MT-124: Metallurgy and Materials

LECTURE NOTES

Chapter 1: Introduction

MATERIALS, MANUFACTURING, AND THE STANDARD OF LIVING

- Standard of living of a society is determined by the goods and services that are available to its people
- Manufactured goods
  - Producer goods:
    Intermediate goods used to manufacture either producer or consumer goods
  - Consumer goods:
    Purchased directly by the consumer

HISTORY OF MATERIALS

- The development of materials and man's ability to process them is linked to the history of man
  - Stone Age
  - Copper and Bronze Age
  - Iron Age
  - Steel Age
- The current age is that of plastics, composite materials, and exotic alloys

PRODUCT DEVELOPMENT

- Sustaining technology:
  - Innovations bring more value to the consumer
  - Improvements in materials, processes, and design
- Product growth normally follows the “S” curve

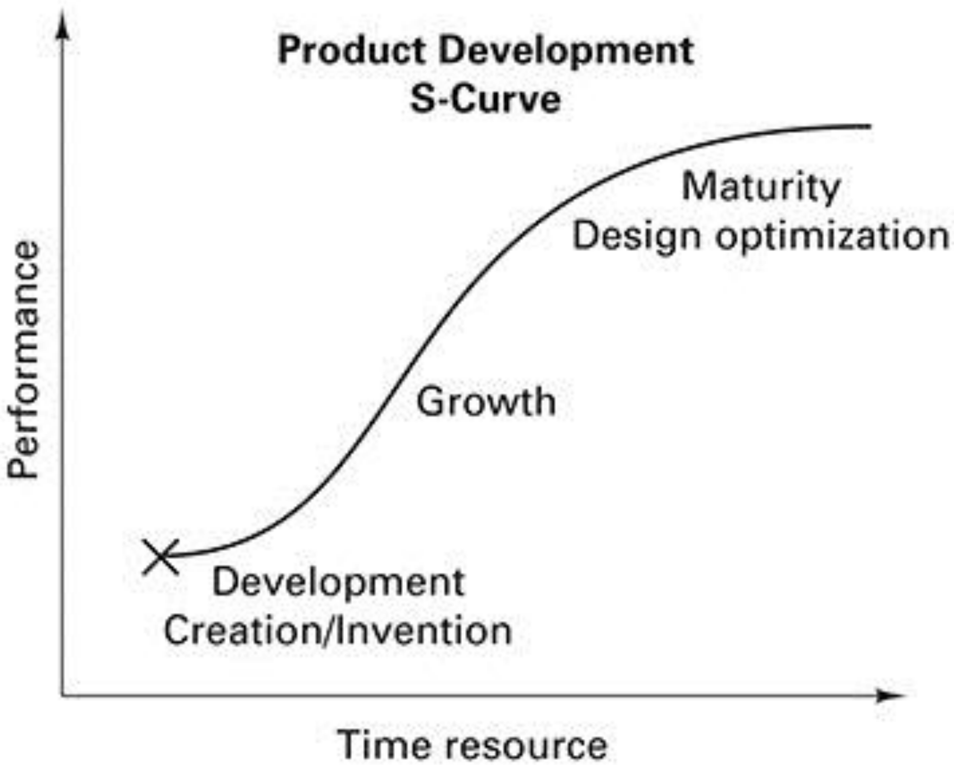
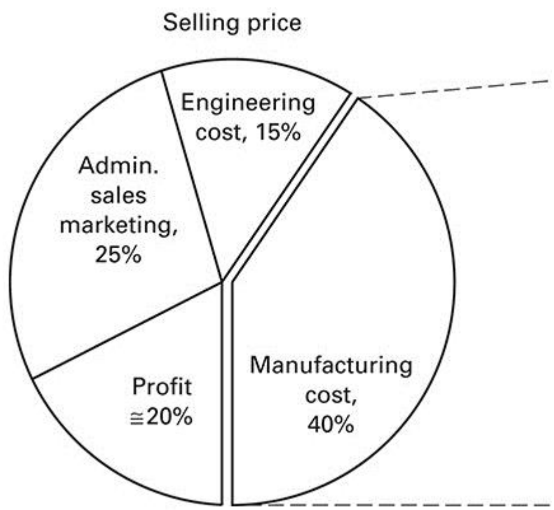


Figure 1-1a) A product development curve

INTERACTIVE FACTORS IN MANUFACTURING



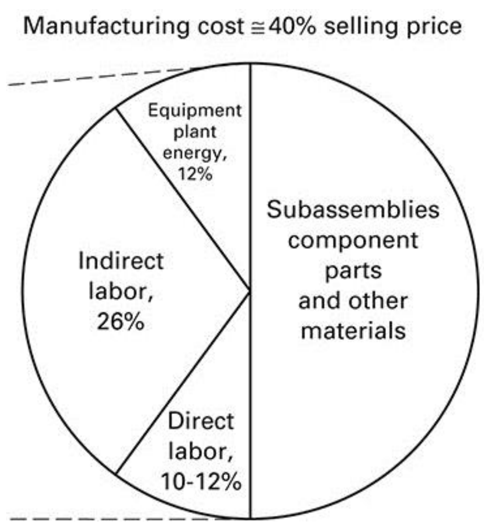


Figure 1-2
Manufacturing cost is the largest part of the selling price, usually around 40%. The largest part of the manufacturing cost is materials, usually 50%.

- Factors
  - Product design
  - Materials
  - Labor costs
  - Equipment
  - Manufacturing costs
- Strategies to reduce cost
  - Lean manufacturing
  - Systems approach

MANUFACTURING AND PRODUCTION SYSTEMS

- Manufacturing is the ability to make goods and services to satisfy societal needs
  - Manufacturing processes are strung together to create a manufacturing system (MS)
- Production system is the total company and includes manufacturing systems

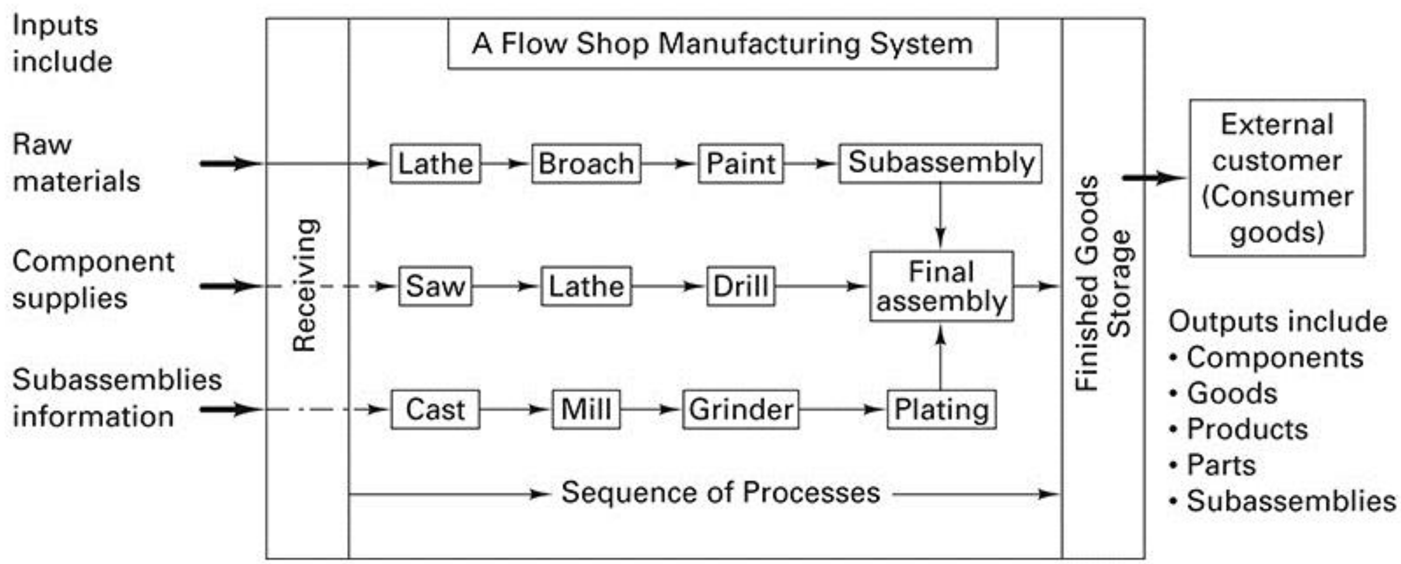


Figure 1-3

The manufacturing system converts inputs to outputs using processes to add value to the goods for the external customer.

MANUFACTURING AND PRODUCTION SYSTEMS

- Goods
  - Material things
- Services
  - Nonmaterial things
- Service Production Systems (SPSs)
  - Nonmaterial systems that do not provide a product (i.e. banking, health care, education, etc.)

