Society of Manufacturing Engineers

Certified Manufacturing Engineering Review Course

Course Description

- A structured review for individuals planning to take the Manufacturing Engineering Certification Examination (CMfgE).
- The body of knowledge covered in the review includes
  – materials,
  – product design
  – manufacturing processes
  – production systems
  – quality
  – automated systems and control
  – manufacturing management
  – engineering economics

Course Objectives

- Identify test taking strategies.
- Identify reference material to be used during the exam.
- Develop solutions to questions similar in nature to the exam questions.

Schedule

- Day 1
  - Part 1 Materials
  - Part 2 Product design
  - Part 3 Manufacturing processes
  - Part 4 Production systems
- Day 2
  - Part 5 Automated systems
  - Part 6 Quality
  - Part 7 Manufacturing management
  - Part 8 Engineering economics

Manufacturing Engineering Exam Format

- Three-hour time limit
- 150 multiple choice questions.
  - 110 cover a breadth of knowledge in manufacturing engineering.
  - 40 questions are designed to test process knowledge in one of the following four focus areas.
  - The 40 focus area questions are dispersed throughout the exam.

Focus Areas

- Integration & Control
  - CIM, robotics, machine vision, common networks, computer systems, CAM
- Processes
  - electronics manufacturing, material removal, material forming, fabrication, assembly, finishing, molding, casting

Focus Areas

- Support Operations
  - maintenance, material handling, scheduling, planning, management, design
- Management
  - quality, systems, projects, leadership, planning, staffing, organization, laws and regulations

Test Taking Strategy

- Make sure you answer the questions you know correctly. Don't make dumb mistakes.
- With four answers to choose from, guessing provides a 25% probability of selecting the correct answer.
- In multiple choice questions some of the answers can be immediately eliminated thus increasing the chances of guessing correctly.
- There is not enough time to look up all the answers. There may be only enough time to look up 5-10 answers.
- The focus area questions are distributed throughout the exam.

Test Taking Strategy

- You may not recognize which questions are general knowledge and which are focus area questions.
- Choose the best answer from the list of possible answers even if it is not the correct answer in your opinion.
- One common test taking strategy is to answer all the questions you know and skip the one's you don't know.
  - When you skip a question however, make sure you mark it and return to it later.

Test Taking Strategy

- If you skip a question, make sure the answer to the following question goes into the correct bubble.
  - For example, if you skip number 28, don’t put the answer to number 29 into number 28 bubble.
  - Some people will fill in a temporary answer to number 28 just to keep this from happening.

Resources

- Some people find it useful to tab various sections or their books for quick reference.
- Other people prefer to use the table of contents or index for reference.
- Fundamentals of Manufacturing, 2nd ed. (SME)
- Machinery's Handbook
- TMEH Desk Edition (SME)
- CMfgE Practice Exam (SME)
- CMfgE Self-Assessment Disk (SME)
- Safety Manual
- Project Management Book
- Manufacturing Processes Book

Part 1
Materials

Material Properties

Brittleness	The tendency of a material to fail suddenly by breaking, without any permanent deformation of the material before failure.
Creep	The slow deformation (for example, elongation) of a metal under prolonged stress.
Ductility	The ability of a material to become permanently deformed without failure.
	- measured by percent reduction in area at fracture or percent elongation at fracture
Elasticity	The ability of a material to return to original shape and dimensions after a deforming load has been removed.

Material Properties

Fatigue strength	The resistance of a material to repetitive or alternating stressing, without failure.
Hardness	The ability of a material to resist indentation, penetration, abrasion,scratching.
	- typically measured with Rockwell or Brinell test
Malleability	The property of being permanently deformed compression without rupturing; that is, the ability to be rolled or hammered into thin sheets.
Modulus of elasticity	The ratio of tensile stress to the strain it causes, within that range of elasticity.The higher the modulus, the lower the degree of elasticity.

Material Properties

Plasticity	The property in a material of being deformed under the action of a force and not returning to its original shape upon the removal of the force.
Specific gravity	The ratio of the weight of a given volume of a material to the weight of an equal volume of pure water at 4°C.
Specific heat	The number of calories required to raise one gram of the material 1°C.
Strain	The physical effect of stress, usually evidenced by stretching or other deformation of the material.
Stress	The load, or amount of a force, applied per unit area.

