Design, Processes, and Drawing
Manufacturing, in its broadest sense, is the process of converting raw materials into products. It encompasses (1) product design, (2) selection of raw materials, and (3) selection of processes by which manufacturing of goods takes place, using various production methods and techniques.

Engineering drawings, whether created with drawing instruments or CAD, are detailed instructions for manufacturing the described objects. The drawings must give information regarding shape, size, materials, finish, and, sometimes; the manufacturing process required.
10.2. The Design Process and Concurrent Engineering

The design process for a product first requires a clear understanding of the functions and the performance expected of that product. Traditionally, design and manufacturing activities have taken place sequentially rather than concurrently or simultaneously.
Design and manufacturing activities traditionally have taken place sequentially rather than concurrently. With CAM, the design process can work simultaneously with the manufacturing process.

**Figure 10.1**
Concurrent engineering is a systematic approach rating the design and manufacture of products the view of optimizing all elements involved in the life cycle of the product. Life cycle means that all of a product (such as design, development, production, distribution, use, and its ultimate disposal and recycling) are considered simultaneously. The basic goals of concurrent engineering are to minimize product design and engineering changes and the time and costs involved in taking the product from design concept to production and introduction of the product into the marketplace.

The philosophy of life cycle engineering requires that entire life of a product be considered in the design i.e., design, development, production, distribution, use, and its ultimate disposal and recycling. Thus, the well-designed product is functional (design stage), well manufactured (production), packaged so that it safely arrives to the end user or customer (distribution), functions effectively for its intended life and has components which can be easily replaced for maintenance or repair (use) and can be disassembled so that components can be recycled (disposal).
10.3. Computer-Aided Design and Production Development

Computer-aided design (CAD) allows the designer to conceptualize objects more easily without having to make costly illustrations, models, or prototypes. These systems are now capable of rapidly and completely analyzing designs, from a simple bracket to complex structures. For example, the two-engine Boeing 777 passenger airplane was designed completely by computer (paperless design) (Figure 102).
10.4. Computer-Aided Design Allows for Easy Future Modification

The use of CAD/CAM systems makes the modifications of the design easy.
10.5. Computer-Aided Design Links All Phases of Design and Manufacturing

The common database is shared by all phases of design and manufacturing that is shared and viewed by all.
In the late 1980’s, Jaron Lanier coined the term virtual reality. Initially, VR referred to the use of immersive systems such as Head Mounted Displays (HMDs), BOOM (Binocular Omni Orientation Monitor), and CAVE (Cave Automatic Virtual Environment) systems. Later, the definition also included semi-immersive and non-immersive systems such as flight simulators.
The next step in the production process is to make and test a prototype, that is an original working model of the product. An important development is rapid prototyping which relies on CAD/CAM and various manufacturing techniques (using metallic or nonmetallic materials) to quickly produce prototypes in the form of a solid physical model of a part and at low cost. For example, prototyping new automotive components by traditional methods of shaping, forming, machining, etc costs hundreds of millions of dollars a year; some components may take a year to produce. Rapid prototyping can cut these costs as well as development times significantly.
10.7. Design for Manufacture, Assembly, Disassembly, and Service

Design and manufacturing must be intimately interrelated; they should never be viewed as separate disciplines or activities. Each part or component of a product must be designed so that it not only meets design requirements and specifications, but also can be manufactured economically and efficiently. This approach improves productivity and allows a manufacturer to remain competitive. This broad view has become recognized as the area of design for manufacturing (DFM). It is a comprehensive approach to production of goods and integrates the design process with materials, manufacturing methods, process planning, assembly, and quality assurance.
## Shapes and Some Common Manufacturing Methods