MANUFACTURING AND PRODUCTION SYSTEMS

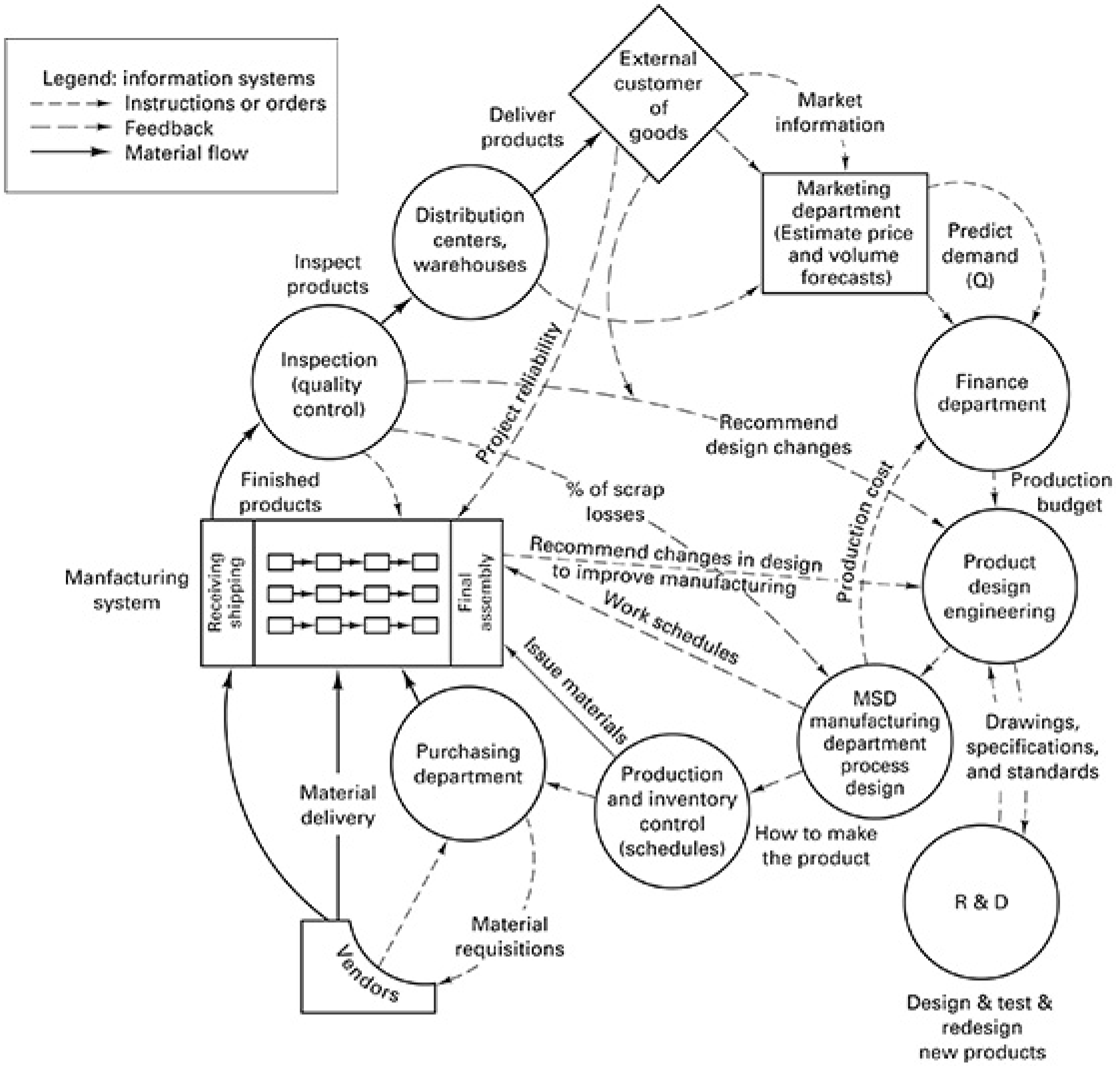


Figure 1-4 The functions and systems of the production system, which includes (and services) the manufacturing system. The functional departments are connected by formal and informal information systems designed to service the manufacturing system that produces the goods.

MANUFACTURING AND PRODUCTION SYSTEMS

TABLE 1-1 Production Terms for Manufacturing Production Systems

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

MANUFACTURING AND PRODUCTION SYSTEMS

TABLE 1-2 Partial List of Production Systems for Producer and Consumer Goods

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

MANUFACTURING AND PRODUCTION SYSTEMS

TABLE 1-3 Types of Service Industries
Advertising and marketing
Communication (telephone, computer networks)
Education
Entertainment (radio, TV, movies, plays)
Equipment and furniture rental
Financial (banks, investment companies, loan companies)
Health care
Insurance
Transportation and car rental
Travel (hotel, motel, cruise lines)

PRODUCTION SYSTEM- THE ENTERPRISE

- Production systems include
  - People
  - Money
  - Equipment
  - Materials
  - Supplies
  - Markets
  - Management
  - Manufacturing System
  - All aspects of commerce

MANUFACTURING SYSTEMS

- Production systems include
- Manufacturing systems
  - Collection of operations and processes to produce a desired product or component
  - Design or arrangement of the manufacturing processes
- Manufacturing processes
  - Converts unfinished materials to finished products
    - Often is a set of steps
  - Machine tool is an assembly that produces a desired result

COMMON ASPECTS OF MANUFACTURING

- Job and station
  - Job is a group of related operations generally done at one station
  - Station is the location or area where production is done
- Operations
  - Distinct action to produce a desired result or effect
  - Categories of operations
    - Materials handling and transport
    - Processing
    - Packaging
    - Inspecting and testing
    - Storing

COMMON ASPECTS OF MANUFACTURING

- Treatments operate continuously on a workpiece
  - Heat treating, curing, galvanizing, plating, finishing, chemical cleaning, painting
- Tools, tooling and workholders
  - Lowest mechanism in the production is a tool
    - Used to hold, shape or form the unfinished product
- Tooling for measurement and inspection
  - Rulers, calipers, micrometers, and gages
  - Precision devices are laser optics or vision systems that utilize electronics to interpret results

PRODUCTS AND FABRICATIONS

- Products result from manufacture
  - Manufacturing can be from either fabricating or processing
    - Fabricating is the manufacture of a product from pieces such as parts, components, or assemblies
    - Processing is the manufacture of a product by continuous operations
- Workpiece and its configuration
  - Primary objective of manufacturing is to produce a component having a desired geometry, size, and finish

MANUFACTURED SURFACES

- Products are manufactured by producing the surfaces that bound the shape. Surfaces may be:
  - Plane or flat
  - Cylindrical (external or internal)
  - Conical (external or internal)
  - Irregular (external or internal)

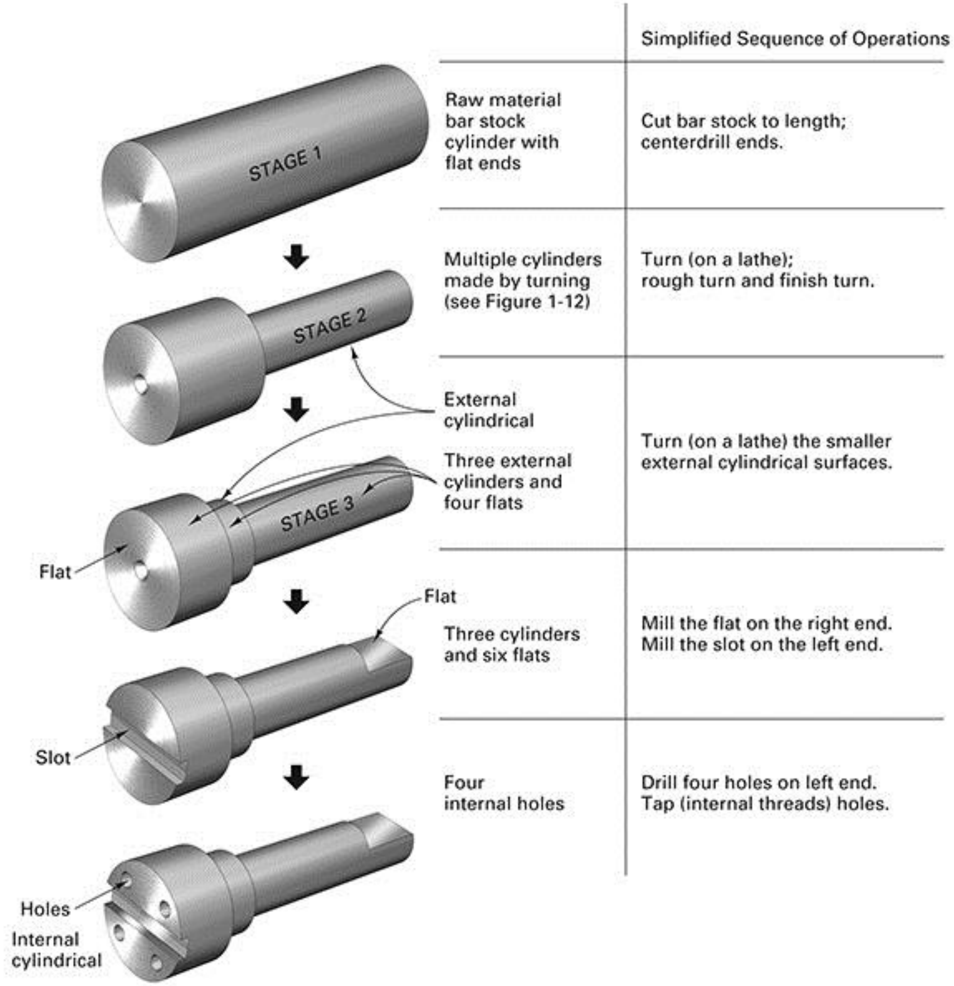


Figure 1-6 The component called a pinion shaft is manufactured by a "sequence of operations" to produce various geometric surfaces.

ROLES OF ENGINEERS IN MANUFACTURING

- Design engineer responsibilities
  - What the design is to accomplish
  - Assumptions that can be made
  - Service environments the product must withstand
  - Final appearance of the product
  - Product designed with the knowledge that certain manufacturing processes will be used

ROLES OF ENGINEERS IN MANUFACTURING

- Manufacturing engineer responsibilities
  - Select and coordinate specific processes and equipment
  - Supervise and manage their use
- Industrial (Manufacturing) engineer
  - Manufacturing systems layout
- Materials engineers
  - Specify ideal materials
  - Develop new and better materials

