Chapter 8

MANUFACTURING

MAJOR OUTCOMES

- You will recognize manufacturing as a 'system'
- You will learn about different ways of classifying manufacturing systems
- You will be able to appreciate the importance of resources for manufacturing
- You will learn about different types of materials used in manufacturing industry today
- You will learn about the processes applied to different materials in workshops and factories
- You will learn about several properties of materials for their proper selection
- You will learn about the overall scope or span of manufacturing activities for a certain product
- You will be able to recognize the use of computers and information systems in modern industry
- You will learn about different phases of planning & control activities in manufacturing

Most of the objects around us that we use everyday are manufactured in factories. Manufactured items are sent to stores, where we can purchase them. We are consumers of manufactured products. Consumers are people who buy and use the items made in factories. We consume products just by using soap, eating food, wearing shoes, driving cars, and reading books.

During the late 1700s, great changes started to take place around the world because of new methods of manufacturing. Because of many important inventions during this period, this period is called the **industrial revolution**. Goods once produced by hand were now produced by machines and power tools. The first factories in the world made textiles in England and Scotland between 1750 and 1800. Textiles are woven fabrics like wool and cotton. The factory's power usually came from rivers that turned water wheels. **James Watt** later designed a steam engine that could operate machines in factories. However, it took many years before factories completely switched from water power to steam engines.

Manufacturing is the application of physical and chemical processes to alter the geometry, properties, and/or appearance of a given starting material (raw or semi finished) to make parts or products. Manufacturing also includes assembly of multiple parts to make products. The processes to accomplish manufacturing involve a combination of resources like people, tools/machinery, and energy etc. as depicted by the Figure 1.

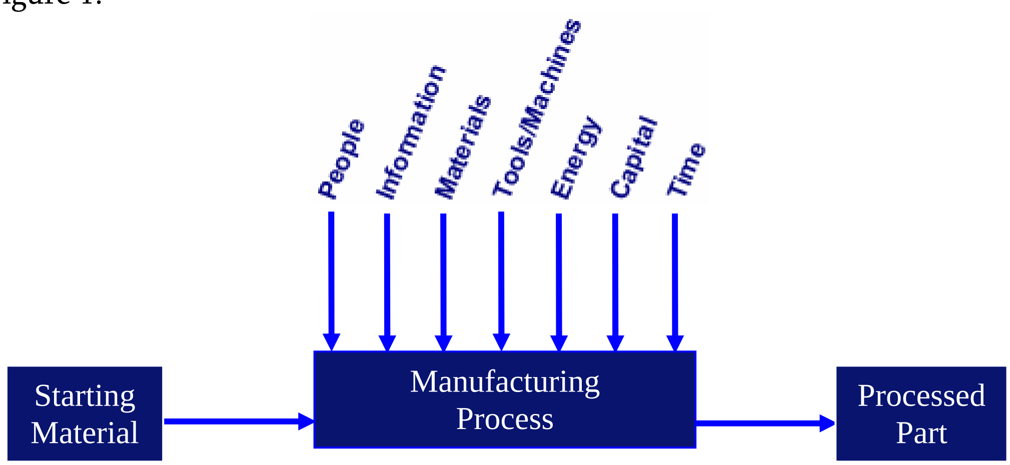


Figure 1 Manufacturing System

Manufacturing is always carried out in a sequence of operations. Each operation brings the material closer to the desired final state. Economically, this sequence of operations adds value to the material by changing its shape or properties. A few examples of raw material and corresponding final products are given in Table 1. It is not always possible for a company to span the whole cycle of manufacturing, starting from crude raw material to the finished product required by the consumer. This whole span is usually divided into categories which will be discussed in the next section.

Raw Material	Product	Raw Material	Product
Cotton	Thread	Animal Hides	Shoes
Wood	Paper	Sand	Glass
Iron Ore	Steel	Steel	Structures
Petroleum	Plastic	Plastic	Patio Chairs

Table 1 Examples of raw materials and corresponding final products

MANUFACTURING INDUSTRIES

Industry consists of enterprises and organizations that produce or supply goods and services. There are several ways to classify manufacturing industries. One is to place a company into one of three categories, as basic producer, converter or fabricator. The three types form a connecting chain in the transformation of natural resources and basic raw materials into goods for the consuming public. The ***basic producers*** cultivate and exploit natural resources and transform them into the raw materials used by other industrial/manufacturing firms. For example, steel producers transform iron ore into steel ingots. The ***converter*** represents the intermediate link in the chain. The converter takes the output of the basic producer and transforms these raw materials into various industrial products and some consumer items. For example, the steel ingot is converted into bar stock or sheet metal. Chemical firms transform petroleum products into plastics for molding. The third category of the manufacturing firms is the ***fabricator***. These firms fabricate and assemble final products. For example the manufacturers of automobiles, appliances and garments. Some firms possess a high degree of vertical integration, which means that their operations include all three categories. The major oil firms are an example of vertical integration.

There is a fourth category of manufacturing firms, named service industry, which works in parallel with the other three and constitutes the service sector of the economy. Some of the industries in these four categories are given in Table 2.

Basic Producers	Converters and Fabricators		Service
Agriculture	Aerospace	Appliances	Repair/Maintenance
Petroleum	Automotive	Pharmaceuticals	Education
Fishing	Beverages	Publishing	Hotel
Mining	Chemicals	Textiles	Tourism
Forestry	Electronics	Tire and Rubber	Transportation

Table 2 Examples of the Categories of Industries

Another classification of manufacturing firms may be by the quantity of the products they make. There can be three types of production that a company follows, (1) job shop production, (2) batch production and (3) mass production.

Job Shop Production

This type of production is used to meet specific customer orders. There is a great variety in the type of work the manufacturing plant must do. The companies have small lot sizes here. The skill level of job shop workers must be relatively high so that they can perform a range of different work assignments. Examples of products made in a job shop are space vehicles, aircraft and machine tools etc.

Batch Production

This type of production involves the manufacture of medium-sized lots of the same item or product. The lots may be produced only once, or they may be produced at regular intervals. The plant here is capable of a production rate that exceeds the demand rate. The workers in a batch production are required to have medium level of skills. Examples are machine shops, casting foundries and pressworking shops etc.

Mass Production

This is the continuous manufacture of identical products. The companies have very high production rates here. The equipment is completely dedicated to the manufacture of a particular product. An entire plant is often designed for producing a particular product. The equipment here is special-purpose rather than general-purpose. The skill level of labor in mass production is lower than in a batch plant or job shop. The features of these three types of production are summarized in Table 3.

	Job Shop	Batch Production	Mass Production
Production quantity	Low	Medium	High
Production rate	Low	Medium	High
Labor skill level	High	Medium	Low

Table 3 Types of production in manufacturing

RESOURCES FOR MANUFACTURING

The companies involved in manufacturing use a complex but coordinated setup of all the basic resources. These resources include people, information, tools/machines etc. This notion is common for all companies, whether it is a small workshop involved in repair works or a huge organization involved in the production of a car from scratch.

People

Some large companies employ hundreds of thousands of employees at many different plants. They need this large workforce because they manufacture several products at the same time. People are required at each and every stage of the manufacturing cycle. They are required to put forward the requirement of a new product. Companies have **research engineers** to look for a feasible material and process for manufacturing this new product. Many other engineers and technologists design these products. They are called **design engineers** or designers/drafters. Others are required to decide the best way to manufacture this product. They decide the steps of manufacturing the product. They are called the **development engineers**. They make a **prototype** of the new product before going onto the full scale or mass production. A prototype is a test version of the product. It helps engineers find out how hard it will be to manufacture the product. Some more people are there in the company who implement the plan given by development department and make the lots of this product. They are called **production engineers**. Some hundreds of **laymen workers** work hard to make this stage (production) possible. Some of these workers operate manufacturing machinery, while others adjust, or set up, the machines. A company needs some skilled and qualified people to inspect the product to be sure that it's all well made and follows the specifications given by the customer. They are called **quality control engineers** or technicians. So many other people are required for planning, managing warehouses, dispatching etc. Others are required to be available there all the time for the repair and maintenance activities. They are called **maintenance engineers** or technicians. Well, this is not the end of the story. Company must employ a handsome workforce to market this product and sell or distribute it in the local and international markets.

Information

There are several forms of information that a company needs in the course of production. They range from the trends in the market, different type of materials and their costs to quality standards and the knowledge of manufacturing processes etc. Many organizations take the help from some university professors for their ongoing problems and forthcoming products. University research can be of great support to a company. In many cases, companies launch new research projects in collaboration with the universities.

Materials

The materials a company uses to make its products are the production materials. They are different from **raw materials**. Raw materials are the materials in the natural state. They include iron ore, trees, and cotton. For example, an automobile company uses steel sheets. These steel sheets come from iron ingots made from coal, limestone and iron ore. A company often has to get material from far away places or even some international markets as it is not locally available or the one available in local markets is not of very good quality (e.g. strength). Companies often make a trade-off between the cost and the quality of a material in this case, i.e. they may use an economical mix of the local and international materials.