Material Properties

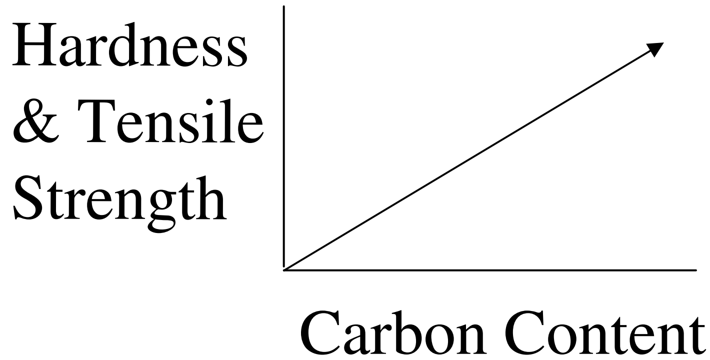
Tensile strength	The resistance of a material to a force which is acting to pull it apart.
Toughness	The ability of a metal to withstand the shock of a rapidly applied load.
Ultimate tensile strength	The maximum pulling force to which the material can be subjected without failure.
Yield strength	The stress level at which permanent deformation results.

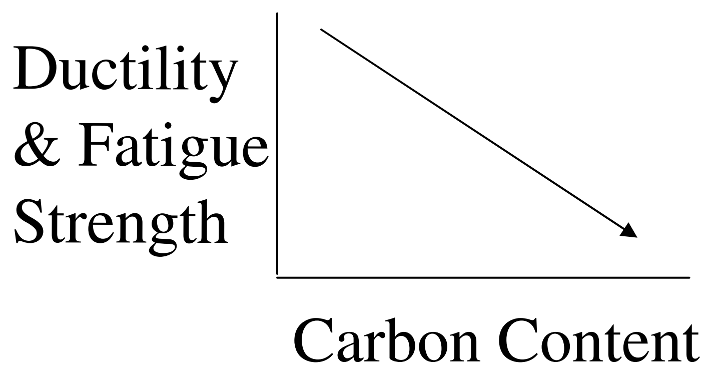
Metals

- Ferrous Metals
  - plain carbon steel
  - high strength low alloy steel
  - maraging steel
  - stainless steel
  - cast iron
  - tool steel
- Nonferrous Metals
  - aluminum
  - copper

Plain Carbon Steel

- Low Carbon Steel
  - 0.001%-0.30% carbon
  - nuts, bolts, sheet, structural shapes
  - high ductility/lower strength
  - free cutting or free machining
  - can be made wear resistant through case hardening





Plain Carbon Steel

- Medium Carbon Steel
  - 0.30%-0.70% carbon
  - crankshafts, axles, gears
  - used for medium to high strength parts
  - can be through hardened and tempered
- High Carbon Steel
  - 0.70%-1.20% carbon
  - high strength, high hardness
  - cutting tools, drill bits, taps

Steel Quality

- Killed Steel
  - strongly deoxidized with the addition of aluminum, manganese or silicon
  - good for forging, extrusion and cold forming
- Semikilled Steel
  - characteristics between a killed steel and a rimmed steel
- Rimmed Steel
  - typically low carbon steels
  - very small percentage of deoxidizers
  - good ductility

Alloying Elements

Element	Percentage	Effect
Aluminum	0.95 - 1.30	- Alloying element in nitriding steels - Deoxidizer
Carbon	0.001-1.300	- Increases Hardness - Decrease corrosion resistance in stainless steels
Chromium	0.5 - 2.0 12 - 30	- Increases hardenability and strength - Increases corrosion resistance
Cobalt		- Imparts the quality red hardness

Alloying Elements

Element	Percentage	Effect
Lead		- Machinability
Manganese	0.25-0.40	- Combines with sulfur to prevent brittleness
	1-15	- Increases toughness and hardenability

Alloying Elements

Element	Percentage	Effect
Molybdenum	0.1-4	- Increases hardenability and strength under dynamic load - Increase creep resistance at high temperatures
Nickel	1-5	- Increases toughness
	12-15	- Increases corrosion resistance

Alloying Elements

Element	Percentage	Effect
Phosphorous	> 0.05	- It is considered an impurity
Silicon	0.2-0.7	- Increases wear resistance in AL
		- Deoxidizer
		- Promotes graphite formation in cast irons
	2	- Used in spring steels
Sulfur	0.1-0.15	- Increases machinability

Alloying Elements

Element	Percentage	Effect
Tungsten		-Maintains hardness at high temperatures - Forms hard carbide
Vanadium	0.15	- Increases impact resistance - Form strong carbides

Carbon Steel Classification Systems

- The two classification systems commonly used are ASTM(American Society for Testing Materials) and AISI-SAE (American Iron and Steel Institute and Society of Automotive Engineers)
- In the AISI-SAE system the first two digits indicate the alloying elements and the last two digits indicate the amount of carbon.
- For example a 1020 steel would have 0.2% carbon by weight.