CHANGING WORLD COMPETITION

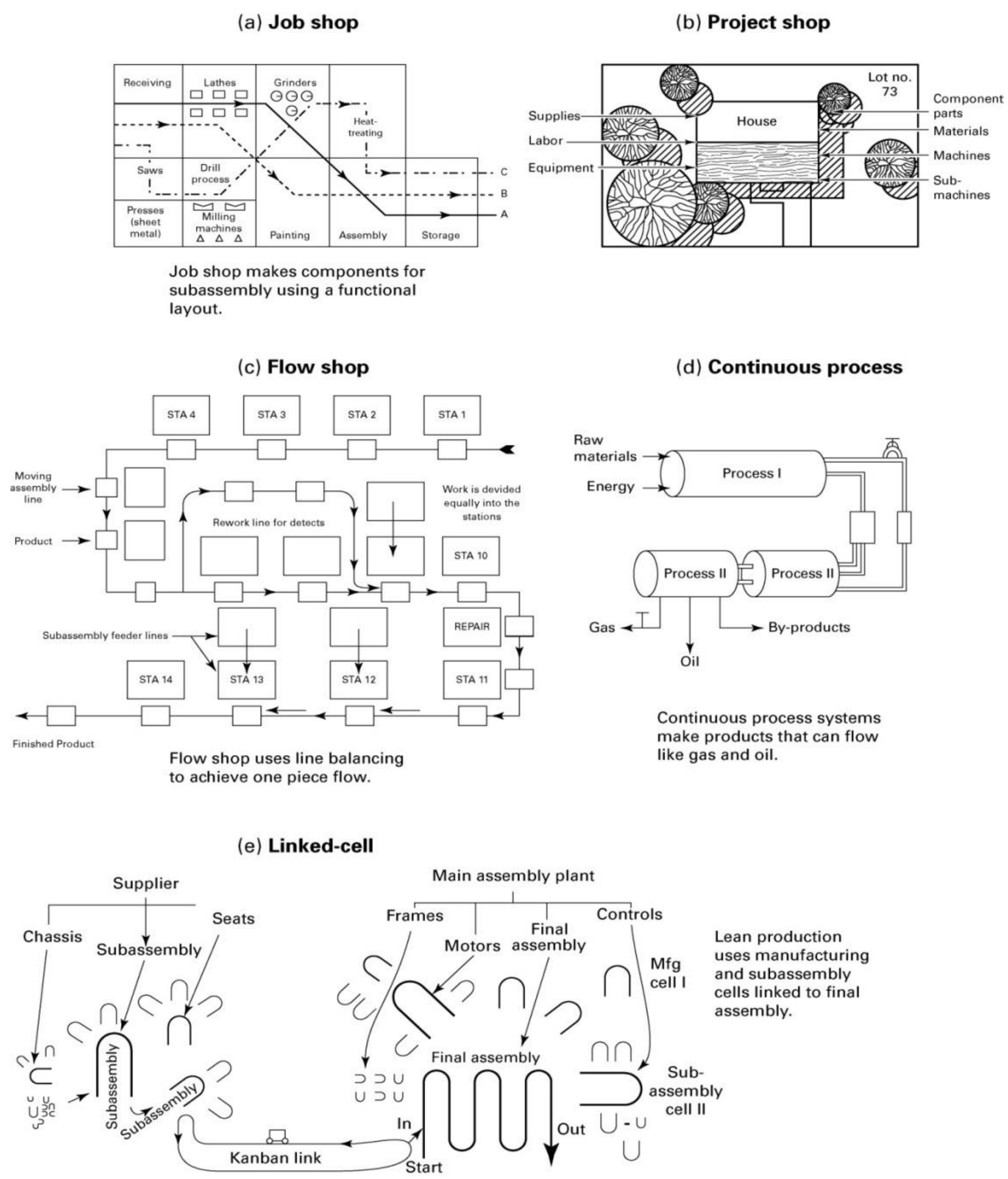
- Globalization has impacted manufacturing
  - Worldwide competition for global products and their manufacture
  - High tech manufacturing for advanced technology
  - New manufacturing systems, designs, and management

MANUFACTURING SYSTEMS DESIGNS

- Five manufacturing system designs
  - Job shop
  - Flow shop
  - Linked-cell shop
  - Project shop
  - Continuous process

MANUFACTURING SYSTEMS DESIGNS

Figure 1-7 Schematic layouts of factory designs.



JOB SHOP

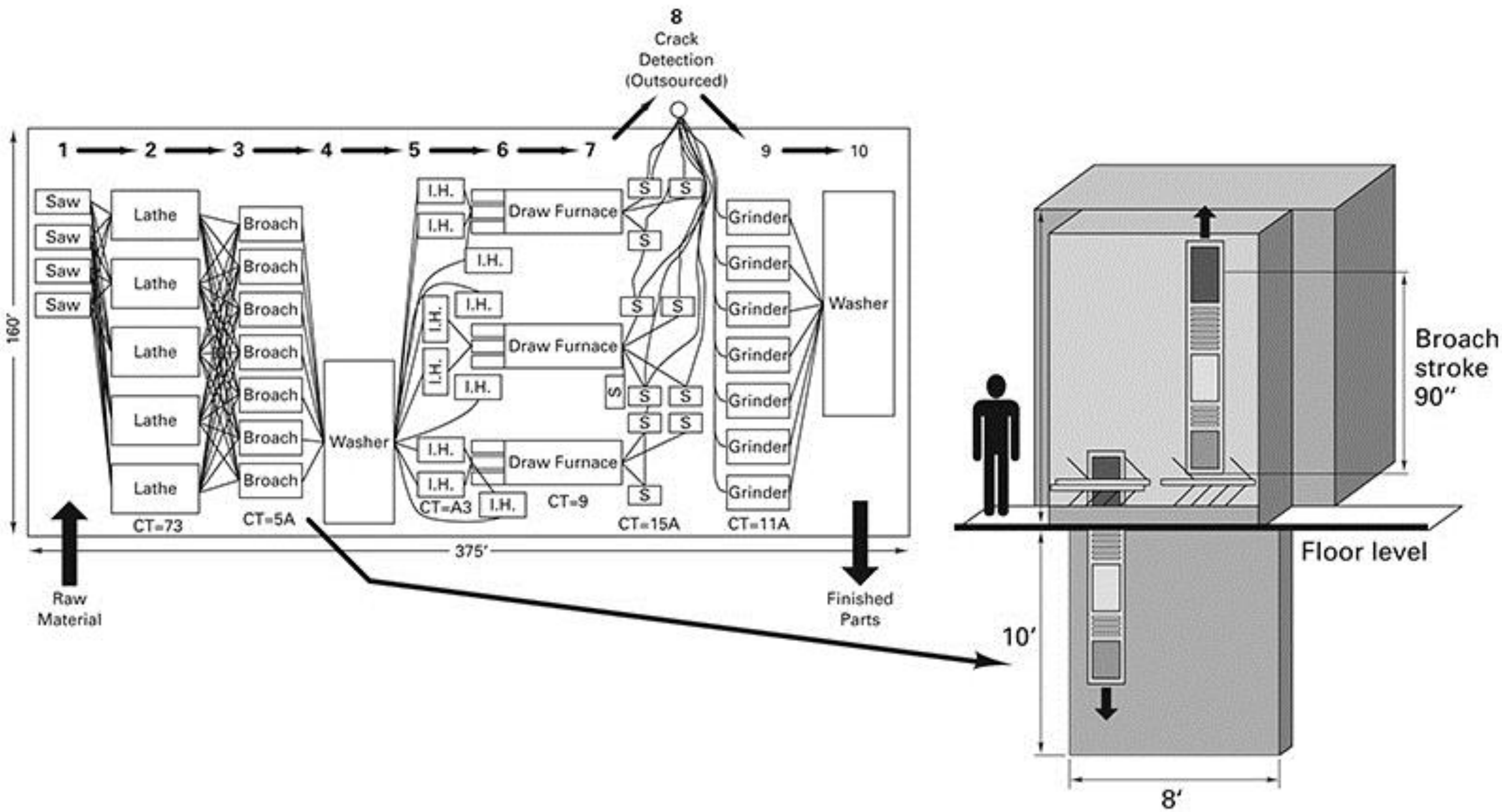
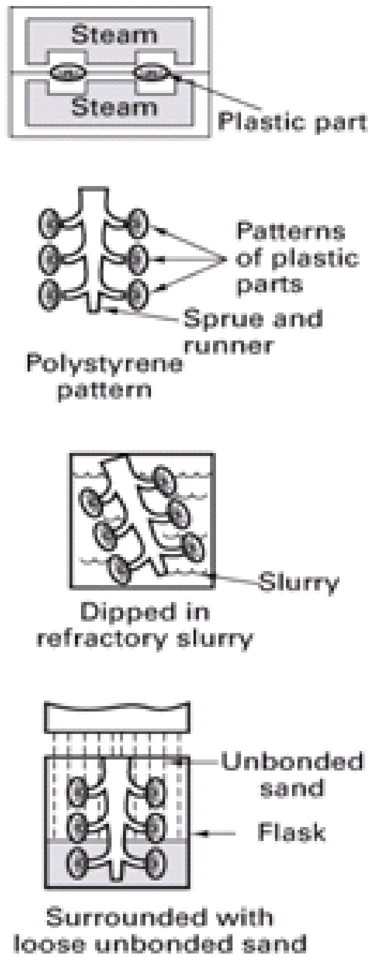


Figure 1-8 This rack bar machining area is functionally designed so it operates like a job shop, with lathes, broaches, and grinders lined up.

BASIC MANUFACTURING PROCESSES

- Casting, foundry, or molding process
- Forming or metalworking processes
- Machining (material removing) processes
- Joining and assembly
- Surface treatments (finishing)
- Rapid prototyping
- Heat treating

LOST-FOAM PROCESS



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

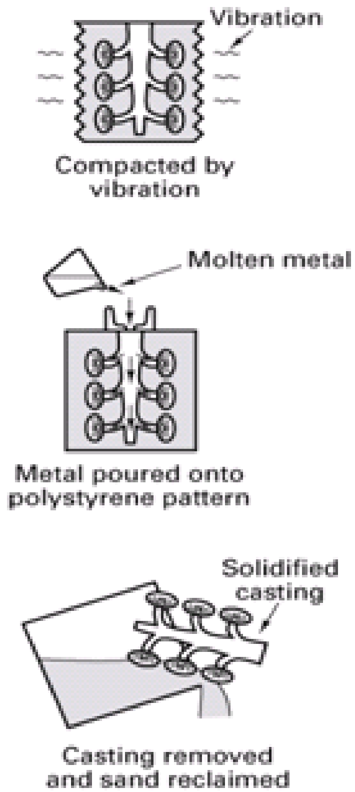
A pattern containing a sprue, runners, risers, and parts is made from single or multiple pieces of foamed polystyrene plastic.

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

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

Figure 1-11 Schematic of the lost-foam casting process.

LOST-FOAM PROCESS



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

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

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

Figure 1-11 Schematic of the lost-foam casting process.