Tools and Machines

A tool usually changes the shape of material or fastens it together. **Hand tools** are those that use the power of our hand or arm. For example a hammer is a hand tool and so are pliers and screwdrivers. A **power tool** uses a small motor and is usually held in our hands. Electric drills and electric screwdrivers are power tools.

Some important tools just facilitate the process of manufacturing, such as **jigs and fixtures**. They can be "generically" defined as devices used to locate and hold work pieces. The characteristic that distinguishes one from the other is that jigs are used to guide the work tool or template while fixtures are used to hold large work pieces. Both are used for holding, assembling or inspecting. Jigs and fixtures can be made from steel, wood or plastics.

Machines are usually operated by electric motors. They bend, cut, drill, grind, and hammer materials into different shapes. Machines used in the modern industry are quite advanced. Most of them are automatic. They run different manufacturing processes under program and feedback control. Some of these machines are called **numerical control machines** which are controlled by punched tapes.

Figure 2 Jigs and fixtures are common in carpentry and sheet-metal workshops

Energy

The energy used in the manufacturing industry today is mostly in the form of electricity. Most manufacturers use electricity from fossil fuels, i.e. coal, oil and natural gas. This type of electricity is usually named as **thermal power**. Other sources of electricity may be hydroelectric and nuclear plants. Companies prefer to have their own power source or to be near the government power supply to keep their transmission costs to the least. Sometimes, an industry can re-use its waste energy. For example, a chemical plant can use its waste heat energy to generate steam which in turn runs the turbines of a small power plant of their own. This process of energy re-use is called co-generation.

Capital

A company must have enough capital to run its operations. There are so many areas where a company must spend for its smooth running. It must buy land, build factories, purchase equipment, pay workers, maintain machines, and advertise their products. This capital may come from different sources. A company may sell shares of stock and make people from the community their partners. Stockholders become partners of their profit or loss. The capital may also come from a venture capitalist who takes a risk of investing in our business. **Venture capital** is money used to finance the costs of starting a new company.

Time

Time is money in manufacturing. The faster products are made, the more profit a company can make. Productivity is how quickly and cheaply a product is made. Productivity could be improved if a company can find ways of better utilizing its present resources, i.e. without introducing any extra cost. One way to improve productivity is called scientific management, suggested by F. W. Taylor. His idea was to study every movement that a worker made. Then the worker's routine was changed to cut out any wasted movements, thus increasing the output.

INDUSTRIAL MATERIALS

Industrial materials can be conveniently grouped into four basic categories: metals, ceramics wood and polymers. Many times a major problem for a research engineer is to select the right material from the many thousands that are available. There can be several criteria for this decision, for example properties of the material, its deterioration-rate, its cost etc. The mechanical and physical properties of the materials are dissimilar, and hence affect the manufacturing process that can be used to make products using them.

Metals

Metals used in the industry are usually alloys, which are composed of two or more elements, at least one of which is a metallic element. Metals can be divided into two basic groups: (1) ferrous, and (2) nonferrous. *Ferrous metals* are based on iron; alloys of iron and carbon form steel and cast iron. These metals constitute the most important group commercially – more than three-quarters of the metal tonnage throughout the world. Steel contains 0.02 to 2.11 % carbon. Its composition often includes other alloying elements as well, such as manganese, chromium and nickel to enhance the properties of the metal. Applications of steel include construction, transportation and consumer products. Cast iron is an alloy of iron, carbon (2 to 4 %) and silicon (0.5 to 3 %). The most important form of cast iron is gray cast iron. Its applications include blocks and heads of internal combustion engines. *Nonferrous metals* include the other metallic elements and their alloys. They include the pure metals and alloys of aluminum, copper, gold, magnesium, nickel, silver, tin, titanium, zinc, and other metals.

Ceramics

Ceramics are compounds containing metallic (or semi metallic) and nonmetallic elements. Typical nonmetallic elements are oxygen, nitrogen, ad carbon. Ceramics include a variety of traditional and modern materials. Traditional ceramics, some of which have been used for thousands of years, include; clay (for brick, tile and pottery), silica (for glass products), and alumina and silicon carbide (for abrasives used for grinding). Modern ceramics include some of the preceding materials, such as enhanced (processed) alumina. Newer ceramics include carbides. Metal carbides such as tungsten carbide and titanium carbide are widely used in cutting tools and grinding abrasives.

Figure 3 Products made from Ceramic Materials

For processing purposes, ceramics can be divided into (1) crystalline ceramics and (2) glass. Crystalline ceramics are formed from powders and then sintered (heated to a temperature below the melting point to achieve bonding between the powders). The glass can be melted and cast, and then formed in processes such as traditional glass blowing.

Wood

Natural wood can be classified into two forms; hardwood and softwood. Each type has characteristics to be considered when building a piece of furniture. "Hardwood" is a term applied to trees that lose their leaves in winter, such as maple, oak and walnut. "Softwood" describes evergreens such as fir, pine and redwood. Some useful types of wood are plywood and hardboard. Plywood is made by gluing together a number of thin veneers or plies of softwood or hardwood. There is always an odd number of veneers. The more veneers used, the stronger the plywood becomes. It can be used inside and outside. Hardboards are a cheaper option than plywood where strength is not required. Hardboard is made from wood fiber extracted from chips and pulped wood waste. Hardboard cannot be used outside as it absorbs water.

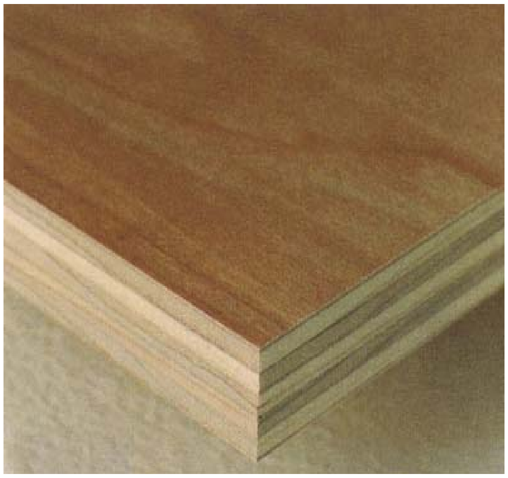


Figure 4 Plywood is graded upon the water resistance of the glue used

Figure 5 A brown hardboard writing surface

Polymers

A polymer is a compound formed of long repeating structures. Polymers usually consist of carbon plus one or more other elements such as hydrogen, nitrogen, oxygen, and chlorine. Thermoplastic polymers soften when heated. When cooled, they are hard again. Common thermoplastics are polyethylene bags, PVC pipes and nylon. Thermoset polymers do not soften when heated. They char and burn instead. Common examples of this type are plastic cups and dishes made of melamine.
Other useful production materials are natural rubber/leather, glass, cotton, silk and wool etc.

MANUFACTURING PROCESSES

The way a factory uses tools and machines to add value to its production materials is called processes. A process involves a number of steps or operations. Each 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 production material. Four basic processes applied on production material are forming, material removal, assembly (or joining) and conditioning. Forming operations change the geometry of the starting material without cutting it. Separating processes remove a part of the starting material using a tool to get the desired geometry. Combining processes join two materials or deposit material onto the exterior surface of the starting material. Conditioning processes add value to the starting material by improving its internal and physical properties.

Forming Processes

There are various ways a material can be formed. Bending a metallic rod to get the desired shape is one example.

Casting

Casting is a process in which a material in a liquid or semisolid form, can be poured or otherwise forced to flow into a mold cavity and allowed to solidify, thus taking the solid shape of the cavity. This process can be applied on metals, ceramics and plastics. Casting is the name commonly used for metals. Another word **molding** is the common term used for plastics. The examples of molds for casting can be a cake-pan, an ice-cube-tray or the footprints of our feet when we walk on a beach.

There can be many types of castings like, sand casting and die casting etc. **Sand casting** consists of pouring molten metal into a sand mold, allowing the metal to solidify, and then breaking up the mold to remove the casting. Sand casting requires a **pattern** – a full sized model of the part, enlarged to account for shrinkage and machining allowances in the final casting. Die casting is a permanent-mold-casting process in which the molten metal is injected into the mold cavity under high pressure. Typical pressures are 7 – 350 MPascal. Molds in this process are called **dies**.