AISI-SAE System

AISI Number	Major Alloying Element(s)
10XX	Carbon
13XX	Manganese
23XX-25XX	Nickel
3XXX	Nickel/Chromium
4XXX	Molybdenum
5XXX	Chromium
6XXX	Chromium/Vanadium
8XXX-9XXX	Chromium/Nickel/Molybdenum

High Strength Low Alloy (HSLA) Steels

- Typically > 0.30% carbon.
- Strength is derived from the alloying elements as opposed to heat treatment.
- High strength to weight ratio.
- High yield strength.

Maraging Steels

- 15%-25% nickel as the major alloying element.
- Age hardened to produce ultra-high strength steels with high fatigue, tensile and yield strengths.
- Through hardening with air cooling.
- Minimal distortion during heat treating.

Stainless Steel

- Austenitic Stainless
  - austenite structure at room temperature
  - not hardenable by heating and quenching
  - highest corrosion resistance
  - nonmagnetic in annealed condition
  - cold working significantly increases its tensile and yield strength
  - used for piping, tubing, and sinks

Stainless Steel

- Ferritic Stainless
  - ferrite structure at room temperature
  - not hardenable by heating and quenching
  - magnetic
  - good ductility
  - automotive exhausts and trim
- Martensitic
  - hardenable by heating and quenching
  - magnetic
  - ball bearings and cutlery

Cast Iron

- Generally 2%-6.7% carbon content.
- Gray Iron
  - carbon forms graphite flakes
  - good machinability
- White Iron
  - rapidly cooled gray cast iron
  - carbon forms cementite rather than graphite flakes
  - wear resistant
- Malleable Iron
  - annealed white cast iron
  - higher ductility and fatigue strength
- Nodular Iron (ductile iron)
  - carbon forms nodules or spheres from the addition of magnesium

Tool Steel

- Tool steels are designed to provide wear resistance, toughness, and high strength.
- Tool steels generally have high hardenability and are typically used for punches, dies, and molds.

AISI-SAE Tool Steel Classification

Type	AISI-SAE Grade	Characteristic
Water Hardening	W	
Cold work	O	Oil hardening
	A	Air hardening
	D	High carbon/high chrome
Shock resisting	S	
High-speed	T	Tungsten based
	M	Molybdenum based
Hot work	H	
Plastic mold	P	
Special purpose	L	Low alloy
	F	Carbon-tungsten

Aluminum

- Aluminum comes in two basic forms, wrought and cast.
  - Wrought aluminum means worked or able to be worked.
  - Wrought aluminum can be forged, extruded, or machined.
- Cast aluminum is used for casting only.
  - Cast aluminum contains different alloying elements that increase its fluidity.

Wrought Aluminum Classification

- Wrought aluminum alloys are identified by four digits and a temper designation (indicating the processing of the material).
  - The major alloying element determines the first digit.
  - The second digit refers to other alloying elements.
  - The third and fourth digits of the 1xxx series indicate the amount of aluminum present in the alloy (e.g. 1070 contains 99.70% aluminum and 1090 contains 99.9% aluminum).

Wrought Aluminum

Number	Alloy	Properties
1xxx	Pure	Corrosion resistant, high electrical and thermal conductivity, good workability, low strength
2xxx	Copper	High strength to weight ratio, low corrosion resistance
3xxx	Manganese	Good workability, moderate strength
4xxx	Silicon	Low melting point
5xxx	Magnesium	Good corrosion resistance, weldable, high strength
6xxx	Magnesium Silicon	Good weldability, machinability, formability corrosion resistance, and medium strength
7xxx	Zinc	High strength

Aluminum Temper Designations

- F- as fabricated
  - no special control over thermal conditions or strain hardening was employed
- O- annealed
  - improved ductility and lower strength
- H- strain hardened
  - H1 strain hardened by cold working
  - H2 strain hardened by cold working followed by partial annealing
  - H3 strain hardened and stabilized