FORMING PROCESS

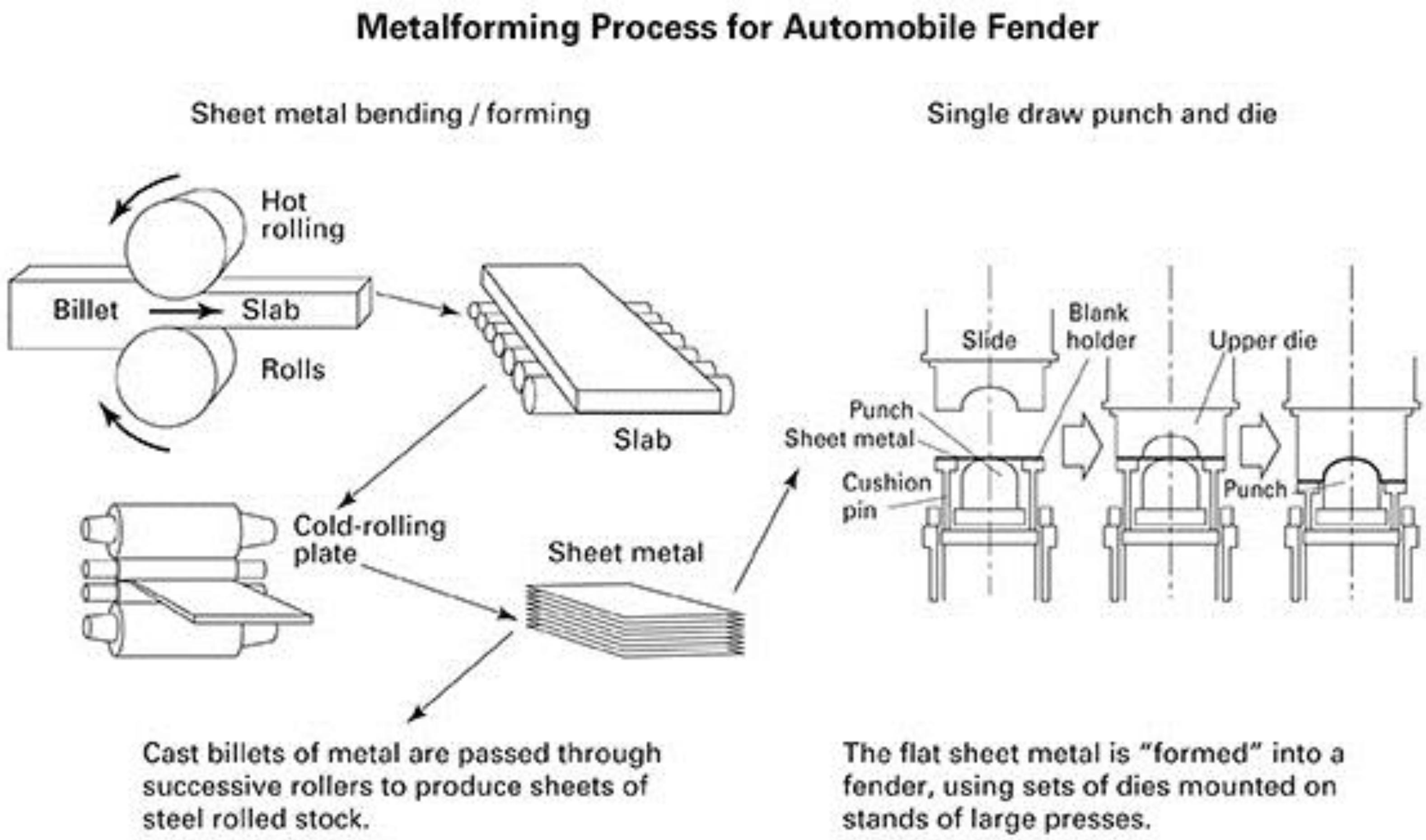


Figure 1-12 The forming process used to make a fender for a car.

FORMING PROCESS

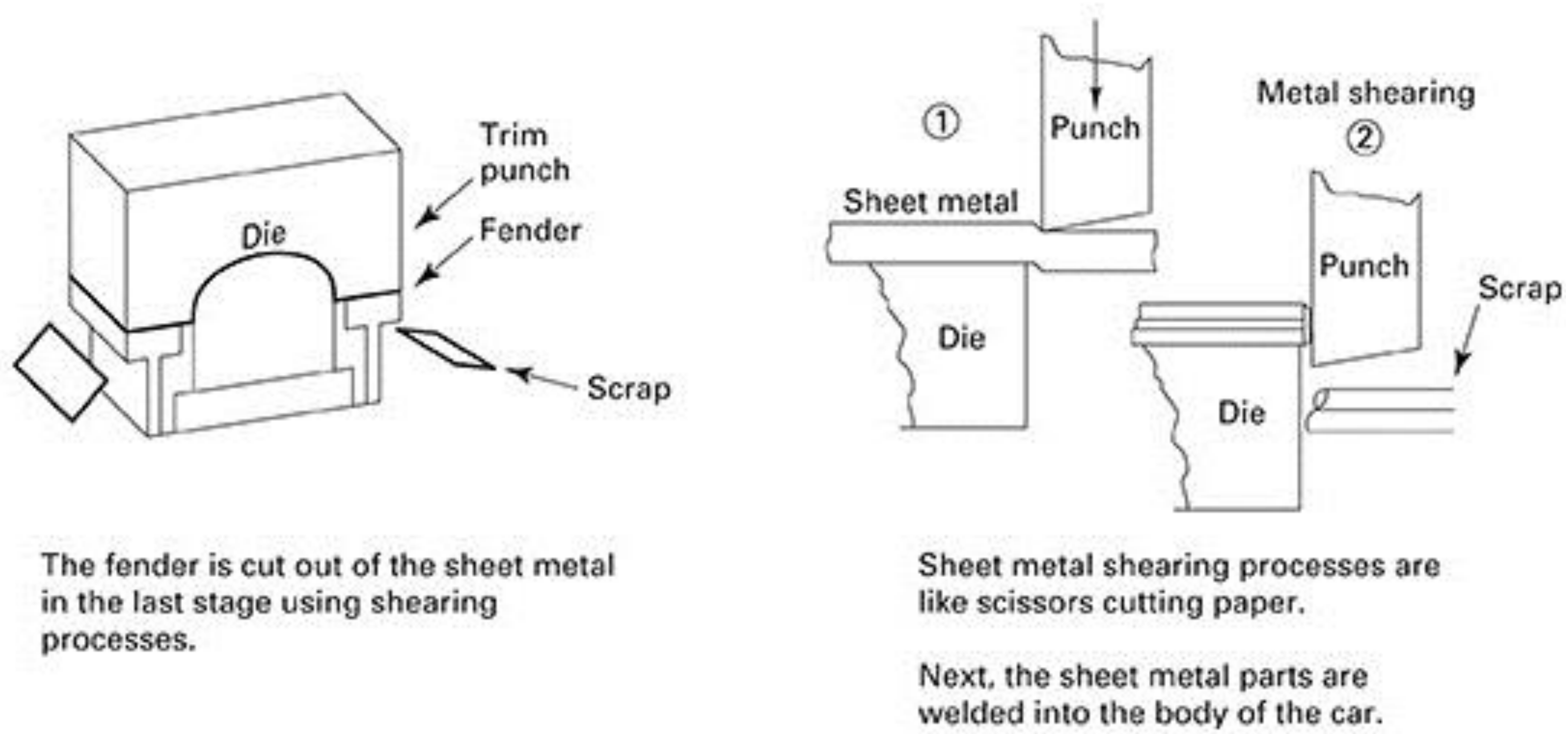
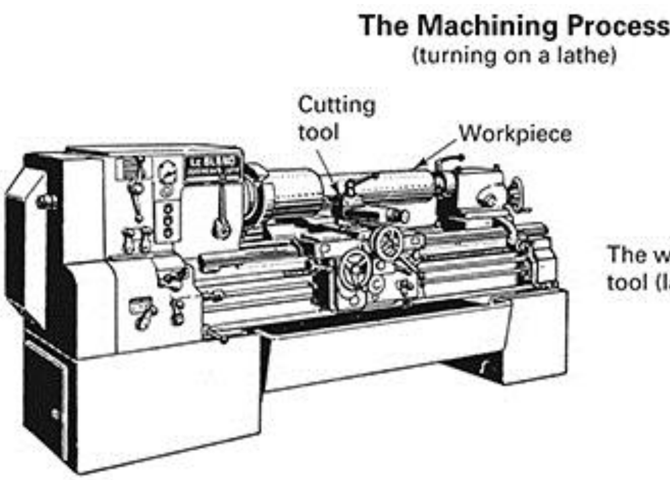
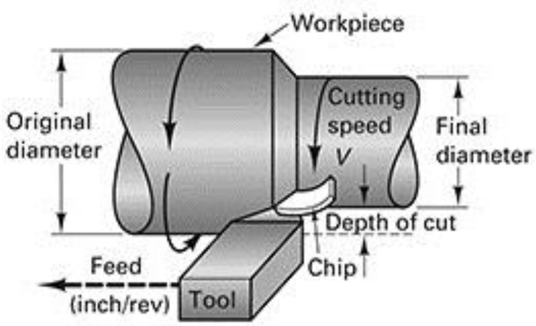


Figure 1-12 The forming process used to make a fender for a car.

SINGLE-POINT METALCUTTING



The workpiece is mounted in a machine tool (lathe) with a cutting tool.



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

Figure 1-13 Single-point metalcutting process (turning) produces a chip while creating a new surface on the workpiece.

JOINING PROCESSES

- Mechanical fastening
- Soldering and brazing
- Welding
- Press, shrink, or snap fittings
- Adhesive bonding
- Assembly processes

SURFACE TREATMENTS

- Finishing operations
- Cleaning
- Removing burrs left by machining
- Providing protective/decorative surfaces
    - Painting
    - Plating
    - Buffing
    - Galvanizing
    - Anodizing

OTHER MANUFACTURING OPERATIONS

- Testing
- Transportation
- Automation
- Removal of material waste
- Packaging
- Storage

CHARACTERISTICS OF PROCESS TECHNOLOGY

- Mechanics (static or dynamic)
- Economics or costs
- Time Spans
- Constraints
- Uncertainties and process reliability
- Skills
- Flexibility
- Process capability

CHARACTERISTICS OF PROCESS TECHNOLOGY

TABLE 1-4 Characterizing a Process Technology

Mechanics (statics and dynamics of the process)
- How does the process work?
- What are the process mechanics (statics, dynamics, friction)?
- What physically happens, and what makes it happen? (Understand the physics.)