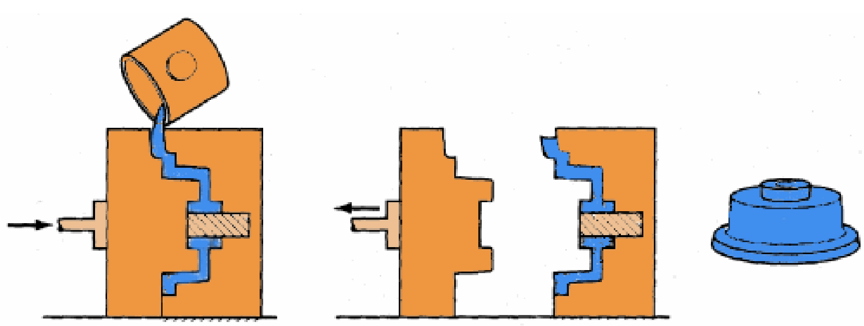


Figure 6 Casting with a two-piece mold

Pressing

Pressing is like casting. A measured amount of material is poured into a mold. A plunger with its own shape is lowered to force the material to spread out and fill the mold. The material is forced into the shape of the mold at the bottom and the shape of the plunger at the top. Pressing is commonly used for majority of sheet metal parts of an automobile. The presses for this purpose can be mechanical or hydraulic and range from 25 tons to 500 tons of force. The plunger and the base of a forming die transform the piece of the sheet metal into the required shape. This process is also referred to as ***drawing***. The fuel tank of a motorbike is an example of this process.

Figure 7 Majority of the parts of a car undergo pressing

Another type of pressing process is rolling. ***Rolling*** is a deformation process in which the thickness of the starting material is reduced by compressive forces exerted by two opposing rolls. The rolls rotate as shown in Figure 8(a) to pull and simultaneously squeeze the work between them.

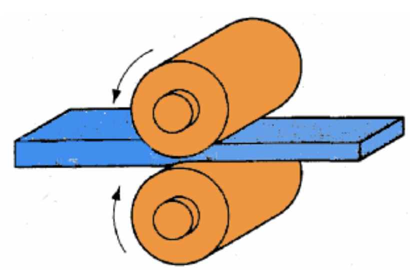


Figure 8 (a) Rolling of a slab

Figure 8 (b) Resulting rolls of sheet metal

Pressing is also used when powdered metal is used to make objects. Great pressure makes the powder into a solid. It is then heated to make the object hard. This process is commonly known as ***sintering***.

Forging

Forging is a process in which the work part is heated and compressed using either impact or gradual pressure to form the part. It is the oldest of the metal forming operations, dating back to about 5000 B.C. Today, forging is an important industrial process used to make a variety of high-strength components for automotive, aerospace, and other applications. These components include engine crank-shafts and connecting rods, gears, aircraft structural components, and jet engine turbine parts. A forging machine that applies an impact load is called a ***forging hammer***, while one that applies gradual pressure is called a ***forging press***.

Extrusion

Extrusion is a compression process in which the work metal is forced to flow through a die opening, thereby taking the shape of the opening as its own cross-section. Toothpaste is a very good example of the process. Squeezing the toothpaste out of the tube gives the paste the shape of the opening. The advantages of this process are: different shapes are possible especially with hot extrusion, the end product does not require much more shaping and machining.

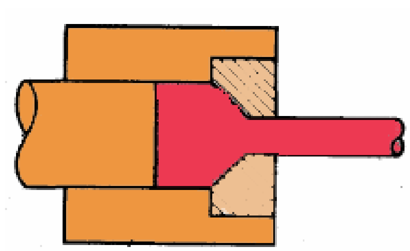


Figure 9 Extruding a red hot metal

Blow Molding

Blow molding is a molding process in which air pressure is used to inflate soft plastic into a mold cavity. It is an important industrial process for making one-piece hollow plastic parts with thin walls, such as bottles and similar containers. Many of these items are used for consumer beverages for mass markets. The technology is borrowed from the glass industry with which plastics compete in the disposable or recyclable bottle market.

Material Removal Processes

Material removal processes are operations that remove excess material from the starting workpiece so that the resulting shape is the desired geometry. The use of knives, scissors is a common example of such processes. The most important processes in this category are shearing, sawing and machining operations such as turning, drilling and milling, shaping and planing. Grinding is another common process in this category. Other material removal processes are known as nontraditional processes because they use lasers, filters, magnets and electrochemical energy rather than cutting or grinding tools.

Sawing

Sawing is a process in which a narrow slit is cut into the workpiece by a tool consisting of a series of narrowly spaced teeth. Sawing is normally used to separate a workpiece into two pieces, or to cut off an unwanted portion of a part. These operations are often referred to as ***cutoff*** operations. In most sawing operations, the work is held stationary and saw blade is moved relative to it. The types of sawing include hacksawing and bandsawing. The ***hacksaw*** blade is a thin straight tool with cutting teeth on one edge. A ***bandsaw*** blade is in the form of an endless flexible loop with teeth on one edge. The sawing machine provides a pulley-like drive mechanism to continuously move and guide the bandsaw blade past the work. Figure 10 explains the operations of hacksawing and bandsawing.

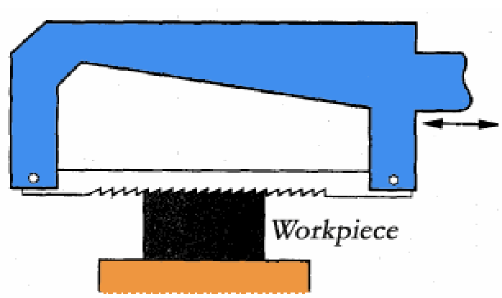


Figure 10(a) A power hacksaw

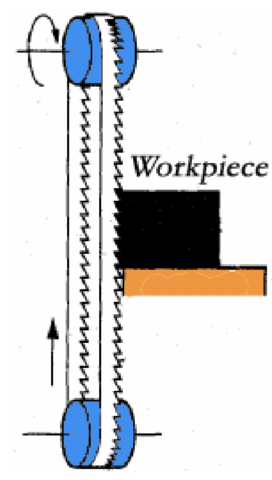


Figure 10(b) A vertical bandsaw

Shearing

Shearing is a metal cutting operation along a straight line between two cutting edges, as shown in Figure 11a. Shearing operation is similar to using a pair of scissors. Shearing is typically used to cut large sheets into smaller sections for subsequent pressworking operations. Other similar processes are ***blanking*** and ***punching***. Typical blanking and punching examples are shown in Figure 11(b).

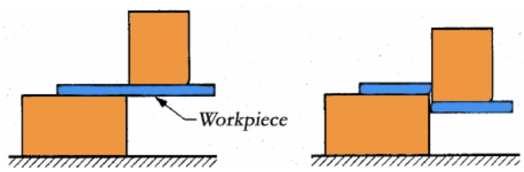


Figure 11(a) Shearing – cutting through sharp edges

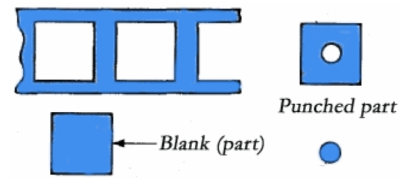


Figure 11(b) Blanking and punching are common in automobile industry

Turning

In turning, a cutting tool with a single cutting edge is used to remove material from a rotating workpiece to generate a cylindrical shape. The cutting tool here moves slowly in a direction parallel to the axis of rotation of the workpiece. Turning is commonly performed using a lathe.

Drilling

Drilling is used to create a round hole. It is usually accomplished by a rotating tool that has two cutting edges. The tool is fed in a direction parallel to its axis of rotation into the workpiece to form the round hole. The holes can be made from 1/10,000 of an inch to 3½ inches.

Milling

In milling, rotating tool with multiple cutting edges is moved slowly relative to the material to generate a plane or straight surface. The most basic forms of milling are vertical milling and horizontal or face milling.

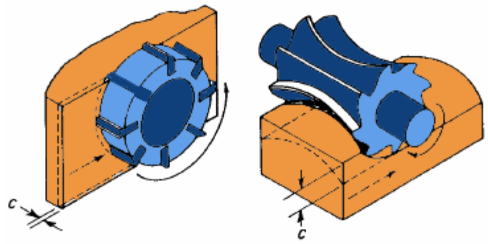


Figure 12 Milling takes off substantial amount of material from the surface

Shaping and Planing

Shaping and planing are similar operations, both involving the use of a single-point cutting tool moved linearly relative to the workpiece. Both the operations create a straight, flat surface. In shaping the tool provides the speed motion and the workpiece remains static. In planing, the speed motion is accomplished by moving the workpiece while the tool remains motionless.

Grinding

Grinding is a material-removal process in which abrasive particles are used to accomplish the task. The common application of the process is the use of a sand paper or a grinding wheel. It is basically used to provide surface finish and the uniform thickness of the workpiece all through its length. Abrasives are very small crushed particles of hard materials like aluminum oxide and silicon carbide. The grinding wheel is usually a disk-shaped, and is precisely balanced for high rotational speeds. We can sharpen tools like knives and scissors by grinding them. Grinding removes a tiny bit of material at a time. ***Polishing***, ***buffing*** and the use of toothpaste are some common forms of grinding. They all remove a tiny bit of material from the surface. The use of grinding wheel for the surface finish of the marble floor and glass and for sharpening knives and scissors is quite common. Figure 13 shows some general purpose sharpening and grinding tools.

