batch quantity = 100. The actual processing time in the operation = 3.72 min. Time to load and unload each workpiece = 1.60 min. Tool cost = $4.40, and each tool can be used for 20 pieces before it is changed, which takes 2.0 min. Before production can begin, the machine must be set up, which takes 2.5 hr. Hourly wage rate of the operator = $16.50/hr, and the applicable labor overhead rate = 40%. Determine (a) the cycle time for the piece, (b) average production rate when setup time is figured in, and (c) cost per piece.

Solution: (a) For Equation (1.1), processing time \( T_o = 3.72 \) min, part handling time \( T_h = 1.50 \) min, and tool handling time \( T_t = 2.00 \) min/20 = 0.10 min.
\[
T_c = 3.72 + 1.60 + 0.10 = 5.42 \text{ min/pc}
\]

(b) The average production time per piece, including setup time, is
\[
T_p = \frac{2.5(60)}{100} + 5.42 = 6.92 \text{ min/pc}
\]

Hourly production rate is the reciprocal of \( T_p \), correcting for time units:
\[
R_p = \frac{60}{6.92} = 8.67 \text{ pc/hr}
\]

(c) The equipment cost rate from Example 1.1 is \( C_{eq} = \$0.402/\text{min} \) (\$24.11/hr). The labor rate is calculated as follows:
\[
C_L = \frac{16.50}{60}(1 + 0.40) = \$0.385/\text{min}(\$23.10/hr)
\]

Cost of tooling \( C_t = 4.40/20 = \$0.22/\text{pc} \). Finally, cost per piece is calculated as
\[
C_{pc} = 2.35 + (0.385 + 0.402)(6.92) + 0.22 = \$8.02/\text{pc}
\]
Equipment reliability and scrap rate of parts are sometimes issues in production. Equipment reliability is represented by the term availability (denoted by the symbol $A$), which is simply the proportion uptime of the equipment. For example, if $A = 97\%$, then for every 100 hr of machine operation, one would expect on average that the machine would be running for 97 hr and be down for maintenance and repairs for 3 hr. Scrap rate refers to the proportion of parts produced that are defective. Let $q$ denote the scrap rate. In batch production more than the specified batch quantity is often produced to compensate for the losses due to scrap. Let $Q$ = the required quantity of parts to be delivered and $Q_o$ = the starting quantity. The following equation can be used to determine how many starting parts are needed, on average, to satisfy an order for $Q$ finished parts:

$$Q_o = \frac{Q}{1 - q} \quad (1.11)$$

Example 1.3  
Scrap Rate  
A customer has ordered a batch of 1000 parts to be produced by a machine shop. Historical data indicate that the scrap rate on this type of part = 4%. How many parts should the machine shop plan to make in order to account for this scrap rate?  

Solution: Given $Q = 1000$ parts and $q = 4\% = 0.04$, then the starting quantity is determined as follows:

$$Q_o = \frac{1000}{1 - 0.04} = \frac{1000}{0.96} = 1041.7 \text{ rounded to } 1042 \text{ starting parts}$$

Of course, in modern manufacturing practice, every effort is made to minimize scrap rate, with the goal being zero defects. Availability and scrap rate also figure into calculations of production rate and part cost, as demonstrated in the following example.

Example 1.4  
Cycle Time and Cost per Piece  
A high-production operation manufactures a part for the automotive industry. Starting material cost = $1.75$, and cycle time = 2.20 min. Equipment cost rate = $42.00/hr, and labor cost rate = $24.00/hr, including overhead costs in both cases. Availability of the production machine in this job = 97\%, and the scrap rate of parts produced = 5\%. Because this is a long-running job, setup time is ignored, and there is no tooling cost to be considered. (a) Determine the production rate and finished part cost in this operation. (b) If availability could be increased to 100\% and scrap rate could be reduced to zero, what would be the production rate and finished part cost?  

Solution: (a) Production rate, including effect of availability $R_p = \frac{60}{2.20}(0.97) = 26.45 \text{ pc/hr}$

However, because of the 5\% scrap rate, the production rate of acceptable parts is

$$R_p = 26.45(1 - 0.05) = 25.13 \text{ pc/hr}$$

Because of availability and scrap rate, the part cost is

$$C_{pc} = \frac{1.75}{(1 - 0.05)} + \left(\frac{24 + 42}{60(1 - 0.05)}\right) = \$4.47/\text{pc}$$
Problems

(b) If \( A = 100\% \) and \( q = 0 \), \( R_p = \frac{60}{2.20} = 27.27 \text{ pc/hr} \)

Part cost \( C_{pc} = 1.75 + (42 + 24)(2.20/60) = $4.17/\text{pc} \)

This is an 8.5\% increase in production rate and a 6.7\% reduction in cost.

References


Review Questions

1.1 Define manufacturing.
1.2 What are the differences between primary, secondary, and tertiary industries? Give an example of each category.
1.3 What is the difference between consumer goods and capital goods? Give some examples in each category.
1.4 What is the difference between soft product variety and hard product variety, as these terms are defined in the text?
1.5 How are product variety and production quantity related when comparing typical factories?
1.6 One of the dimensions of manufacturing capability is technological processing capability. Define technological processing capability.
1.7 What are the four categories of engineering materials used in manufacturing?
1.8 What is the definition of steel?
1.9 What is the difference between a thermoplastic polymer and a thermosetting polymer?
1.10 Manufacturing processes are usually accomplished as unit operations. Define unit operation.
1.11 In manufacturing processes, what is the difference between a processing operation and an assembly operation?
1.12 One of the three general types of processing operations is shaping operations. What are the four categories of shaping operations?
1.13 What is the difference between net shape processes and near net shape processes?
1.14 Identify the four types of permanent joining processes used in assembly.
1.15 What is the difference between special purpose and general purpose production equipment?
1.16 Define batch production and describe why it is often used for medium-quantity production.
1.17 What is the difference between a process layout and a product layout in a production facility?
1.18 What are overhead costs in a manufacturing company?
1.19 Name and define the two categories of overhead costs in a manufacturing company.
1.20 What is the difference between fixed costs and variable costs?