Economics or costs
- What are the tooling costs, the engineering costs?
- Which costs are short term, which long term?
- What are the setup costs?

Time spans
- How long does it take to set up the process initially?
- What is the throughput time?
- How can these times be shortened?
- How long does it take to run a part once it is set up (cycle time)?
- What process parameters affect the cycle time?

Constraints
- What are the process limits?
- What cannot be done?
- What constrains this process (sizes, speeds, forces, volumes, power, cost)?
- What is very hard to do within an acceptable time/cost frame?

Uncertainties and process reliability
- What can go wrong?
- How can this machine fail?
- What do people worry about with this process?
- Is this a reliable, stable process?

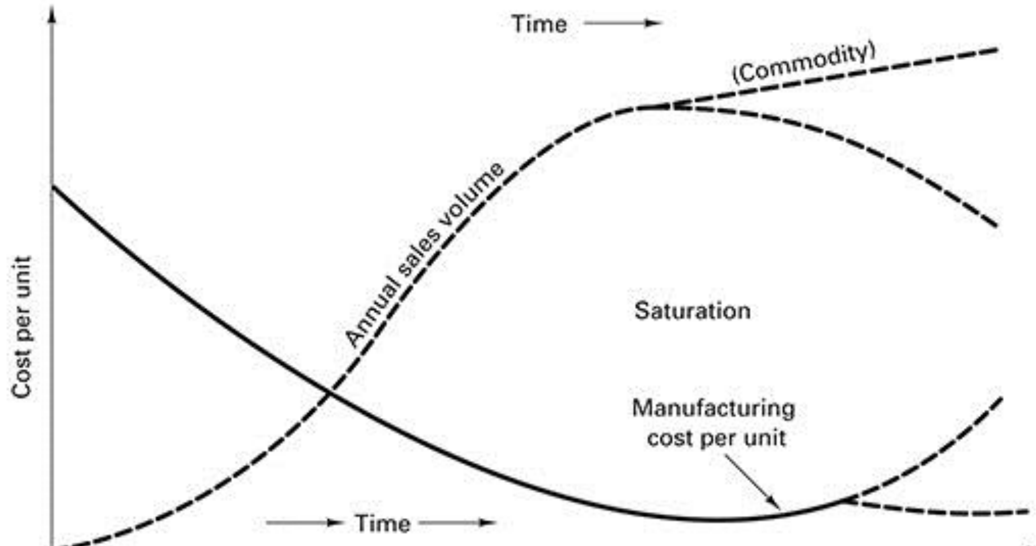
Skills
- What operator skills are critical?
- What is not done automatically?
- How long does it take to learn to do this process?

Flexibility
- Can this process be adapted easily for new parts of a new design or material?
- How does the process react to changes in part design and demand?
- What changes are easy to do?

Process capability
- What are the accuracy and precision of the process?
- What tolerances does the process meet? (What is the process capability?)
- How repeatable are those tolerances?

CHARACTERISTICS OF PROCESS TECHNOLOGY

Figure 1-15 Product life-cycle costs change with the classic manufacturing system designs.



	Startup	Rapid growth	Maturation	Commodity or decline
Manufacturing system design	Job shop	Production job shop with some flow	Production job shop with some flow lines and assembly lines	More flow mass-produce
Product variety:	Great variety; product innovation great	Increasing standardization; less variety	Emergence of a dominant standard design	High standardization "Commodity" characteristics
Industry structure:	Many small competitors	Fallout and consolidation	Few large companies	"Survivors" become commodities
Form of competition:	Product characteristics	Product quality, cost, and availability	Price and quality with reliability	Price with consistent quality
Process innovation:	Low	Medium to high	High	Medium
Automation:	Low	Medium	Medium to high	High

MANUFACTURING SYSTEM DESIGN

- Two consumers in a product design
  - External consumer who buys the product
    - Global
    - Demands greater variety, superior quality and reliability
  - Internal consumer who manufactures the product

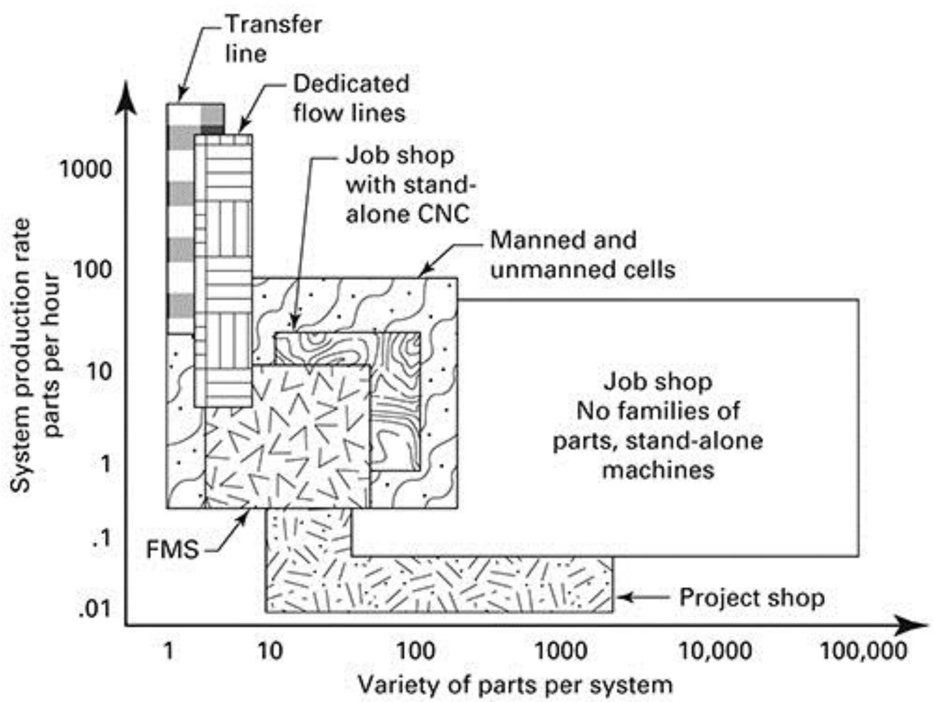


Figure 1-16 Different manufacturing system designs produce goods at different production rates.

NEW MANUFACTURING SYSTEMS

- Toyota Production System
  - Lean manufacturing system
  - 100% good units flow without interruption
  - Integrated quality control
  - Responsibility for quality is given to manufacturing
  - Constant quality improvement

MANUFACTURING SYSTEMS AND PRODUCTION VOLUMES

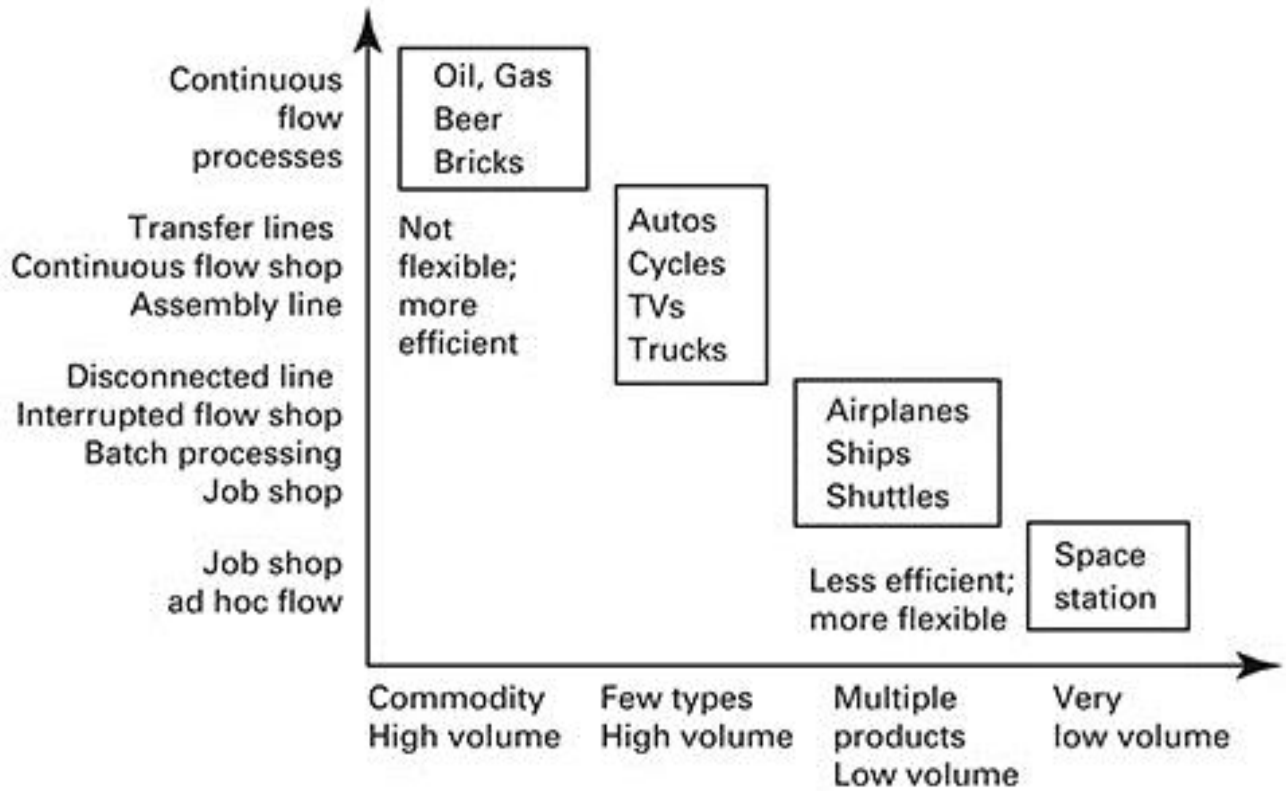
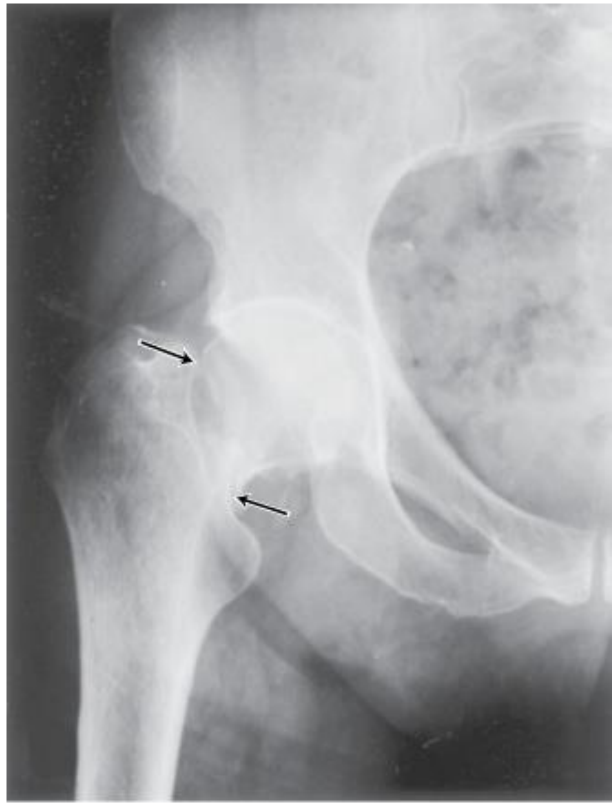