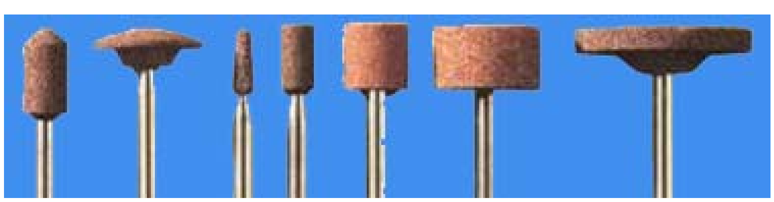


Figure 13 General purpose sharpening and grinding tools

Assembly Processes

This is a basic manufacturing operation in which two or more separate parts are joined to form a new entity. Components of the new entity are connected, either permanently or semi permanently. Many types of assembly operations are followed by the industry which includes mechanical methods, thermal methods and adhesive bonding methods.

Mechanical Assembly

Mechanical assembly involves the use of various fastening methods to mechanically attach two (or more) parts together. In most cases, the fastening method involves the use of discrete hardware components, called *fasteners*, which are added to the parts during the assembly operation. Mechanical assembly methods can be divided into the category of nails, threaded fasteners and rivets. Many consumer products are assembled largely by mechanical fastening methods: automobiles, large and small appliances, telephones, furniture, utensils – even wearing apparel are "assembled" by mechanical means. Mechanical assembly is often preferred over other joining processes for

- Ease of assembly
- Ease of disassembly

Nails are most commonly used fasteners for wood. They can be categorized as finishing nails, box nails and common nails. Finishing nails have small heads and are used in wooden frames and doors. Finishing nails are sometimes covered up with a filler to hide them even more. Other nails have larger flat heads and are used where appearance is not important. For example house construction requires several different sizes of common nails. Figure 14 illustrates types of nails.

Figure 14 Common types of nails

Threaded fasteners are discrete hardware components that have external or internal threads for assembly of parts. The common threaded fastener types are screws, bolts, and nuts. Screws and bolts have external threads. There is a technical distinction between a screw and a bolt that is often blurred in popular usage. A ***screw*** is an externally threaded fastener that is generally assembled into a blind threaded hole. Some types, called ***self-tapping screws***, possess geometries that permit them to form or cut the matching threads in the hole. A ***bolt*** is an externally threaded fastener that is inserted through holes in the parts and "screwed" in to a nut on the opposite side. A ***nut*** is an internally threaded fastener having standard threads that match those on bolts of the same diameter, pitch, and thread form. Some common styles of nuts are shown in figure 15. Screws and bolts also come in a variety of sizes, threads, and shapes.

Figure 15 Types of nuts used in the industry

A **washer** is a hardware component often used with threaded fasteners to ensure tightness of the mechanical joint. Three common types of washers are illustrated in Figure 16, which are (a) plain (flat) washer; (b) spring washers, used to dampen vibration or compensate for wear; and (c) lock washer designed to resist loosening of the bolt or screw. Washers serve various functions:

1. Distribute stresses that might otherwise be concentrated at the bolt or screw head and nut
2. Provide support for large clearance holes in the assembled parts
3. Protect part surface
4. Seal the joint
5. Resist inadvertent unfastening

Figure 16 Types of washers

A ***rivet*** is an unthreaded, headed pin used to join two (or more) parts by passing the pin through holes in the parts and then forming (upsetting) a second head in the pin on the opposite side. Rivets are widely used for achieving a permanent mechanically fastened joint. Riveting is one of the primary fastening processes in the aircraft and aerospace industries. Rivet type refers to five basic geometries that affect how the rivet will be upset to form the second head. The basic types, illustrated in Figure 17 are (a) solid, (b) tubular, (c) semi tubular, and (d) bifurcated.

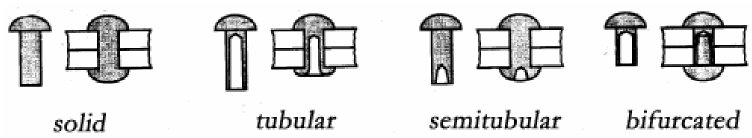


Figure 17 Basic types of rivets

There are several other mechanical assembly techniques that involve the use of fasteners. These include stitching, stapling and sewing.

Thermal Assembly

Thermal assembly involves the use of heat and can be categorized as a permanent joining process. The commonly used processes that fall into this group are welding, brazing and soldering.

Welding is an assembly operation in which two or more parts are coalesced at their contacting surfaces by a suitable application of heat and /or pressure. Welding is most commonly associated with metal parts and is usually performed on parts made of the same metal. Though process is technologically important for many reasons, it has got some disadvantages too. A few advantages and disadvantages of welding are listed below.

Advantages	***Disadvantages***
It's a permanent joint	Expensive in terms of labor cost
Welded joint can be stronger than the parent material	Involves high energy and is inherently dangerous
It is economical in terms of material usage and fabrication cost	The permanent bond does not allow for convenient disassembly
It can also be accomplished in field	Quality defects reduce the strength of joint

The welding operation mostly used in the industry is *fusion welding* which uses heat to melt the base metals. In many fusion welding operations, a filler metal is added to the molten pool to facilitate the process and provide bulk and strength to the welded joint. Some types of fusion welding are:

1 – *Arc welding* – An electric arc is maintained between an electrode and the workpiece. The arc generates immense heat causing the metal to melt. In some cases, the electrode provides the filler metal. Figure 18 shows the filler (flux) being added to a workpiece undergoing electric arc welding.

2 – *Resistance welding* – an electric current passes through two pieces of metal that are held together under pressure. The electric resistance across the surface discontinuity generates heat and the pressure causes the bond. Spot welding and seam welding are two popular examples of resistance welding. Figure 19 (a) and (b) show a diagram of a spot welder and a seam welder respectively. The shape of the fuel tank in a motorbike is obtained through seam welding.

3 – *Beam welding* – This process supplies heat by bombarding the workpiece with a concentrated beam of (1) electrons (electron beam welding) or (2) a high-energy light beam (laser welding). The term *laser* is an acronym for “light amplification by stimulated emission of radiation”.

4 – *Gas welding* – a combustible gas is burned with air or oxygen in a concentrated flame which heats the parent metal and the filler for welding. The most important process in this group is oxyacetylene welding.

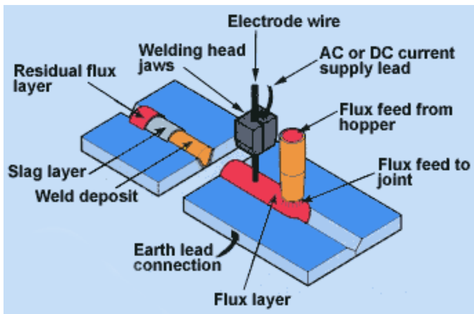


Figure 18 Filler material strengthens the joint in arc welding

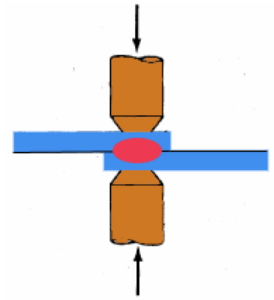


Figure 19(a) Spot welding

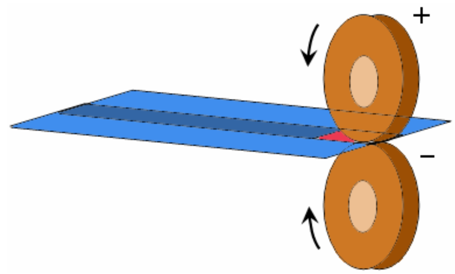


Figure 19(b) Seam welding

A **weld joint** is the junction of the edges or surfaces of parts that have been joined by welding. There can be different types of joints like butt joint, corner joint, lap joint etc.

Brazing is a joining process in which filler metal is melted and distributed between the fusion surfaces of the metal parts being joined. The filler metal has a melting temperature that is below the melting point of the base metal. The strength of a brazed joint is generally less than that of a welded joint, but this process has many advantages as (a) dissimilar metals can be joined; (b) less heat and power are required than in fusion welding, etc. Approximate brazing temperatures for typical filler metals are given in Table 4.

Filler Metal	Brazing Temperature °C
Aluminum alloys	600
Silver alloys	730
Nickel alloys	1120

Table 4 Brazing temperatures for different filler metals

Soldering is similar to brazing. The melting point of the filler metal here does not exceed 450°C. The filler metal, called **solder**, is added to the joint, which distributes itself between the closely fitting parts. As an industrial process, soldering is most closely associated with electronics assembly, but its applications also include automobile radiators, food containers etc. It requires low energy input and provides good electrical and thermal conductivity in the joint. Most solders are alloys of tin and lead.