Aluminum Temper Designations

- T - heat treated
  - T1 cooled from hot working and naturally aged
  - T2 cooled from hot working, cold worked, and naturally aged
  - T3 solution heat treated, cold worked, and naturally aged
  - T4 solution heat treated and naturally aged
  - T5 cooled from hot working and artificially aged
  - T6 solution heat treated and artificially aged
  - T7 solution heat treated and stabilized

Aluminum Temper Designations

  - T8 solution heat treated, cold worked, and artificially aged
  - T9 solution heat treated, artificially aged, and cold worked
  - T10 cooled from hot working, cold worked, and artificially aged.
- W- solution heat treated only

Cast Aluminum Classification

- The designations for cast aluminum alloys also uses four digits with a decimal point added between the third and fourth digit.
  - The first digit indicates the major alloying element.
  - The second and third digit indicate the particular alloy or purity(for 1XX.X series).
  - The last digit, separated by a decimal point indicates the product form.
    - O indicates casting
    - 1 indicates ingot

Cast Aluminum Alloys

Number	Alloy	Properties
1XX.X	Commercially Pure	Corrosion resistant
2XX.X	Copper	High strength and ductility
3XX.X	Silicon	Good machinability (with copper or magnesium)
4XX.X	Silicon	Good castability, corrosion resistant
5XX.X	Magnesium	High strength
6XX.X	Unused	
7XX.X	Zinc	High strength, excellent machinability

Copper

- Advantages of Copper Alloys
  - corrosion resistance
  - ease of fabrication
  - high electrical and thermal conductivity
- Disadvantages of Copper Alloys
  - lower strength-to-weight ratio
  - subject to work hardening
  - some alloys are subject to stress-corrosion cracking

Pure Copper

- Electrolytic Tough-Pitch Copper
  - high electrical conductivity
  - subject to embrittlement when heated in reducing atmospheres
- Deoxidized Copper
  - lower conductivity
  - better welding and brazing characteristics
  - improved cold working characteristics
- Oxygen-Free Copper
  - thoroughly deoxidized
  - better welding and brazing characteristics
  - same conductivity as electrolytic tough-pitch copper

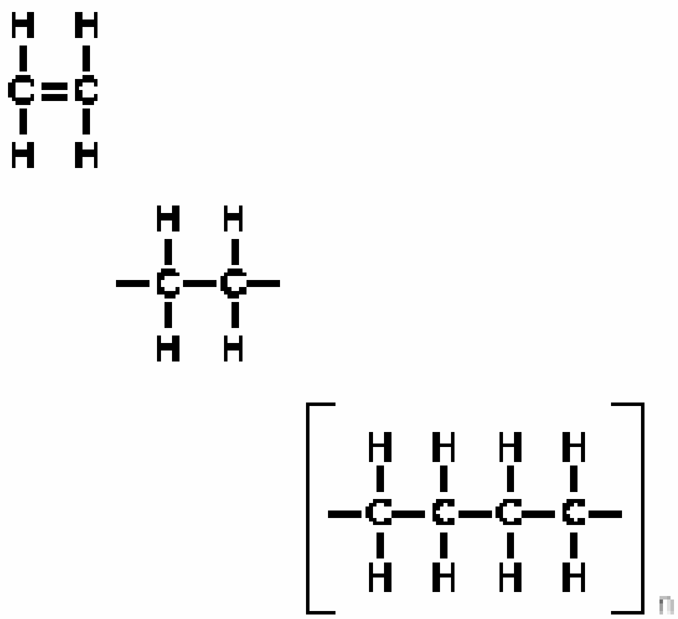
Plastics

- According to ASTM
  - contains, as an essential ingredient, an organic substance of large molecular weight
  - is solid in its finished state
  - at some stage in is manufacture or in its processing into finished articles, can be shaped by flow
- Plastics are composed of long chain-like molecules and are also called polymers.

Polymers

- The word polymer means many (poly) mers.
- Mers are small units, generally simple organic molecules.
- Mers are also called monomers when only one type of molecule is present.
- A rule of thumb is that a polymer must contain at least 100 mers.