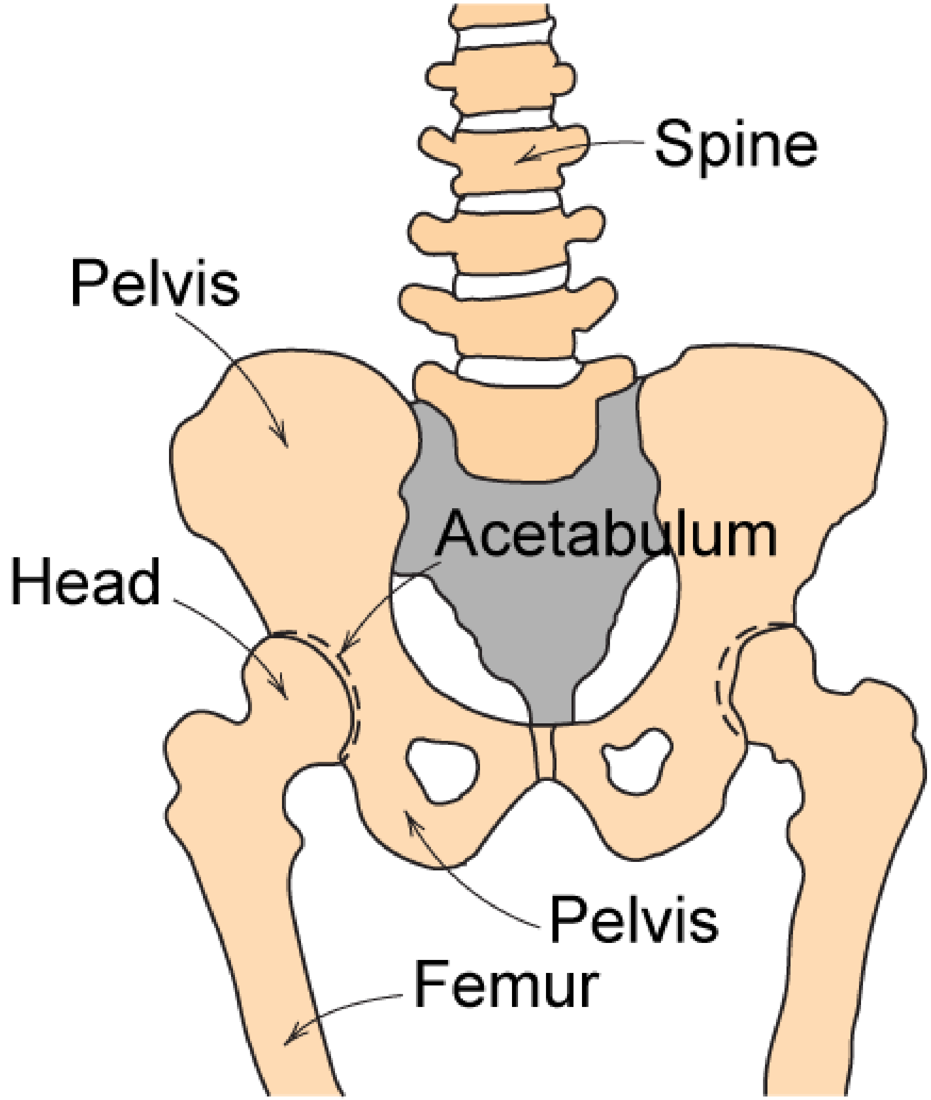
Figure 1-17 This figure shows in a general way the relationship between manufacturing systems and production volumes.

EXAMPLE – HIP IMPLANT

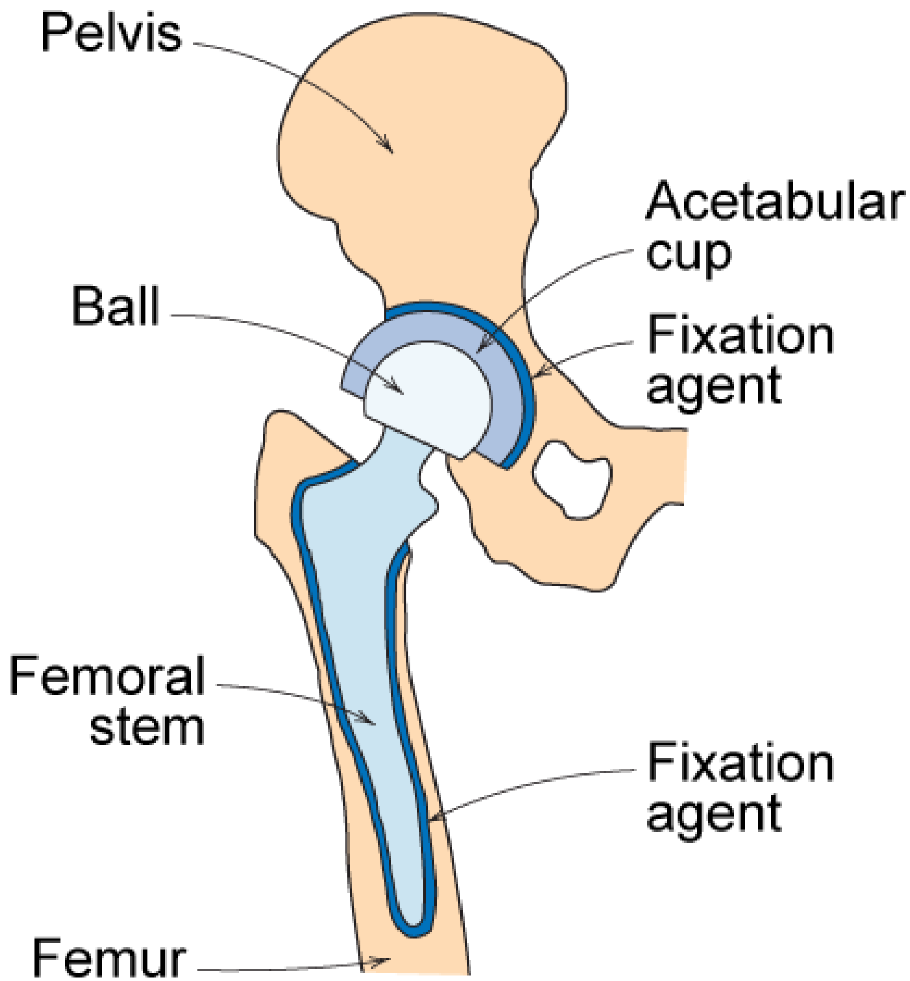
- With age or certain illnesses joints deteriorate. Particularly those with large loads (such as hip).



EXAMPLE – HIP IMPLANT



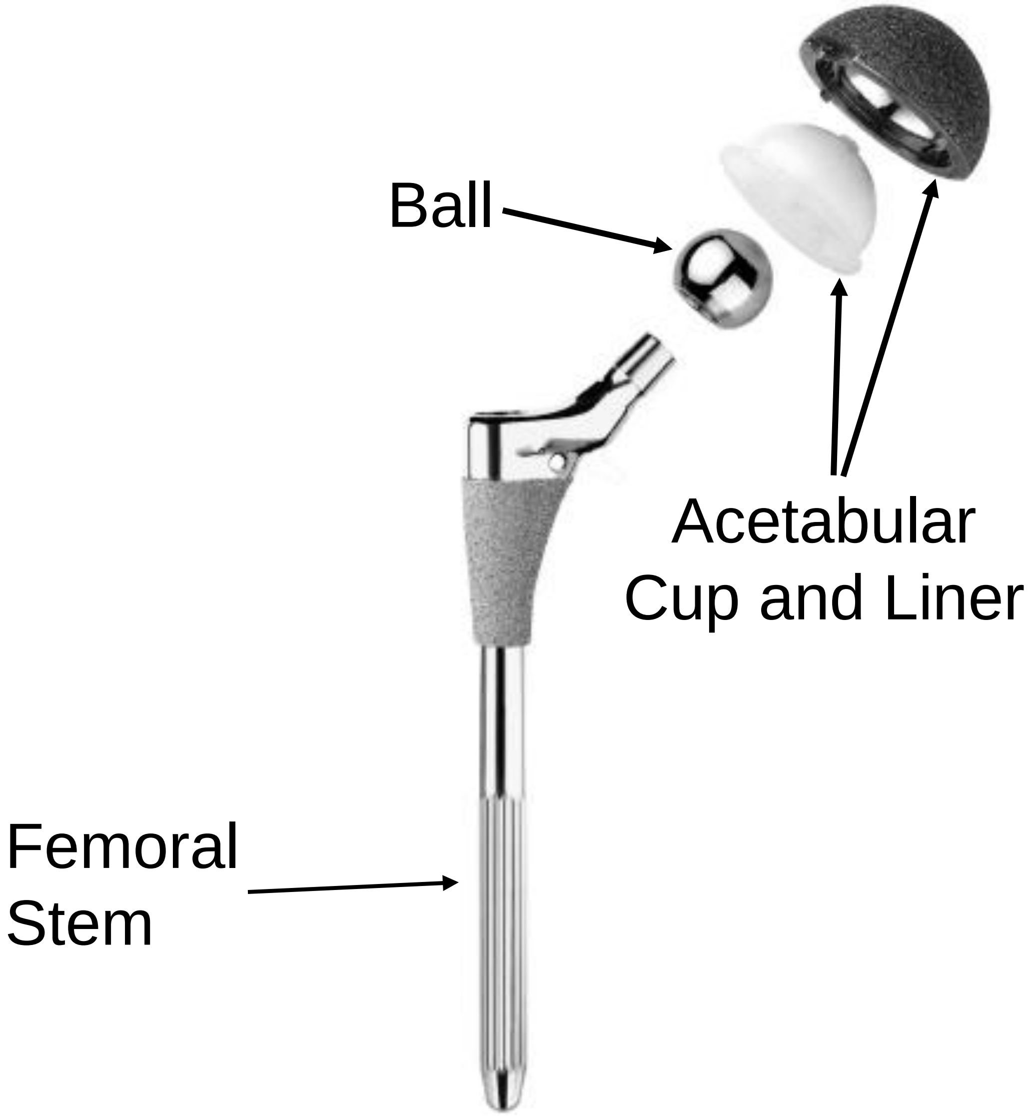
EXAMPLE – HIP IMPLANT



(a)