Adhesive bonding is another commonly used assembly operation. It was probably the first of the permanent joining methods. Today, adhesives are used joining similar and dissimilar materials such as metals, plastics, ceramics, wood, paper and cardboard. **Adhesive bonding** is a joining process in which a filler material is used to hold two (or more) closely spaced parts together by surface attachment. **Adhesive** is a nonmetallic substance – usually a polymer. The curing or setting of adhesives takes time. **Curing time** or setting time is the time required to change the physical properties of an adhesive from a liquid to a solid state, usually by a chemical reaction. Some commonly used adhesives are epoxy, silicon and urethane. The applications of adhesive bonding are widespread and growing. Major users are automotive, aircraft, building products, and packaging industries; other industries include footwear, furniture, bookbinding, electrical, and shipbuilding.

Conditioning Processes

These processes change internal properties of a material. For example, we can magnetize a piece of steel. The magnetizing force makes the molecules of the steel line up in one direction. Conditioning may be classified into mechanical, chemical and thermal conditioning. In all of these processes, the change takes place inside the material itself.

Mechanical conditioning is a process in which a piece of metal is hammered, so that it becomes harder and its crystal structure changes, getting longer and thinner. **Chemical conditioning** is process in which a chemical reaction takes place to change the internal proprieties and structure of a material. For example, when we mix plaster and water, heat is given off and the plaster hardens. **Thermal conditioning**, also named as **heat treatment** also changes the internal characteristics through controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. This process is often associated with increasing the strength of material. Heat treatment itself can be categorized into different types. This treatment is most commonly used in the industry to obtain different hardness/softness levels of the same metal. For example, we raise the temperature of a piece of steel to red-hot, in a furnace and keep the piece in the furnace for a long time after switching off the furnace. This allows the metal to gain the most uniform crystal structure and become quite soft. This process is known as **annealing**. If the same red-hot piece of steel is cooled in water, it becomes harder. This is called **hardening**. If we heat the steel again, not quite as hot, and cool it quickly, the steel becomes less brittle. This is **tempering**. If we heat steel red hot and allow it to cool very quickly, for example in ice-cold water, the crystals have no time to gain a proper structure and the material becomes most brittle. This is called **quenching**. Some other examples of conditioning from our daily life are listed below.

Conditioning Operations

- Light exposing photographic film
- Baking a cake
- Cooking an egg
- Making butter from cream
- Boiling water
- Freezing water
- Using radiation on a tumor
- Making wine from grape juice

PROPERTIES OF MATERIALS

Materials are chosen for their characteristics or **properties**. We use glass for windows because light can pass through it. We use plastic for dishes because it is strong and be cleaned easily. We make electrical wires out of copper because conducts electricity well. There can be hundreds of examples like this. Common properties of materials include strength, hardness, appearance, ability to conduct electricity, and resistance to corrosion etc. Properties of materials can be classified as mechanical, electrical and magnetic, thermal and optical properties.

Mechanical Properties

Mechanical properties of a material determine its behavior when subjected to mechanical forces. These properties are important in design because the function and performance of a product depend on its capacity to resist deformation under forces encountered in service. We will discuss some of these properties.

A material's **strength** is its ability to keep its own shape when a force is applied to it. Four kinds of force can be applied to materials. **Tension** is a force that pulls on a piece of material, e.g. pulling a spring. **Compression** is a force that pushes on or squeezes a material, e.g. squeezing s sponge. **Torque** or torsion is the twisting force, e.g. using a wrench to turn a bolt. A **shear** force acts on a material like a pair of scissors. One part of the material slides in one direction and the other part slides in the opposite direction. These four types of forces are shown in Figure 20.

Hardness is the ability of a material to withstand penetration forces, e.g. the teeth of a circular saw blades are often made of tungsten carbide as it is very hard. **Toughness** is the ability of a material to absorb energy without breaking, e.g. leather is tough. Figure 21 shows a typical example of a toughness test for cars.

Malleability is the ability of a material through which it can be shaped or extended, e.g. thin wires are drawn from rods of some malleable material. **Ductility** is the ability of a material through which it can be bent without breaking, e.g. the material of pots and pans has to be ductile enough. **Elasticity** is the stiffness of a material. A material that can bend and then come back to its original shape and size is **elastic**, e.g. rubber band. **Plastic** materials can be bent and will stay bent. The material we call plastic got its name because of this property. For example, modeling clay is a plastic material. **Yield strength** marks the transition of a material from elastic to plastic state, i.e. a material will not regain its original shape and size if it undergoes a force beyond its yield strength.

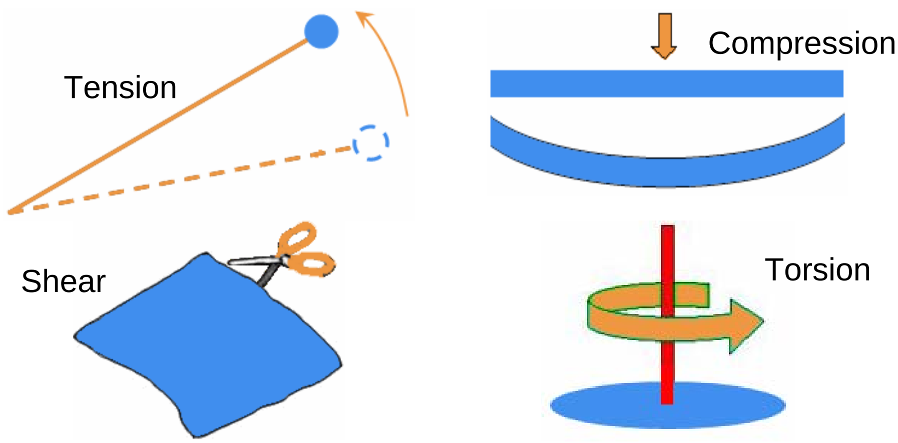


Figure 20 Types of mechanical forces

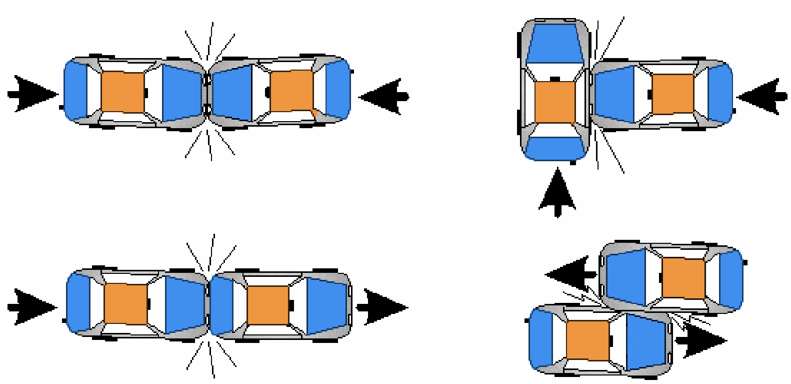


Figure 21 Car-manufacturers test the toughness of their product in a number of ways

Electrical and Magnetic Properties

Conductors are the materials that offer very little resistance to the flow of electricity. Silver is the best conductor. The next best is copper. Most of the cables are made of

copper as silver is much more costly. **Insulators** are the materials that resist the flow of electricity most strongly, e.g. plastic and rubber.
Materials that can be attracted by a magnet are called **magnetic** materials, e.g. iron, nickel etc. An **electromagnet** can be made by wrapping a wire around a piece of iron. When electric current flows through the wire, the piece of iron becomes a magnet.

Thermal Properties

The word "therm" means heat. Therefore, thermal properties are related to the ability of a material to conduct heat. Words like thermostat and thermos bottle name things related to heat. Copper and aluminum are the two best conductors of heat. A layer of material that is used to prevent the movement of heat is called **insulation**. The names like thermoplastics and thermosets come from the response of a material to the application of heat.

Optical Properties

Optical properties refer to a material's ability to transmit or reflect light. Window is a very common example of transmitting light. Plastics are also used for this purpose as they are light-weight. For example the use of plastics in making contact lenses. Other scientific applications of these properties are fiber optics, telescopes, microscopes, headlights and flashlights etc.

CYCLE OF MANUFACTURING

Manufacturing is a very large system, often hard to manage. It spans a sequence of phases that are all interrelated. It involves research, development, design, production, quality control, selling and servicing of a product. Let suppose that there is a company named ABC Moldings. Its management is thinking of manufacturing a fiberglass seat-support (base) for a motor bike. To the best of their knowledge, no one has ever made such a product. Let's now investigate what happens in the whole course of manufacturing.

Research & Development

How can the company decide if they want to manufacture a fiberglass seat-support? That's the job of their research and development (R & D) department. Research is an activity that looks at brand new ideas. Development uses research to create new products. Research is the looking, and development is the doing.

The research group at ABC Moldings does market research to see if current motor-cycle manufacturers would be interested in buying such a seat-support. They also look for a new soft fiberglass material that could be made into a comfortable base. The development group makes sure that the new material is strong enough. They give their feedback to the research group on the choice of material. The research group and the development group work closely. That's why they are often in the same department. So, they recommend some choices of material to be chosen for this new product.

Design

The design department takes over after the R & D department has completed its work. They decide the size, color, the material, the shape, and everything else that is part of a product's design.