Monomer, Mer, and Polymer



Groups of Plastics

- Thermoplastics
  - plastics which are solid at room temperature, but when heated they soften and can be reformed
  - they soften over a range of temperatures
  - these materials can be reused and recycled easily
- Thermosets
  - soften during original processing, but once finished, they can not easily be reprocessed

Homopolymers

- Homopolymer plastics come from only one basic kind of building block or monomer.
  - polyethylene
  - polypropylene
  - polystyrene

Copolymers

- Copolymers contain two chemically different mers.
- Types of copolymers
  - alternating copolymers
    - ABABABABABABAB
  - block copolymers
    - AAAAABBBAAAAABBBAAAA.
  - graft copolymers
    - The backbone is usually one type, and the other becomes short branches off the main chain.

Thermoplastics Categories

- Thermoplastics can be categorized by their end use.
  - commodity
  - intermediate
  - engineering
  - advanced

Commodity Thermoplastics

- Containers for foods, cosmetics, and beverages are usually made of commodity plastics.
- Common commodity thermoplastics
  - polyethylene (PE)
  - polypropylene (PP)
  - polystyrene (PS)
  - polyvinylchloride (PVC)

Recycling Codes

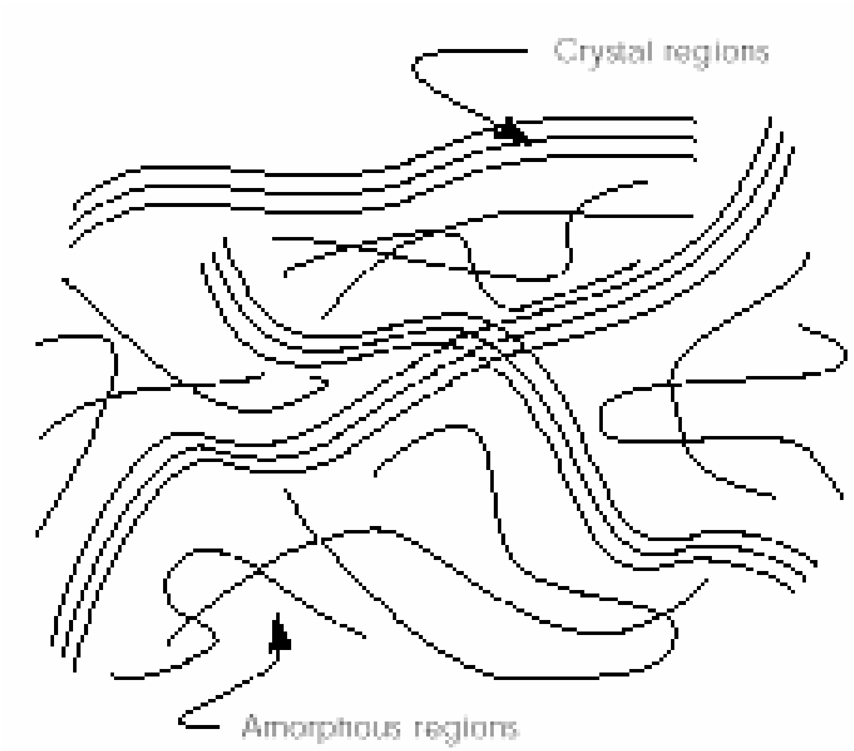
Number	Abbreviation	Name
1	PETE	Polyethylene terephthalate
2	HDPE	High density polyethylene
3	V	Vinyl (polyvinyl chloride)
4	LDPE	Low density polyethylene
5	PP	Polypropylene
6	PS	Polystyrene
7	Other	

Polyethylene

- LDPE (low density polyethylene)
  - generally has low crystallinity and therefore less rigidity
  - used primarily as film
- HDPE (high density polyethylene)
  - has high crystallinity and therefore more rigidity
  - used primarily in injection-and blow-molding
- Attributes
  - good solvent resistance
  - good insulator
  - susceptible to environmentally induced damage
  - low softening point

Crystalline vs. Amorphous

- In crystalline regions, the molecular chains take on highly ordered structure. Generally, the way this occurs is that the chains fold back and forth causing increased density.



Polypropylene

- Polypropylene is about 5% less dense than polyethylene and does not environmentally stress-crack.
- Polypropylene is more susceptible to oxidation and UV degradation than HDPE, but also more amenable to additives to reduce this tendency.
- Polypropylene is slightly tougher and more rigid than HDPE.