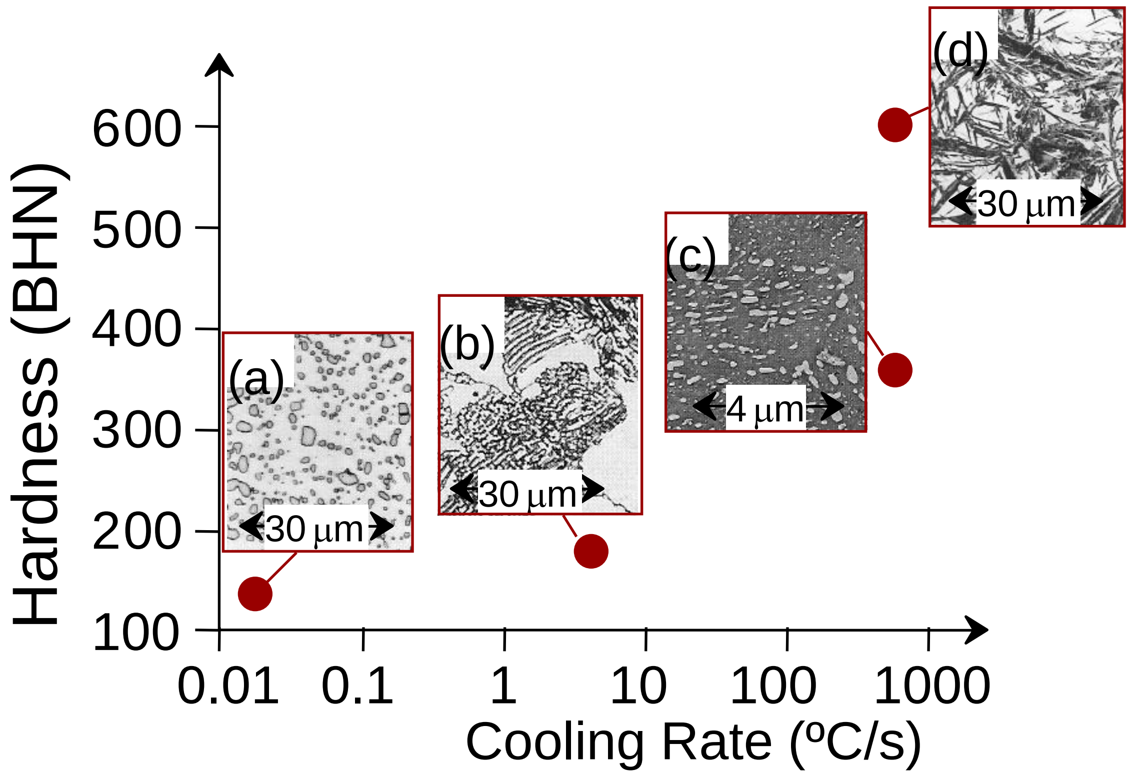
(b)

EXAMPLE – HIP IMPLANT

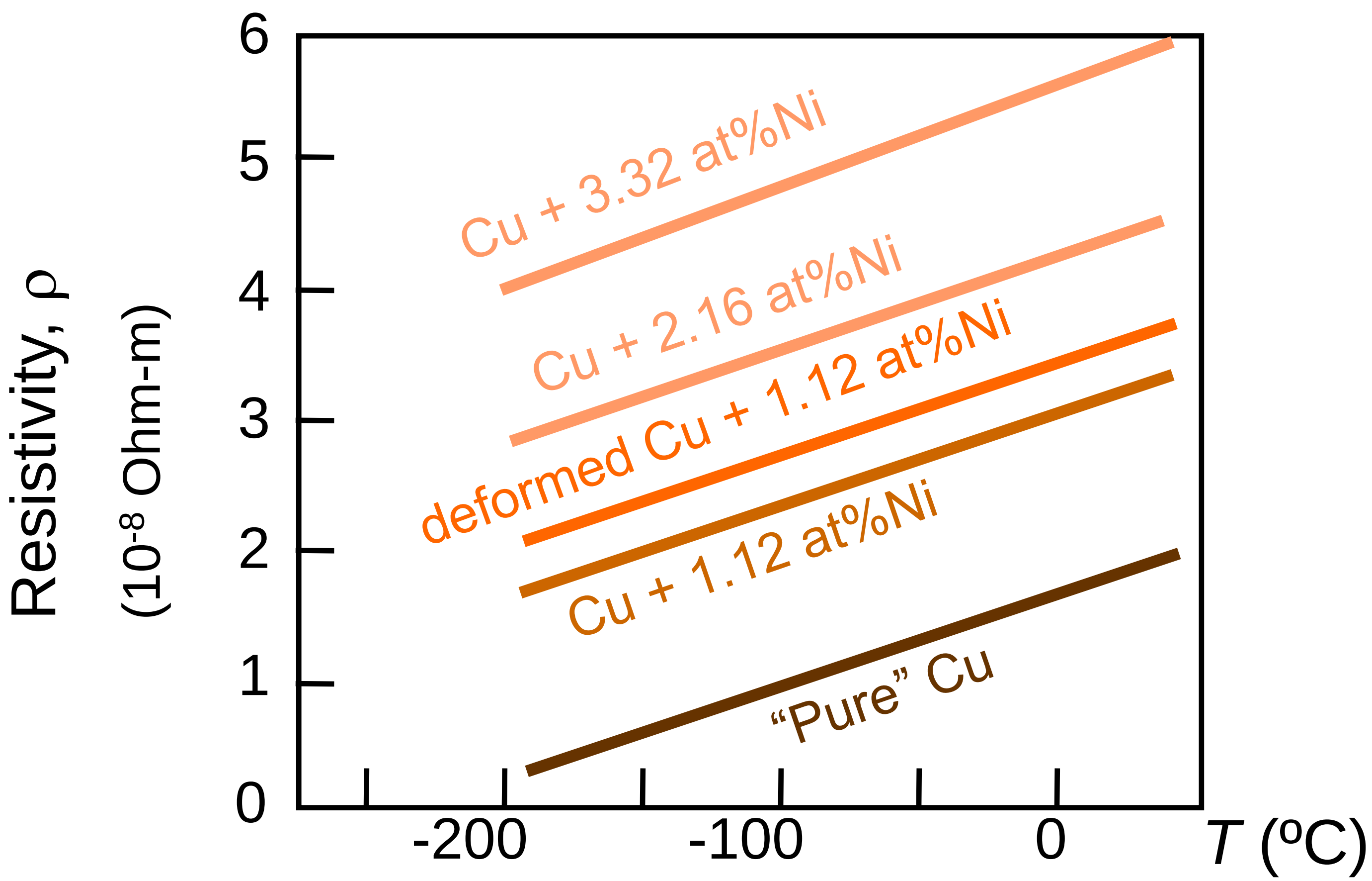


STRUCTURE, PROCESSING & PROPERTIES

ex: hardness vs structure of steel



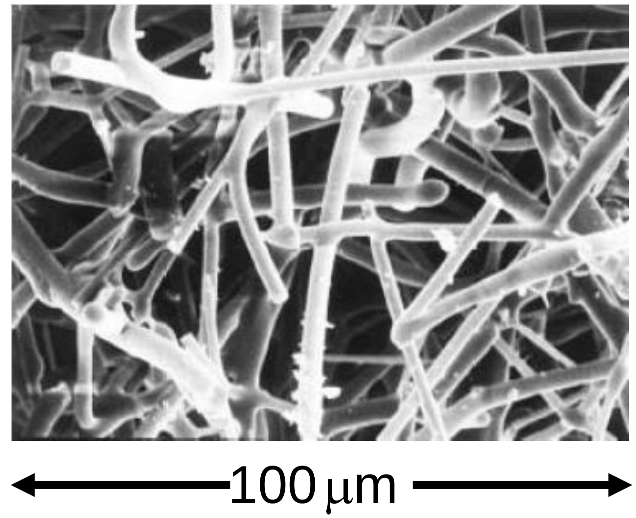
ELECTRICAL



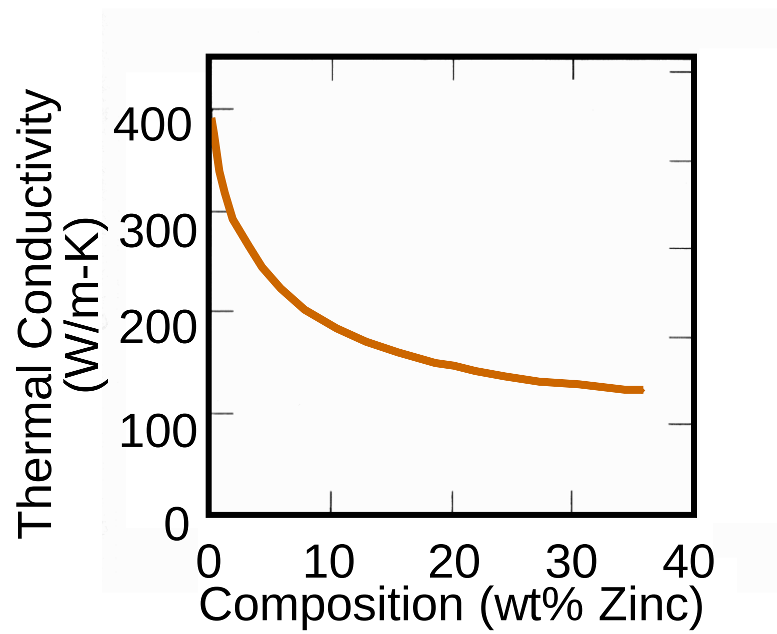
Resistivity, ρ
(10-8 Ohm-m)
6
5
4
3
2
1
0
-200
-100
0
T (ºC)
Cu + 3.32 at%Ni
Cu + 2.16 at%Ni
deformed Cu + 1.12 at%Ni
Cu + 1.12 at%Ni
"Pure" Cu

THERMAL

- Space Shuttle Tiles:
  -- Silica fiber insulation
     offers low heat conduction.