Some design engineers think the seat-support should be made of grade 1 fiber-glass for the best softness while others think grade 2 is better. Some prefer a step surface so that the seat could fix properly while a few others think it should have a plane surface. How can they resolve these differences of opinion?
One way is to make an experimental prototype. A **prototype** is a handmade test model of the product. The design department asks their technicians to make two prototype seat-supports. One seat-support will be of grade 1 fiberglass with step surface while the other will be grade 2 material with a plane surface. Once the experimental prototype seat-supports are completed, technicians test them. They see how easily each seat-support can be assembled and taken apart. They check for their softness and strength. The technicians take a ride on motorbikes with these two seat-supports.

After the tests are over, the design engineers look at all the information they have obtained. They discuss the test results among themselves and come up with a final design. They decide that the seat-support will be made of grade 1 material with a step surface.

The engineers draw their plans for the steps of manufacturing this new product with computer-aided design (CAD) equipment. The plans are later used by the production department.

Production

The production department is responsible for actually making the company's product. It must be a quality product and manufactured to a specific schedule. A schedule is a timed plan, such as fifty seat-supports a day.

The production engineers follow the instructions given by development engineers on how many steps to make a seat-support.
The production department tells the purchasing department the type of the fiberglass. The purchasing department contacts the suppliers and arranges to have fiberglass material delivered according to their schedule. This supply of raw material would follow the production schedule of the company

Quality Control

Every company today is concerned about quality control. Companies build quality into their products during manufacture. They don't just inspect the final product and throw away all the bad ones. That would be expensive and wasteful.

This process starts from incoming quality control. ABC Moldings has to perform inspection on each of the lot of raw material they receive. Then, they inspect the seat-supports many times during each step of the manufacturing process. If a problem is found, the operators can quickly adjust the robots or the other machine tools. The final step in QC is the inspection of the end-product. Good quality control means that there are fewer parts that have to be scrapped, or thrown away. It also means that the product is the best the company can make. Quality control also helps a company make sure that its products are all alike or **uniform**. Many companies check the quality control used by their suppliers. A supplier must pass a test before a company will buy their parts. That is why ABC Moldings gets their new products approved by the representative engineers of their customers before going onto large scale production. After passing the test and being approved, a supplier receives a Supplier Certification Award.

One important note here in quality control is the standards followed by the industry. A **standard** is a system used for comparison. For example, in our seat-supports, grade 1 fiberglass is different from grade 2 fiberglass. Standards help your customers see the quality and performance easily. Several groups have established industrial standard for different materials. One group is the American National Standards Institute (ANSI), and another is the American Society for Testing and Materials (ASTM). The Society of Automobile Engineers (SAE) sets standards for car-manufacturers.

Another important note here is the **measurement units**. Most American companies manufacture products using the **metric measurement system**. Metric measurements are those based on meters and centimeters. On the other hand, some companies follow **British measurement system** which is based on feet and pounds.

Safety

Nothing is more important in a factory than the safety of the people who work there. Safety means freedom from injury or any danger of injury. To keep everyone aware of safety, many colorful and eye-catching signs are posted around the ABC Moldings factory.

Many factory safety rules are required by federal or state laws. The federal government's Occupational Safety and Health Administration (OSHA) establish safety rules and checks up on companies. The National Institute of Occupational Safety and Health (NIOSH) approve protection equipment such as hard hats and safety glasses. Environmental Protection Agency (EPA) restricts hazardous materials thrown into air or water, mostly from chemical plants.

Marketing

The next step in the manufacturing system is handled by the marketing department. They find buyers for the company's product. The company may sell their products to wholesalers or dealers. A **wholesaler** is a company that purchases large amounts from a manufacturer and then sells smaller amounts to retailers. A **retailer** is a company, or store, that sells products to consumers. Examples of retailers are Sears, Wal-Mart etc.

Servicing

This is the last step in the manufacturing. A manufacturer must have a plan to take care of products that need maintenance or that have been broken after they were sold. Most products now come with a warranty. It gives the terms under which a company will repair or replace a defective product. After the warranty period, the product becomes either a throwaway or a repairable product. The company may prefer to have its own repair shop along with the factory or they can give this task to the dealers.

The job of the design and R & D departments is not over once the company starts producing seat-supports on full-scale. They keep on looking for the methods that could improve the comfort level, productivity of the seat-supports. **Productivity** is the ratio of the overall outputs to the inputs of a company. At the same time, these departments work on the upcoming products of the company.

MANUFACTURING APPROACHES

People have been making objects, for centuries, on their own, for their families only. Then they started specializing in certain trades like carpentry, shoemaking and glassblowing etc. They would make goods not only for their families but for other people as well. These people are called **craftspeople**. They would exchange their products from other craftspeople. This methodology of manufacturing is known as **crafts approach**. People still want craft approach products that are designed and made to meet their particular needs. These products are named as **custom-made** items. For example, an exotic sports car or products for handicapped people.

The other manufacturing methodology is **factory system** which came into being during industrial revolution in late 1700s. The first factory was a big cotton mill in Massachusetts. Its construction started in 1821. The people who were running their own trade at their homes were now gathered under one roof to work for the manufacturing of one factory's products. In this way, the activities of workers could be tightly supervised (tasks assigned, output accurately measured and time attendance checked etc). Over the years, the factory system replaced the craft system in the manufacture of most goods. The factory system has advanced a lot since its birth. A division of labor was crucial in forging the link between efficiency and control. The splitting up of work into specialized functions, organized by departments and sections, raised the productive powers of labor at the same time as it enabled the central control.

Factory system gave way to another idea – mass production and assembly line production. **Mass production** means production of goods in large quantities by groups of workers. The work is divided into steps or stages. Each worker does one step and passes the item on for the next step. This is called an **assembly line** – a system by which the item is moved quickly from one work station to the next. This way, more products can be manufactured in a given period of time. The beauty of assembly line production is that parts are **standardized** – all alike which makes them **interchangeable**. Any part from the line could be used in the assembly of the final product. Some differences in the two approaches are listed below.

Craft Production	***Mass Production***
Workers are skilled	Workers need limited skill
Workers make a product from start to end	Workers work for only one step or stage of assembly line
Work is varied and interesting	Work is routine and boring
No two parts are exactly alike	Parts are interchangeable
Only one item is produced at a time	Many items are produced in one production run
The work could stop anytime	All the operations are synchronized
Each item takes long time	Time of production per part is reduced
Cost of each item is very high	Cost of each item is very low
Quality depends mainly on the skills of the craftsman	Quality depends on the accuracy of the machines and how well the stages are arranged

Factory system brought many changes to the society. As newer products were available in local markets, the standard of living of the people living in industrialized nations improved. The workers now had to spend a specific time in factories and didn't have liberty of working upon their own schedules. As the competition in the market grew, manufacturers started cutting down the wages of labor and putting extra work load on each worker. **Unions** were thus formed to protect the rights of workers. Child labor laws were passed to ensure that children were treated fairly. The number and importance of schools and day-care-centers increased with the development of the factory system.

CONTEMPORARY TRENDS IN MANUFACTURING

Manufacturing industry is fast moving towards automation. **Automation** is the process of controlling machines automatically. Machines in many factories today are run through a set of instructions called a **program**. This kind of control is called **program control**. Some modifications might be necessary in these programs during a process upon the feedback given by a sensor. A **sensor** is a device that gathers information about its environment. This kind of a control is called **feedback control**. The concepts introduced by automation are robotics, CNC, CAD, CAM and CIM.

Robotics is a part of technology that deals with the use of industrial robots. An industrial robot has one mechanical arm and is controlled by a computer. The end of the robot's arm might have a gripper to grip items and move them from place to place.

The end also can have a paint sprayer, a welding rod or other devices for different jobs. Many industries use just pick-and-place robots.

Robots do jobs that are hazardous, boring, or otherwise unpleasant for people. They can be easily reprogrammed to do other tasks.

CNC, CAD, CAM, and CIM are groups of letters that refer to industrial activities that use computers. The letter C stands for computer.

With **CNC**, or **computerized numerical control**, machine tools operate by commands from a computer. With **CAD**, or **computer aided design**, designers and engineers use computers to draw plans for the parts. With **CAM**, or **computer-aided manufacture**, machine tool operators program computers to operate all the machinery. And with CIM, or computer-integrated manufacture, all the computers in the company are linked together, or integrated.

CNC equipments are usually tied with a system known as CAM. With CAM equipment, operators write software programs. The CAM equipment thus follows the instructions. An example can be a CNC wire-cut machine, in which a hard wire can cut the given profile of a thick metallic piece very quickly. Figure 22 shows a wire-cut machine used to cut the profile of a T-shaped-die from a thick steel block. With CIM, the design and production departments of a company can communicate instantly. The purchasing department can tell their suppliers when to deliver production materials. The marketing department can plan when to start selling products. Management can direct the entire company from one location.