Polyvinylchloride

- Plasticized PVC
  - a flexible, almost rubbery, type of polymer used extensively as wire insulation
- Unplasticized PVC
  - a rigid plastic that is used for piping and building materials
- Attributes
  - will not burn
  - excellent solvent stability
  - chlorine content

Polystyrene

- Stiffness and brittleness normally associated with a glass.
- Only commodity polymer translucent at greater than film thicknesses.
- Because of polystyrene's extreme brittleness, a large portion of styrene monomer production is used in copolymers.
- Attributes
  - translucent at greater than film thicknesses
  - significant applications as a foam
  - poor solvent stability
  - brittle

Engineering Thermoplastics

- Thermoplastic engineering resins are characterized as those resins with the following combination of properties.
  - thermal, mechanical, chemical, corrosion resistance, and fabricability
  - ability to sustain high mechanical loads, in harsh environments, for long periods of time
  - predictable, reliable performance
- The most common engineering thermoplastics.
  - nylon
  - acetal
  - polycarbonate

Nylon

- Nylon is a trade name for polyamide plastics.
- Nylons are semicrystalline materials with high strength, stiffness, and heat resistance.
- They are categorized by the number of carbon atoms in the amine and acid groups.
  - nylon -6
  - nylon -6,6
  - nylon -11
  - nylon -12

Nylon Applications

- Nylon-6 is used for sewing thread, fishing line, household/industrial brushes, and level-filament paint brushes.
- Nylon-6,6, stiffer than nylon-6, is used for sewing thread and household/industrial brushes.
- Nylon is also extruded into rods, tubes, and shapes for machining.
- Nylon-11 is used for powder coatings and for flexible tubing.

Acetal Applications

- Acetal is frequently used for gears, cams, valves, switches, springs, and pumps.

Polycarbonate

- Polycarbonate is an amorphous engineering thermoplastic.
- The transparency of polycarbonate, combined with its extrudability and impact resistance, makes it a strong competitor for acrylic sheet in replacing flat glass.
- Widely used in blow molding for water bottles, milk bottles, baby nursing bottles, and miscellaneous packaging.
- Uncoated polycarbonate windows are very strong, but scratch easily.

Thermosets

- Many types of thermosets are manufactured in a two-stage process.
  - the uncross-linked polymer is processed by methods similar to those for thermoplastic polymers
  - next, the polymer is cross-linked by the introduction of chemicals or heat and pressure
- The amount of cross-link density affects polymer properties.

Thermoset Types

- Thermosetting polymers above the glass transition temperature.
  - elastomers
  - classic rubbers
- The glass transition temperature is the temperature at which materials loose their ductility and become brittle.
- Thermosetting polymers below the glass transition temperature.
  - phenolics

Elastomers

- The long polymer chains are in coils that uncoil when load is applied and recoil when the load is removed.
- Cross-linking the chains prevents viscous deformation while retaining the elastic response.
- Large amounts of cross-linking make the material stiffer and more brittle.

Rubber

- Most synthetic rubbers are copolymers of a diene monomer with another monomer such as styrene or acrylonitrile.
- In key areas natural rubber products are superior.
  - SBR tires have poorer resilience and tend to have higher heat build-up.
- For other, less demanding, applications, styrene-butadiene rubbers are usually more likely to be used because of their lower cost.
  - belts, hoses, electrical insulators, and shoe soles

Hard Thermosets

- Phenolic
  - Phenolics are hard and heat-resistant materials, but susceptible to attack from strong acids or bases.
  - Phenolic resins are used in cookware, knobs, and handles, as well as in many other applications.

Hard Thermosets

- Urea-formaldehyde resins.
  - UF materials are generally cheaper and lighter in color and have superior insulating properties relative to the phenolic resin.
  - UF resins are used primarily as bottle caps and electrical fittings.

Hard Thermosets

- Epoxide resins.
  - prized for their toughness and high adhesion properties
- Polyester resins.
  - achieved great commercial success as composite materials such as the matrix that holds load carrying fibers in place

Strengthening and Enhancing Plastics and Polymers

- Chain length
- Cross linking
- Copolymerization
- Fiber reinforcements
- Additives
- Crystallization
- Chain alignment

Chain Length

- Increased molecular weight(chain length) increases strength and creep resistance.
- Long chains tend to intertangle and hold together while short chains pull apart easily and transfer little if any force to adjacent chains.
- As molecular weight increases, so do the melt temperature and viscosity of the polymer.

Cross-Linking

- Atoms or small molecules chemically link adjacent polymer chains to one another.
- Cross-linked polymers have good strength, environmental
- resistance, thermal resistance, and low creep.
- They are, however, often brittle.