<table>
<thead>
<tr>
<th>Shape of Feature</th>
<th>Production Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat surfaces</td>
<td>Rolling, planing, broaching, milling, shaping, grinding</td>
</tr>
<tr>
<td>Parts with cavities</td>
<td>End milling, electrical-discharge machining, electrochemical machining, ultrasonic machining, casting</td>
</tr>
<tr>
<td>Parts with sharp features</td>
<td>Permanent mold casting, machining, grinding, fabricating, powder metallurgy</td>
</tr>
<tr>
<td>Thin hollow shapes</td>
<td>Slush casting, electroforming, fabricating</td>
</tr>
<tr>
<td>Tubular shapes</td>
<td>Extrusion, drawing, roll forming, spinning, centrifugal casting</td>
</tr>
<tr>
<td>Tubular parts</td>
<td>Rubber forming, expanding with hydraulic pressure, explosive forming, spinning</td>
</tr>
<tr>
<td>Curvature on thin sheets</td>
<td>Stretch forming, peen forming, fabricating, assembly</td>
</tr>
<tr>
<td>Opening in thin sheets</td>
<td>Blanking, chemical blanking, photochemical blanking</td>
</tr>
<tr>
<td>Cross-sections</td>
<td>Drawing, extruding, shaving, turning, centerless grinding</td>
</tr>
<tr>
<td>Square edges</td>
<td>Fine blanking machining, shaving belt grinding</td>
</tr>
<tr>
<td>Small holes</td>
<td>Laser, electrical discharge machining, electrochemical machining</td>
</tr>
<tr>
<td>Surface textures</td>
<td>Knurling, wire brushing, grinding, belt grinding, shot blasting, etching, deposition</td>
</tr>
<tr>
<td>Detailed surface feature</td>
<td>Coining, investment casting, permanent-mold casting, machining</td>
</tr>
<tr>
<td>Threaded parts</td>
<td>Thread cutting, thread rolling, thread grinding, chasing</td>
</tr>
<tr>
<td>Very large parts</td>
<td>Casting, forging, fabricating, assembly</td>
</tr>
<tr>
<td>Very small parts</td>
<td>Investment casting, machining, etching, powder metallurgy, nanofabrication, micromachining</td>
</tr>
</tbody>
</table>
10.8. Material Selection

An ever-increasing variety of materials is now available, each having its own characteristics, applications, advantages, and limitations. The following are the general types of materials used in manufacturing today either individually or in combination.

- **Ferrous** metals: carbon, alloy, stainless, and tool and die steels.
- **Nonferrous** metals: aluminum, magnesium, copper, nickel, titanium, superalloys, refractory metals, beryllium, zirconium, low-melting alloys, and precious metals.
- **Plastics**: thermoplastics, thermosets, and elastomers.
- **Ceramics**: glass ceramics, glasses, graphite, diamond, and diamond-like materials.
- **Composite** materials: reinforced plastics, metal-matrix and ceramic-matrix composites. These are also known as engineered materials.
- **Nanomaterials**: shape-memory alloys, amorphous alloys, superconductors, and various other materials with unique properties.
## 10.9. Properties of Materials

**Mechanical properties**: strength, toughness, ductility, hardness, elasticity, fatigue, and creep.

Also, the **strength-to-weight and stiffness-to-weight ratios** are important factors in selecting materials.

**Chemical properties** plays an important role in hostile as well as normal environments. Oxidation, corrosion, general degradation of properties, toxicity and flammability are some of the examples.

Further, **manufacturing properties** of materials determine whether they can be cast, formed, machined, welded, and heat treated with relative ease.
Cost and availability of raw and processed materials and manufactured components are major concerns in manufacturing. Competitively, the economic aspects of material selection are as important as the technological considerations of properties and characteristics of materials.

If raw or processed materials or manufactured components are not available in the desired shapes, dimensions and quantities, substitutes and/or additional processing will be required, which can contribute significantly to product cost.

Different costs are involved in processing materials by different methods. Some methods require expensive machinery, others require extensive labor, and still others require personnel with special skills, a high level of education, or specialized training.
### TABLE 10.2  General Manufacturing Characteristics of Various Alloys.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Castability</th>
<th>Weldability</th>
<th>Machinability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>E</td>
<td>E</td>
<td>G-E</td>
</tr>
<tr>
<td>Copper</td>
<td>F-G</td>
<td>F</td>
<td>F-G</td>
</tr>
<tr>
<td>Gray cast iron</td>
<td>E</td>
<td>D</td>
<td>G</td>
</tr>
<tr>
<td>White cast iron</td>
<td>G</td>
<td>VP</td>
<td>VP</td>
</tr>
<tr>
<td>Nickel</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Steels</td>
<td>F</td>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>Zinc</td>
<td>E</td>
<td>D</td>
<td>E</td>
</tr>
</tbody>
</table>

E, excellent; G, good; F, fair; D, difficult; VP, very poor.
10.11. Appearance, Service Life, and Recycling

The appearance of materials after they have been manufactured into products influences their appeal to the consumer. Color, feel, and surface texture are characteristics that we all consider when making a decision about purchasing a product.