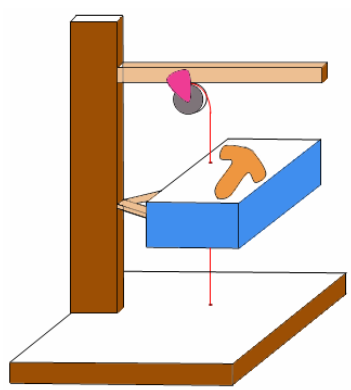


Figure 22 Cutting a T-shaped profile using a CNC wire-cut machine

Some other concepts used by the modern industry are just-in-time (JIT) manufacturing flexible manufacturing. **JIT** implies that a company does not spend anything on storage of material. The parts are ordered in such a way that they arrive at the factory only when they are needed. The finished products are immediately shipped to the customers. This saves a company the cost of storage space and their operators. **Flexible manufacturing** is the efficient way of producing small amounts of products. A company may produce different models of a product in small batches at the same time. It would be using the same set of machines and assembly lines for different models. The idea is also applicable to a small workshop where a company produces parts for many companies. The company just spends a small setup cost at the start of a new batch of parts.

PLANNING & CONTROL IN MANUFACTURING

Modern manufacturing industry consists of fabrication and assembly processes. Consider, for example, a plant that manufactures television sets, radios, and stereos. This plant must purchase materials, and perhaps parts, convert these materials into specific components, and then assemble the components into the several products offered to the consumers. This process is represented in Figure 23.

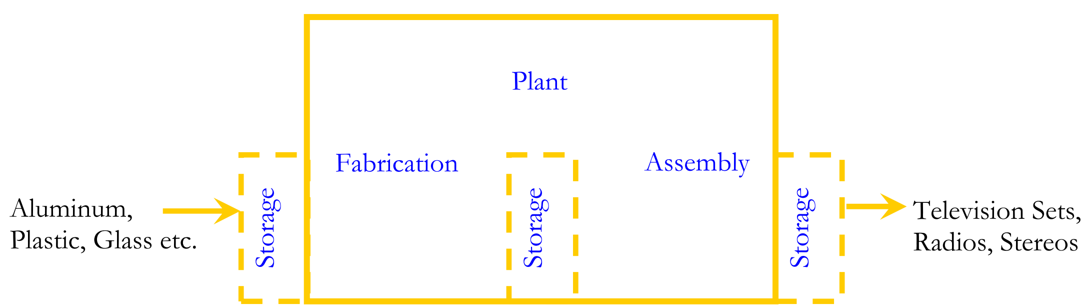


Figure 23 Representation of a typical manufacturing plant

Several observations are important at this point. First, there could be many different configurations of each of the three primary products. For example, there are many sizes and styles of television sets. Second, different products could contain several common components. It would not be surprising, for example, to find the same power switch in all three products. Third, different components could contain common raw materials.

A manufacturing setup like this can be taken as an integrated planning and control system. The information-subsystems that play a vital role in the smooth running of the company are

1) Demand forecasting
2) Operations planning

3) Inventory planning and control
4) Operations scheduling
5) Dispatching

Demand history and the current trends help the **demand forecasting** function. The general economic health of the society is also important here. Sales data reflects how good the demand was forecasted. Sometimes, recognition of the declining demand of a certain product may result in its phase-out. **Operations planning** may be short-term or long-term. The development engineers look for a better manufacturing sequence. They take input from standard operation times, setup times for scheduling activities for a certain product. Then, they group machines and other facilities for a proper assembly-line operation. Cancellation of orders of labor strikes may disturb these schedules. **Inventory planning and control** includes parts, raw materials, assemblies, supplies etc. It depicts the order quantities; reorder points, safety stocks of raw materials, and manufacturing batch sizes. **Operations scheduling** gives you a detailed operation sequence for individual activities, as well as start and stop times for all operations. Schedule conflicts on production facilities are resolved here. **Dispatching** function is responsible for initializing production, that is, for releasing work orders to production operations at the appropriate time.

Operations scheduling is the heart of entire planning and control systems. It is here that compromises must be made between economic batch sizes, due dates, resource constraints, manpower leveling, and facility utilization. Managers use **program evaluation review technique (PERT) charts** for their scheduling activities. It is a powerful tool. It lists operations necessary to finish a project. The time needed for each operation is also shown. It tells a manager the **critical activities** that consume the largest part of the project-completion-time. The sequence of these activities is named as the **critical path** of the project. That is why this method is known as **critical path method (CPM)**. The effect of a late completion date on the rest of the schedule can be quickly seen on the PERT chart. Using this chart, a manager can instantly make corrective actions very easily. A typical example of the planning of manufacturing activities is shown below along with its network diagram. The activities with a red arrow represent the critical path.

Activity	Description	Required Predecessor	Duration
A	Product design	None	6
B	Market research	None	2
C	Production analysis	A	3
D	Product model	A	4
E	Sales brochure	A	3
F	Cost analysis	C	4
G	Product testing	D	5
H	Sales training	B, E	3
I	Pricing	H	2
J	Project report	F, G, I	1

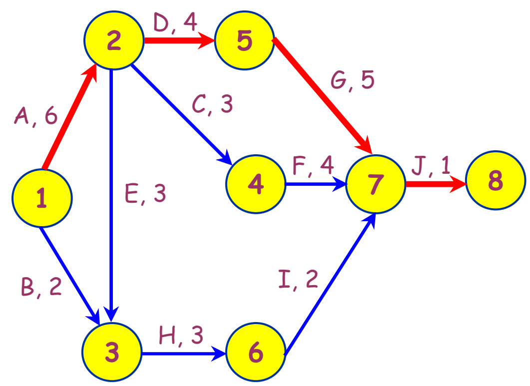


Figure 24 Typical activities in a manufacturing project

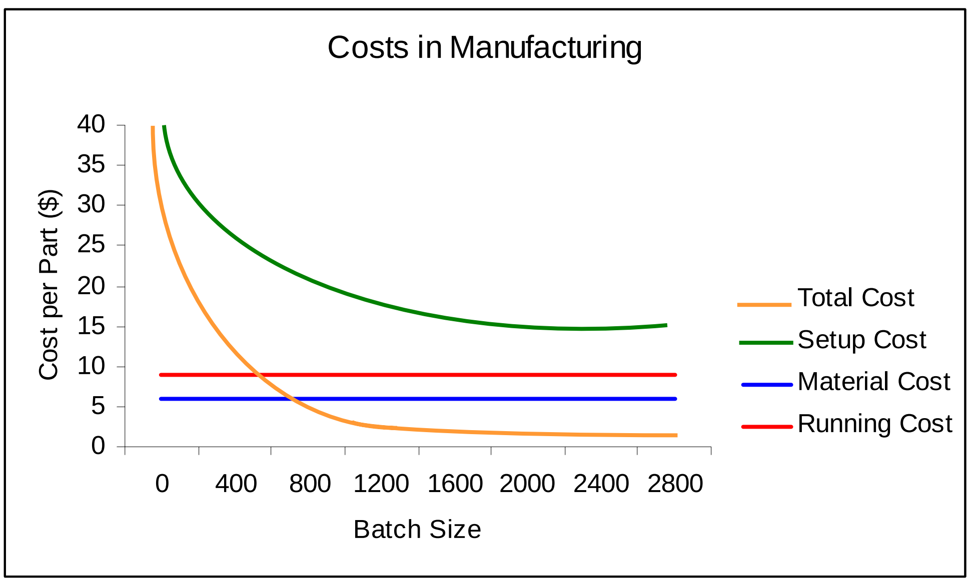
Chapter Summary

In this chapter, we tried to cover the span of manufacturing activities. The different types of materials are discussed. We then, introduced the basic kinds of manufacturing processes used to enhance or add to the value of these materials. The core details of such processes are beyond the scope the text. The nature and response of the materials to manufacturing processes is explained through their properties or characteristics. Some recent trends in the industry are illustrated along with the emphasis on planning and control activities.