Copolymerization

- When polymerized is in a controlled repeating sequence, ABS has properties that exceed those of individual constituent mers.
  - rigid like styrene
  - hard like acrylic
  - tough like butadiene, a rubber

Fiber Reinforcement

- Fiber reinforcement is the predominant method for strengthening and enhancing polymers in a nonchemical manner.
- Glass is the most common fiber for reinforcement, but carbon, Kevlar, and metals are also used.
- Composites have a fiber to resin ratio greater than 50% fiber by weight.

Additives

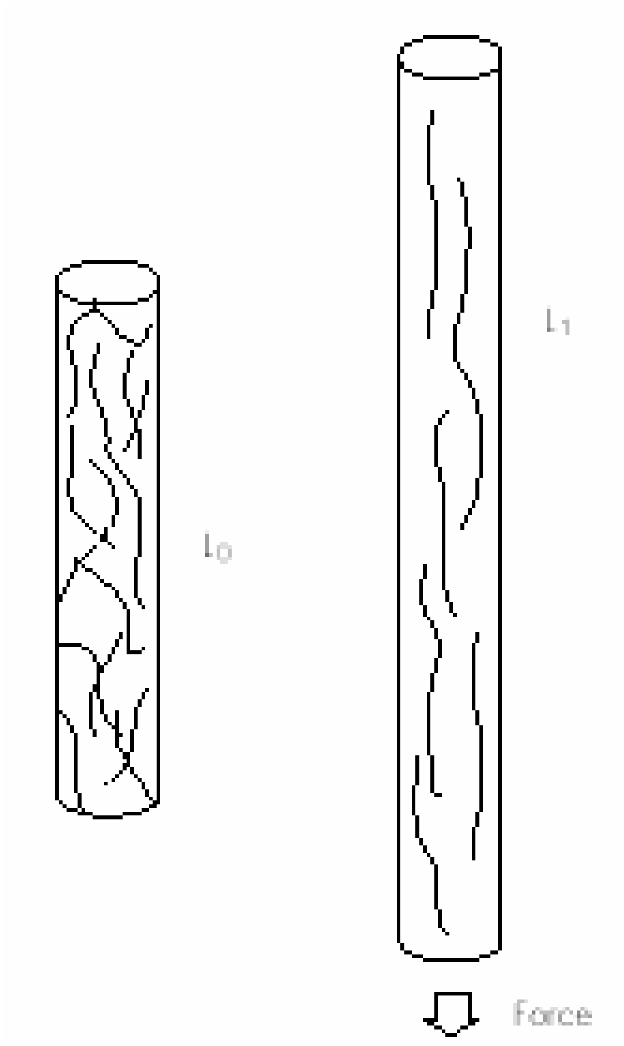
- Additives
  - colorants
  - lubricants
  - plasticizers
  - light inhibitors
  - fungicides
  - pesticides
  - odorants
  - impact modifiers
  - foaming agent
- Fillers
  - wood paste
  - minerals
- Fillers can improve thermal and mechanical properties and alter electrical characteristics.

Crystallization

- Crystals tend to enhance the properties of polymers.
- Amorphous sections loses strength and viscosity at higher temperatures.
- Crystal sections retain strength and rigidity.

Chain Alignment

- Chain alignment orients polymer chains along a common axis from forces encountered during processing.
- Alignment pulls chains into a parallel structure that greatly improves strength in the direction of alignment.



Chain Alignment

- However, one region of high friction in injection molds is the gate where plastic first enters the mold cavity.
- In many cases this alignment at the gate is at right angles to the direction of loading that the part will encounter in final use.
- This misalignment in relation to forces applied often results in failure parallel to the axis of alignment.

Advanced Composites

- Advanced resin matrix composites can include:
  - hybrids
  - mixtures of fibers in various forms in the resin (usually epoxy) matrix
- Strengthening effects are derived from:
  - percentage of fibers
  - type of fiber
  - orientation with respect to loading

The Matrix

- The matrix serves two important functions in a composite.
  - it holds the fibers in place
  - under an applied force, it deforms and distributes the stress to the high-modulus fibrous constituent
- The matrix material for a structural fiber composite must have a greater elongation at break than the fibers for maximum efficiency.
- The matrix must transmit the force to the fibers and change shape as required.