Time- and service-dependent phenomena such as wear, fatigue, creep, and dimensional stability are important. These phenomena can significantly affect a product's performance and, if not controlled, can lead to total failure of the product. Similarly, compatibility of materials used in a product is important. Friction and wear, corrosion, and other phenomena can shorten a product’s life or cause it to fail prematurely. An example is galvanic corrosion between mating parts of dissimilar metals.

Recycling or proper disposal of materials at the end of their useful service lives has become increasingly important in an age when we are more conscious of preserving resources and maintaining a clean and healthy environment.
10.12. Manufacturing Processes

Before preparing a thawing for the production of a part, the drafter/designer should consider what manufacturing processes are to be used. These processes will determine the representation of the detailed features of the part, the choice of dimensions and the machining of processing accuracy. Many processes are used to produce parts and shapes (Table 10.1) and there is usually more than one method of manufacturing a part from a given material. The broad categories of processing methods for materials are:
a. **Casting**

Expendable molds (e.g., sand casting) and permanent molds (Fig. 10-5).

**FIGURE 10.5** This casting mold is an example of a permanent mold.
b. Forming and shaping

Rolling, forging, extrusion, drawing, sheet forming, powder metallurgy, and molding (Figure 10.6.a - d).
Rolling

Ingot

Rolls

Plate, Sheet or Foil
Forging (click the figure below to see the simulation)

See forging video here.
c. Machining

Turing, boring, drilling, milling, planing, shaping, broaching, grinding, ultrasonic machining; chemical, electrical, and electrochemical machining; and high-energy beam machining (Figure 10.7 a - g).
Engine Lathes and Milling Machines (See video of milling here)
Reaming is a process which slightly enlarges a pre-existing hole to a tightly tolerated diameter.
**Boring machines** are devices for producing smooth and accurate holes in a workpiece by enlarging existing holes with a bore. Boring machines are developed to make a bore in the shortest time and produce the highest possible surface finish and tolerances.
d. Joining

Welding, brazing, soldering, diffusion bonding, adhesive bonding, and mechanical joining (Figure 10.8 a—b).
Roughing is usually followed by finishing such as honing, lapping, polishing, burnishing, deburring, surface treating, coating, and plating.

Honing is a final finishing operation conducted on a surface, typically of an inside cylinder, such as of an automotive engine block. Abrasive stones are used to remove minute amounts of material in order to tighten the tolerance on cylindricity. Hones can be of the multiple pedal type (pictured below) or the brush type. Either type applies a slight, uniform pressure to a light abrasive that wipes over the entire surface.
**Single piece lapping** is the attempt to flatten an item by rubbing it against a flat surface using an abrasive to remove the "high" spots.

**Two Piece Lapping:** Since the purpose of lapping is generally concerned with the mating of the surface that matters, not the flatness, both mating pieces (e.g., CPU and heatsink) can be lapped together in order to achieve the good mating.
Burnishing tools are used to impart a gloss or fine surface finish, often in processes that involve the cold working of metal surfaces. The Surface of metal parts worked through turning, reaming or boring operations is a succession of PROJECTIONS or PEAKS and INDENTATIONS or VALLEY when microscopically examined. (See Fig1.) The Roller burnishing operation compresses the Projection (Peaks) into the indentation (Valleys) thus forming a smooth mirror finished surface (as in fig.2). Any material not exceeding 40 Rockwell Hardness "C" can be roller burnished.
Size, thickness, and shape complexity of the part have a major bearing on the manufacturing process selected to produce it.

Flat parts with thin cross-sections, for example, cannot be cast properly. Complex parts cannot be formed easily and economically, whereas they maybe cast or fabricated from individual pieces.

Tolerances and surface finish obtained in hot-working operations cannot be as good as those obtained in cold-working (room temperature) operations because dimensional changes, warpage, and surface oxidation occur during processing at elevated temperatures. Some casting processes produce a better surface finish than others because of the different types of mold materials used and their surface finish.

The size and shape of manufactured products vary widely. For example, the main landing gear or a twin engine, 400-passenger Boeing 777 jetliner is 4.3 m (14 ft) high, with three axles and six wheels, made by forging and machining processes.
The machinists’ steel ruler or scale that has up to 0.010 decimal scale is a commonly used measuring tool in the shop.