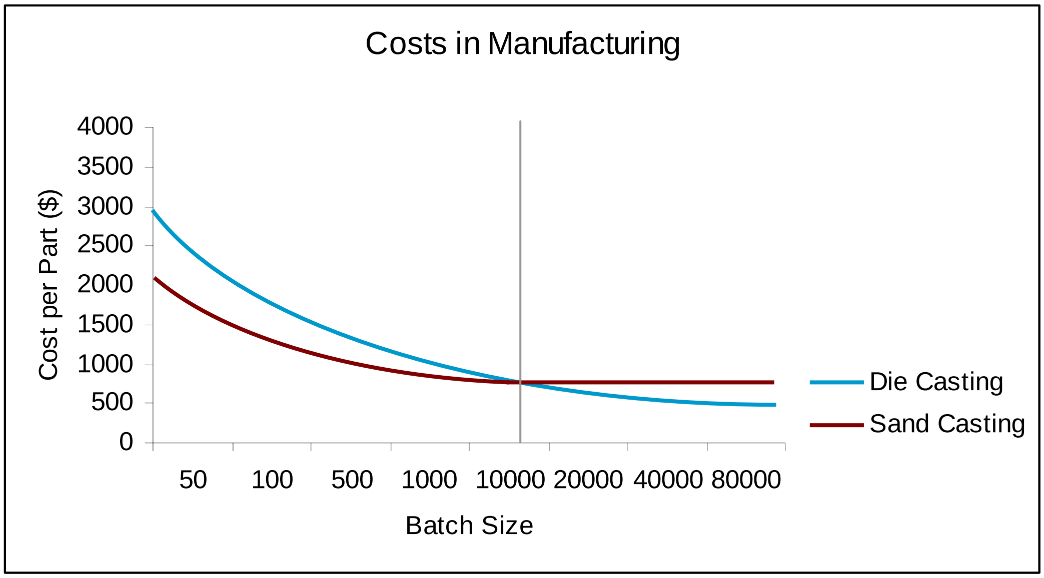
CASE STUDIES

1. Selection of a Manufacturing Process

The selection of a suitable process to manufacture a component is not a straightforward matter. There are many factors which need to be considered, for example: size of component, material to be processed and tolerance on dimensions. Whilst all processes have slightly different capabilities, there is also a large overlap – for many components there are a large number of processes which could be applied. MK Engineering Works Ltd. is looking for a suitable casting process for making a complex metallic part. The two choices that the company has are: sand casting and die casting. They investigate the manufacturing cost involved in the two processes. The easiest way is to notice that the basic manufacturing cost has 3 main elements: material cost, start up cost and the running cost. Material cost depends on the size of the part. All new products have a once-invested setup cost. It is shared by all the components produced – batch size. The running costs for many manufacturing operations are charged on hourly basis. The total cost thus, is the sum of these three costs. These costs for different batch sizes can be plotted as shown below



It is obvious from the total cost above that for a small batch size, the setup cost dominates while for large batch sizes material and running costs dominate. After a careful analysis of the costs of the two types of castings they try to find the better one of the two. The total cost of the two casting processes varies with the batch size, as shown below.



The point at which the costs of two castings cross each other is called the cross-over point and the production quantity at this point is known as economic batch size. It can be said that sand casting is economic for batch sizes less than 7,000 and die casting is economic for batch sizes greater than 7,000. We could say that sand casting has an economic batch size of 0 to 7,000 and die casting has an economic batch size of 7,000+.

So, the result is that, if the company needs to manufacture less than 7,000 parts it will select sand casting and it will select die casting if it has to manufacture more than 7,000 parts.

2. Quality Control – Design of a Control Chart

Many quality characteristics cannot be conveniently represented numerically. For example the surface-finish of a fuel tank. In such cases, we usually classify each item inspected as either conforming or nonconforming to the specifications on that quality characteristic. Quality characteristics of this type are called **attributes**.

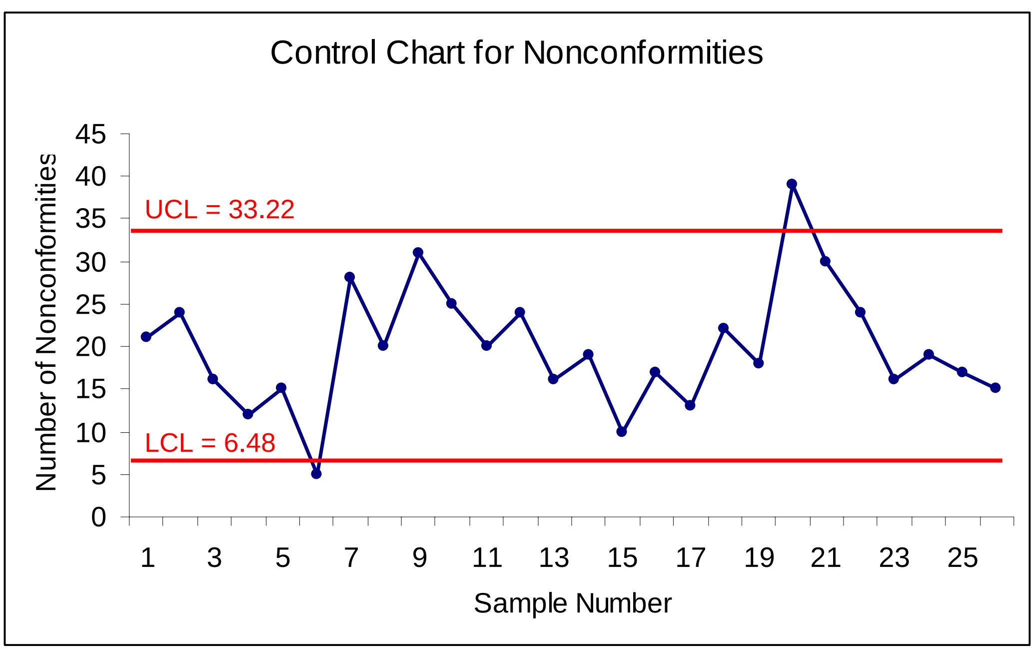
ABC Inc. is a printed circuit board manufacturer. They have a number of attributes upon the basis of which they accept or reject the 'lots' of their PCBs. They take random samples for inspecting their PCBs. They have got certain **control-limits** on the number of nonconformities in their samples. This case study shows how ABC set their control limits. The table below presents the number of nonconformities observed in 26 successive samples of size 100 (PCBs).

Sample Number	Number of Nonconformities	Sample Number	Number of Nonconformities
1	21	14	19
2	24	15	10
3	16	16	17
4	12	17	13
5	15	18	22
6	5	19	18
7	28	20	39
8	20	21	30
9	31	22	24
10	25	23	16
11	20	24	19
12	24	25	17
13	16	26	15

The analysis of their design engineer sets the control limits as

Upper Control Limit (UCL)	=	33.22
Center Line	=	19.85
Lower Control Limit (LCL)	=	6.48

The control chart with these parameters is shown below. Two points plot outside the control limits, samples 6 and 20. Investigation of sample 6 revealed that a new inspector had examined the boards in this sample and that he did not recognize several of the types of nonconformities that could have been present.

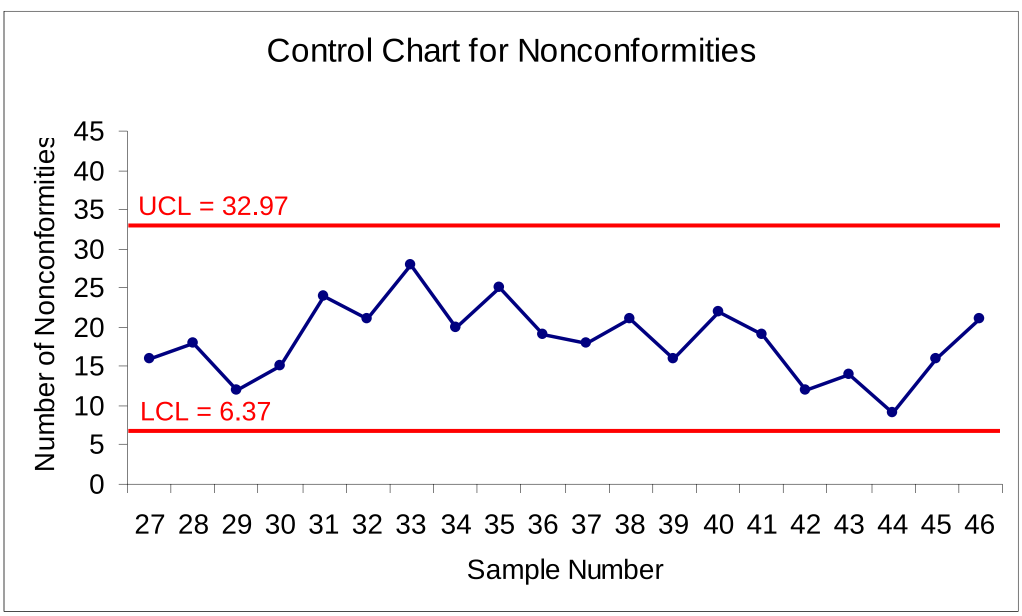


Furthermore, the unusually large number of nonconformities in sample 20 resulted from a temperature control problem in the soldering machine, which was later repaired. Therefore, ABC excludes these two samples and revise their control limits as

Upper Control Limit (UCL)	=	32.97
Center Line	=	19.67
Lower Control Limit (LCL)	=	6.37

These values now become the **standard for production**. Twenty new samples are subsequently selected and the number of nonconformities recorded, as shown below. These values are plotted as shown below. No lack of control is indicated; however, the number of nonconformities per sample is still very high.

Sample Number	Number of Nonconformities	Sample Number	Number of Nonconformities
27	16	37	18
28	18	38	21
29	12	39	16
30	15	40	22
31	24	41	19
32	21	42	12
33	28	43	14
34	20	44	9
35	25	45	16
36	19	46	21



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