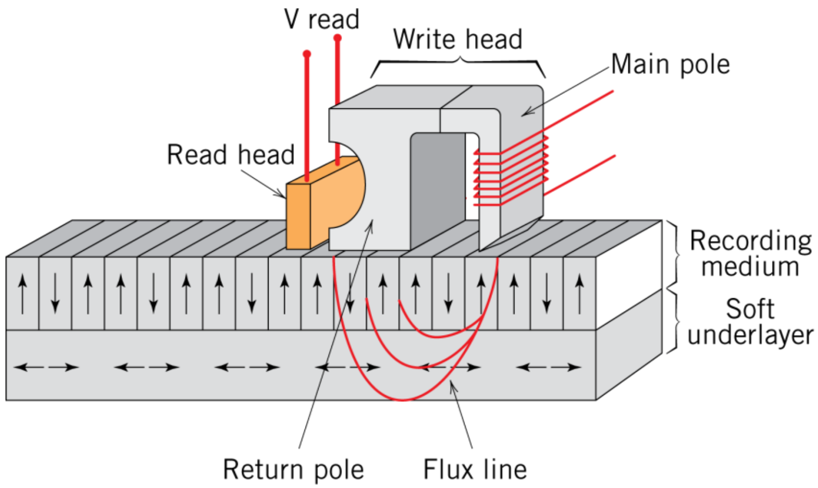
- Thermal Conductivity
  of Copper:
  -- It decreases when
     you add zinc!



MAGNETIC

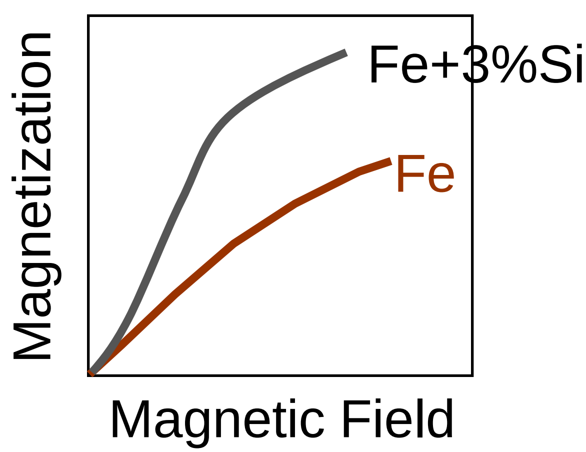
- Magnetic Storage:

  -- Recording medium is magnetized by recording head.



- Magnetic Permeability vs. Composition:

  -- Adding 3 atomic % Si makes Fe a better recording medium!



OPTICAL

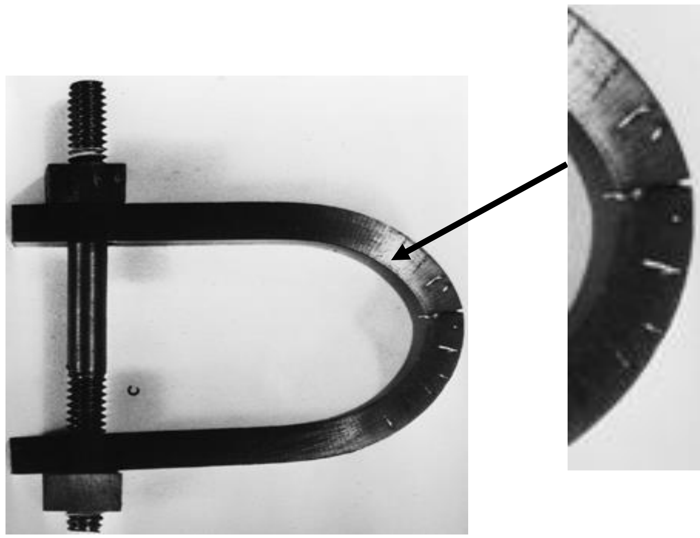
single crystal

polycrystal:
low porosity

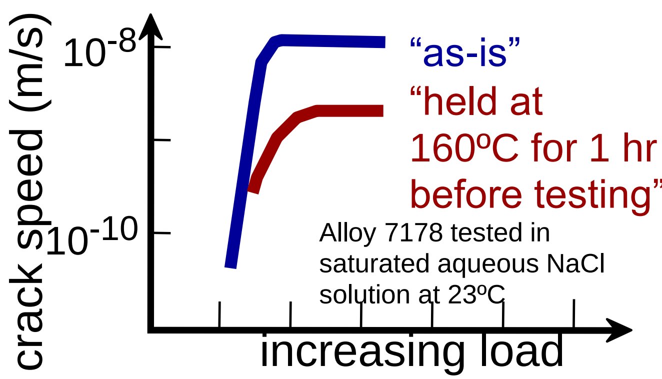
polycrystal:
high porosity

DETERIORATIVE

- Stress & Saltwater causes cracks



- Heat treatment: slows crack speed in salt water



SUMMARY

- Economical and successful manufacturing requires knowledge of the relationships between labor, materials, and capital
- Design a manufacturing system that everyone understands
- Engineers must possess a knowledge of design, metallurgy, processing, economics, accounting, and human relations

CHAPTER 1 CASE STUDY

Famous Manufacturing Engineers

Manufacturing engineering is that engineering function charged with the responsibility of interpreting product design in terms of manufacturing requirements and process capability. Specifically, the manufacturing engineer may:

- Determine how the product is to be made in terms of specific manufacturing processes.
- Design workholding and work transporting tooling or containers.
- Select the tools (including the tool materials) that will machine or form the work materials.
- Select, design, and specify devices and instruments that inspect products that have been manufactured to determine their quality.
- Design and evaluate the performance of the manufacturing system.
- Perform all these functions (and many more) related to the actual making of the product at the most reasonable cost per unit without sacrifice of the functional requirements or the users' service life.

There's no great glory in being a great manufacturing engineer (MfE). If you want to be a manufacturing engineer, you had better be ready to get your hands dirty. Of course, there are exceptions. There have been some very famous manufacturing engineers. For example:

- John Wilkinson of Bersham, England built a boring mill in 1775 to bore the cast iron cylinders for James Watt's steam engine. How good was this machine?
- Eli Whitney was said to have invented the cotton gin, a machine to separate seeds from cotton. His machine was patented but was so simple, anyone could make one. He was credited with "interchangeability"—but we know Thomas Jefferson observed interchangeability in France in 1785 and probably the French gunsmith LeBlanc is the real inventor here. Jefferson tried to bring the idea to America and Whitney certainly did. He took 10 muskets to Congress, disassembled them, and scattered the pieces. Interchangeable parts permitted them to be reassembled. He was given a contract for 2000 guns to be made in two years. But what is the rest of his story?

CHAPTER 1 CASE STUDY

- Joe Brown started a business in Rhode Island in 1833 making lathes and small tools as well as timepieces (watchmaker). Lucian Sharp joined the company in 1848 and developed a pocket sheet metal gage in 1877 and a 1-inch micrometer, and in 1862 developed the universal milling machine.
- At age 16, Sam Colt sailed to Calcutta on the Brig "Curve." He whittled a wood model of a revolver on this voyage. He saved his money and had models of a gun built in Hartford by Anson Chase, for which he got a patent. He set up a factory in New Jersey—but he could not sell his guns to the Army because they were too complicated. He sold to the Texas Rangers and the Florida Frontiersmen, but he had to close the plant. In 1846, the Mexican war broke out. General Zachary Taylor and Captain Sam Walters wanted to buy guns. Colt had none but accepted orders for 1000 guns and constructed a model (Walker Colt); he arranged to have them made at Whitney's (now 40-year-old) plant in Whitneyville. Here he learned about mass production methods. In 1848, he rented a plant in Hartford, Connecticut, and the Colt legend spread. In 1853 he had built one of the world's largest arms plant in Connecticut, which had 1400 machine tools. Colt helped start the careers of
  - E. K. Root, mechanic and superintendent, paying him a salary of $25,000 in the 1800s. Abolished hand work—jigs and fixtures.
  - Francis Pratt and Amos Whitney—famous machine tool builders.
  - William Gleason—gear manufacturer
  - E. P. Bullard—invented the Mult–An–Matic Multiple spindle machine, which cut the time to make a fly-wheel from 18 minutes to slightly over 1 minute. Sold this to Ford.
  - Christopher Sponer.
  - E. J. Kingsbury—invented a drilling machine to drill holes through toy wheel hubs that had a spring-loaded cam that enabled the head to sense the condition of the casting and modify feed rate automatically.

CHAPTER 1 CASE STUDY

Now here are some more names from the past of famous and not-so-famous manufacturing, mechanical, and industrial engineers. Relate them to the development of manufacturing processes or manufacturing system designs.

- Eli Whitney
- Henry Ford
- Charles Sorenson
- Sam Colt
- John Parsons
- Eiji Toyoda
- Elisha Root
- John Hall
- Thomas Blanchard
- Fred Taylor
- Taiichi Ohno
- Ambrose Swasey