For dimensions that require more precise measurements, the vernier caliper or the micrometer caliper may be used. It is common practice to check measurements to 0.025 mm (.0010) with these instruments, and in some instances they are used to measure directly to 0.0025 mm (.00010).

An ultraprecision electronic digital readout micrometer and caliper that contain integral microprocessors is also available these days.
(a) Steel Ruler or Scale, (b), (c), (f) Outside Spring Caliper, (d), (e) Inside Spring Caliper, (g) Combination Square, (h), (j) Vernier Caliper, (k) Micrometer Caliper and Computerized Measuring Devices
The design and cost of tooling, the lead time required to begin production, and the effect of workpiece material on tool and die life are major considerations. Depending on its size, shape, and expected life, the cost of tooling can be substantial. For example, a set of steel dies for stamping sheet-metal fenders for automobiles may cost about $2 million.

For parts made from expensive materials, the lower the scrap rate, the more economical the production process will be; thus, every attempt should be made for zero-base waste. Because it generates chips, machining may not be more economical than forming operations, all other factors being the same.

Availability of machines and equipment and operating experience within the manufacturing facility are also important cost factors. If they are not available, one parts may have to be manufactured by outside firms.

The number of parts required (quantity) and the required production rate (pieces per hour) are important in determining the processes to be used and the economics of production.

The safe use of machinery is another important consideration, requiring precautions to eliminate hazards in the workplace.
10.17. Net-Shape Manufacturing

Finishing operations can contribute significantly to the cost of a product. Consequently, the trend has been for net-shape or near-net-shape manufacturing, in which the part is made as close to the final desired dimensions, tolerances, surface finish, and specifications as possible.

Typical examples of such manufacturing methods are near-net-shape forging and casting of parts, stamped sheet-metal parts, injection molding of plastics, and components made by powder-metallurgy techniques.
The major goals of automation in manufacturing facilities are to integrate various operations to improve productivity, increase product quality and uniformity, minimize cycle times, and reduce labor costs.

Beginning in the 1940s, automation has accelerated because of rapid advances in control systems for machines and in computer technology. Few developments in the history of manufacturing have had a more significant impact than computers. Computers are now used in a very broad range of applications, including control and optimization of manufacturing processes, material handling, assembly, automated inspection and testing of products, as well as inventory control and numerous management activities. Beginning with computer graphics and computer-aided design and manufacturing (CAD/CAM), the use of computers has been extended to computer-integrated manufacturing (CIM). Computer-integrated manufacturing is particularly effective because of its capability for:
The major applications of computers in manufacturing are:

a. Computer numerical control (CNC) is a method of controlling the movements of machine components by direct insertion of coded instructions in the form of numerical data. Numerical control was first implemented in the early 1950s and was a major advance in automation of machines.

b. Adaptive control (AC). The parameters in a manufacturing process are adjusted automatically to optimize production rate and product quality, and to minimize cost. Parameters such as forces, temperatures, surface finish, and dimensions of the part are monitored constantly. If they move outside the acceptable range, the system adjusts the process variables until the parameters again fall within the acceptable range.
c. **Industrial robots.** Introduced in the early 1960s, industrial robots have been replacing humans in operations that are repetitive, boring, and dangerous, thus reducing the possibility of human error, decreasing variability in product quality, and improving productivity. Robots with sensory perception capabilities are being developed (intelligent robots), with movements that simulate those of humans.

d. **Automated handling of materials.** Computers have allowed highly efficient handling of materials and products in various stages of completion (work in progress), such as from storage to machines, from machine to machine, and at the points of inspection, inventory, and shipment.

e. **Automated and robotic assembly systems** are replacing costly assembly by operators. Products are designed or redesigned so that they can be assembled more easily by machine.

f. **Computer-aided process planning (CAPP)** is capable of improving productivity in a plant by optimizing process plans, reducing planning costs, and improving the consistency of product quality and reliability. Functions such as cost estimating and work standards (time required to perform a certain operation) can also be incorporated into the system.
g. Group Technology (GT). The concept of group technology is that parts can be grouped and produced by classifying them into families, according to similarities in design and similarities in manufacturing processes to produce the part. In this way, part designs and procedure plans can be standardized and families of parts can be produced efficiently and economically.