Problems

Answers to problems labeled (A) are listed in the Appendix at the back of the book.

Manufacturing Economics

1.1 (A) A company invests $950,000 in a piece of production equipment. The anticipated life of the machine = 10 yr. The cost to install the equipment = $50,000. The machine will be used 8 hr per shift, five shifts per week, 50 weeks per year. Applicable overhead rate = 15\%. Assume availability = 100\%. Determine the equipment cost rate if (a) the plant operates one shift per day and (b) the plant operates two shifts per day.
1.2 A production machine was purchased 7 yr ago for a price of $600,000, including installation. At that time it was anticipated that the machine would last 10 yr and be used 2000 hr/yr. However, it is now in need of major repairs that will cost $150,000. If these repairs are made, the machine will last 3 more years, operating 2000 hr/yr. Applicable overhead rate = 20%. Assume availability = 100%. Determine the equipment cost rate for this machine.

1.3 A production machine is used to process parts in batches. In one batch of interest, the starting piece is a casting that costs $7.00 each. Batch quantity = 50. The actual machining time in the operation = 8.50 min. Time to load and unload each workpiece = 3.0 min. Cost of the cutting tool = $4.00, and each tool must be changed every 15 pieces. Tool change time = 1.5 min. Setup time for the batch = 1.75 hr. Hourly wage rate of the operator = $14.00/hr, and the applicable labor overhead rate = 40%. Hourly equipment cost rate = $20.00/hr, which includes overhead. Assume availability = 100% and scrap rate = 0. Determine the (a) cycle time for the piece, (b) average hourly production rate when setup time is figured in, and (c) cost per piece.

1.4 (A) A stamping press produces sheet-metal stampings in batches. The press is operated by a worker whose labor rate = $15.00/hr and applicable labor overhead rate = 28%. Cost rate of the press = $20.50/hr and applicable equipment overhead rate = 22%. In a certain order, batch size = 800 stampings, and the time to set up the die in the press = 55 min. The die cost $40,000 and is expected to last for 160,000 stampings. Each cycle in the operation, the starting blanks of sheet metal are manually loaded into the press, which takes 42 sec. The actual press stroke takes only 8 sec. Unloading the stamping from the press takes 13 sec. Cost of the starting blanks = $0.20/pc. The press operates 250 days per year, 7.5 hr per day, but the operator is paid for 8 hr per day. Assume availability = 100% and scrap rate = 0. Determine the (a) cycle time, (b) average production rate with setup time included, and (c) cost per stamping produced.

1.5 A semiautomatic production machine must be tended by a worker 100% of the time to load and unload parts. Cost of the starting parts = $0.25/pc. The job runs several months so setup can be neglected. The equipment cost rate of the machine = $24.00/hr including applicable overhead costs. The worker’s cost rate = $21/hr including applicable labor overhead rate. Each cycle, the actual process time = 36 sec, and time to load and unload the part = 14 sec. A proposal has been made to install an automatic parts-loading-and-unloading device on the machine, which would cost $48,000 and would reduce the parts-loading-and-unloading time to 5 sec each cycle. Its expected life = 4 yr. The device would also relieve the worker from full-time attention to the machine. Instead, the worker could tend four machines, effectively reducing the labor cost to 25% of its current rate for each machine. The operation runs 250 days per year, 8 hr per day. Assume availability = 100% and scrap rate = 0. Determine the cost per part (a) without the parts loading device and (b) with the parts loading device installed. (c) How many days of production are required to pay for the automatic loading device? In other words find the breakeven point.

1.6 In an automated production operation, the starting work part cost = $0.50 each, and cycle time = 1.0 min. Equipment cost rate = $30.00/hr, and labor cost rate = $25.00/hr. Both rates include overhead costs. Tooling cost = $0.08/pc. Availability of the production machine = 96%, and the scrap rate = 3%. Determine the (a) production rate and (b) finished part cost.

1.7 A production process consists of two operations. The scrap rate in the first operation = 4.2%, and scrap rate in the second operation = 28%. The total number of acceptable parts in a certain production order = 9000 units. How many starting work units are required to satisfy this order?

1.8 (A) In 40 hr of an automated production operation, 456 acceptable (non-defective) parts and 16 defective parts were produced. The operation cycle consists of a processing time of 4.35 min, and a part handling time of 0.35 min. Every 60 parts, a tool change is performed, and this takes 9.0 min. The machine experienced several breakdowns during the week. Determine the (a) hourly production rate of acceptable parts, (b) scrap rate, and (c) availability (proportion uptime) of the machine during this week.

1.9 A high-production operation was studied during an 80-hr period, during which a total of 11 equipment breakdowns occurred for a total lost production time of 4.2 hr, and the operation produced 31 defective products. No setups were performed during the period. The operation cycle time (processing and part handling) = 3.27 min, and a tool change is required every 25 parts, which takes 2.0 min. Determine the (a) hourly production rate of acceptable parts, (b) proportion uptime, and (c) scrap rate during the period.