h. Just-in-time production (JIT). The principal of JIT is that supplies are delivered just in time to be used, parts are produced just in time to be made into subassemblies and assemblies, and products are finished just in time to be delivered to the customer. In this way, inventory-carrying costs are low, part defects are detected right away, productivity increased, and high-quality products are made at low cost.

i. Cellular manufacturing. Cellular manufacturing invokes workstations, which are manufacturing cells usually containing several machines and with a central robot, each performing a different operation on the part.
j. Flexible manufacturing systems (FMS) integrate manufacturing cells into a large unit, all interfaced with a central computer. Flexible manufacturing systems have the highest level of efficiency, sophistication, and productivity in manufacturing. Although costly, they are capable of producing parts randomly and changing manufacturing sequences on different parts quickly; thus, they can meet rapid changes in market demand for various types of products.

k. Expert systems, which are basically intelligent computer programs, are being developed rapidly with capabilities to perform tasks and solve difficult real-life problems as human experts would.

l. Artificial intelligence (AI) involves the use of machines and computers to replace human intelligence. Computer-controlled systems are becoming capable of learning from experience and making decisions that optimize operations and minimize costs. Artificial neural networks, which are designed to simulate the thought processes of the human brain, have the capability of modeling and simulating production facilities, monitoring and controlling manufacturing processes, diagnosing problems in machine performance, conducting financial planning, and managing a company’s manufacturing strategy.
Although large corporations can afford to implement modern technology and take risks, smaller companies generally have difficulty in doing so with their limited personnel, resources, and capital. More recently, the concept of shared manufacturing has been proposed. This consists of a regional or nationwide network of manufacturing facilities with state-of-the-art equipment for training, prototype development and small-scale production runs, and is available to help small companies develop products that compete in the global marketplace.

In view of these advances and their potential, some experts have envisaged the factory of the future. Although highly controversial and viewed as unrealistic by some, this is a system in which production will take place with little or no direct human intervention. The human role is expected to be confined to supervision, maintenance, and upgrading of machines, computers, and software.
Virtual **Meetings** on the Fly

Here’s how the latest collaboration technologies work, illustrated by a scenario at fictional company Double Eagle Sporting Goods.

1. **CONTACT** Product V-P Jane Smith sends an e-mail to Don Jones, president of Noonan Clubs, a design firm, setting up a video Web conference to discuss a new golf club design. The e-mail includes a date for the meeting and a link to launch the session.

2. **INITIAL MEETING** Once the Web conference starts, the participants see live videos of each others’ faces on their computer screens. They look at photos of golf clubs, sketch designs on a shared “virtual whiteboard,” and review contracts.

3. **PRODUCT DESIGN** Noonan designers and Double Eagle planners use peer-to-peer software that allows them to share spaces on each others’ computers. The program lets them take turns modifying designs and tracks all the changes. Alternatively, they could set up an internal Web site to share ideas.
Designing a part requires to consider what materials and manufacturing processes are to be used. These processes will determine the representation of the detailed features of the part, the choice of dimensions, and the machining or processing accuracy.

Principal types of metal forming are (1) casting, (2) machining from standard stock, (3) welding, (4) forming from sheet and (5) forging. A knowledge of these processes, along with a thorough understanding of the intended use of the part, will help determine some basic manufacturing processes. Drawings that reflect these manufacturing methods are shown in Figure 10.18.

In sand casting, for example, as shown in Figure, all cast surfaces remain rough textured, with all corners filleted or rounded. Sharp corners indicate that at least one of the surfaces is finished (i.e., machined further usually to produce a flat surface), and finish marks are shown on the edge view of the finished surface.

Other examples are also shown in the Figure below.
METRIC

4XØ 12.5
Ø38.05-38.10

Ø140
16
50
Ø70

C1-1 REQD
FILLETS & ROUNDS R3

(a) SAND CASTING
MATL: SAE 1040 - FAO-1 REQD.
HEAT TREAT P55Z

(b) MACHINING FROM STOCK.
MATL: .026 ALUMINUM ALY
1 REQD

(d) SHEET METAL
ALL FILLETS R.188 & ROUNDS R.125

SECT A-A

MATL: 4130 STL -2 REQD NORMALIZE PER AN-QQ-H-201

ALL DRAFT ANGLES 7°