The Matrix

- The matrix influences other properties of the composite, such as:
  - chemical resistance
  - thermal conductivity
  - electrical conductivity
  - corrosion resistance
- The matrix can be a thermoset or thermoplastic.

Types of Fibers

- Carbon/Graphite
- Kevlar Aramid
- Boron
  - exhibit the highest level of stiffness in resin matrices of all commercial fibers used today
- Glass

Composite Classification

- Fiber
  - continuous fibers in yarns or tows (untwisted yarns) are used in filament windings and in unidirectional tape form
  - woven-fiber fabrics, or broadgoods, can be easily laid atop complex mold structures
- Laminar
  - made from layers of materials
- Particulate
  - made from particles in a matrix

Traditional Ceramics

- Earthenware
  - fired at a lower temperature producing a relatively porous and earthy structure
- Stoneware
  - higher firing temperature and less porosity than earthenware
  - unattacked by most acids
- China
  - fired at a higher temperature to obtain a translucent object when a large portion of the quartz crystals are converted to clear glass
- Porcelain
  - fired at higher temperatures making the product very hard and dense

Engineering Ceramics

Class	**Examples**	**Uses**
Single Oxide	Alumina (Al_2O_3) Chromium Oxide (Cr_2O_3) Zirconia (ZrO_2) Siica (SiO_2)	Electrical insulator Wear coating Thermal insulation Abrasive, glass
Mixed Oxides	Kaolinite (Al_2O_3 + $2SiO_2$ +$2H_20$)	Clay products
Carbides	Vanadium carbide Tungsten Carbide Silicon Carbide	Wear resistance Cutting tools Abrasives
Sulfides	Molybdenum disulfide (MoS_2)	Lubricant
Nitrides	Boron Nitride (BN)	Wear parts
Metalloid elements	Germanium (Ge) Silicon (Si)	Electronic devices Electronic devices
Intermetallics	Nickel Aluminide (NiAl)	Wear coatings

Ceramic Mechanical Properties

- Brittle.
- Low impact strength.
- Tensile strength less than metals but higher than plastics.
- No yield strength.
- No plastic deformation before reaching their tensile strength.
- No elongation or reduction in area.
- High hardness and compressive strength.
- Stiffest engineering material(high modulus of elasticity).
- Poor fatigue strength (tension).

Ceramic Physical & Chemical Properties

- Physical Properties
  - denser than plastics and comparable to metals
  - higher melting point than metals or plastics
  - most have low electrical and thermal conductivity
  - lower thermal expansion than metals or plastics
- Chemical Properties
  - corrosion resistance of ceramics is usually high, however not all ceramics are resistant to all chemicals

Part 2
Product Design

GD&T Terms and Definitions

- Actual Size
  - measured size of a feature
- Basic Dimension
  - theoretical value used to describe the exact size or location of a feature
  - used as the basis from which permissible variations are established
- Bonus Tolerance
  - additional amount of tolerance for a geometric tolerance
  - permissible whenever an MMC or LMC modifier is specified

GD&T Terms and Definitions

- Datum
  - origin from which the location or geometric characteristics of features of a part are established
- Datum Feature
  - actual feature of a part that is used to establish a datum
- Datum Target
  - point, line, or small area specified on the drawing to establish corresponding contact places with the tooling
- Feature
  - general term applied to a physical portion of a part, such as a surface, hole, pin, slot, or tab

GD&T Terms and Definitions

- Feature of Size (FOS)
  - cylindrical or spherical surface, or a set of two plane parallel surfaces, each of which is associated with a dimension
- Least Material Condition
  - condition of a part feature wherein it contains the least (minimum) amount of material
  - smallest shaft or largest diameter hole

GD&T Terms and Definitions

- Maximum Material Condition
  - condition where a feature of size contains the maximum amount of material within the stated limits of size
  - largest shaft diameter or smallest hole
- Regardless of Feature Size (RFS)
  - condition where a specified geometric tolerance must be met irrespective of where the feature lies within its size tolerance

Rule 1 and 2

- Rule 1 (Perfect form at MMC)
  - Where only a tolerance of size is specified, the limits of size of an individual feature prescribe the extent to which variations in its form as well as its size, are allowed.
- Rule 2
  - Regardless of feature size (RFS) applies, with respect to the individual tolerance, datum reference(s), or both, where no modifying symbol is specified.

Design for Manufacture (DFM)

- DFM is a methodology that simultaneously considers all of the design goals and constraints for products that will be manufactured.

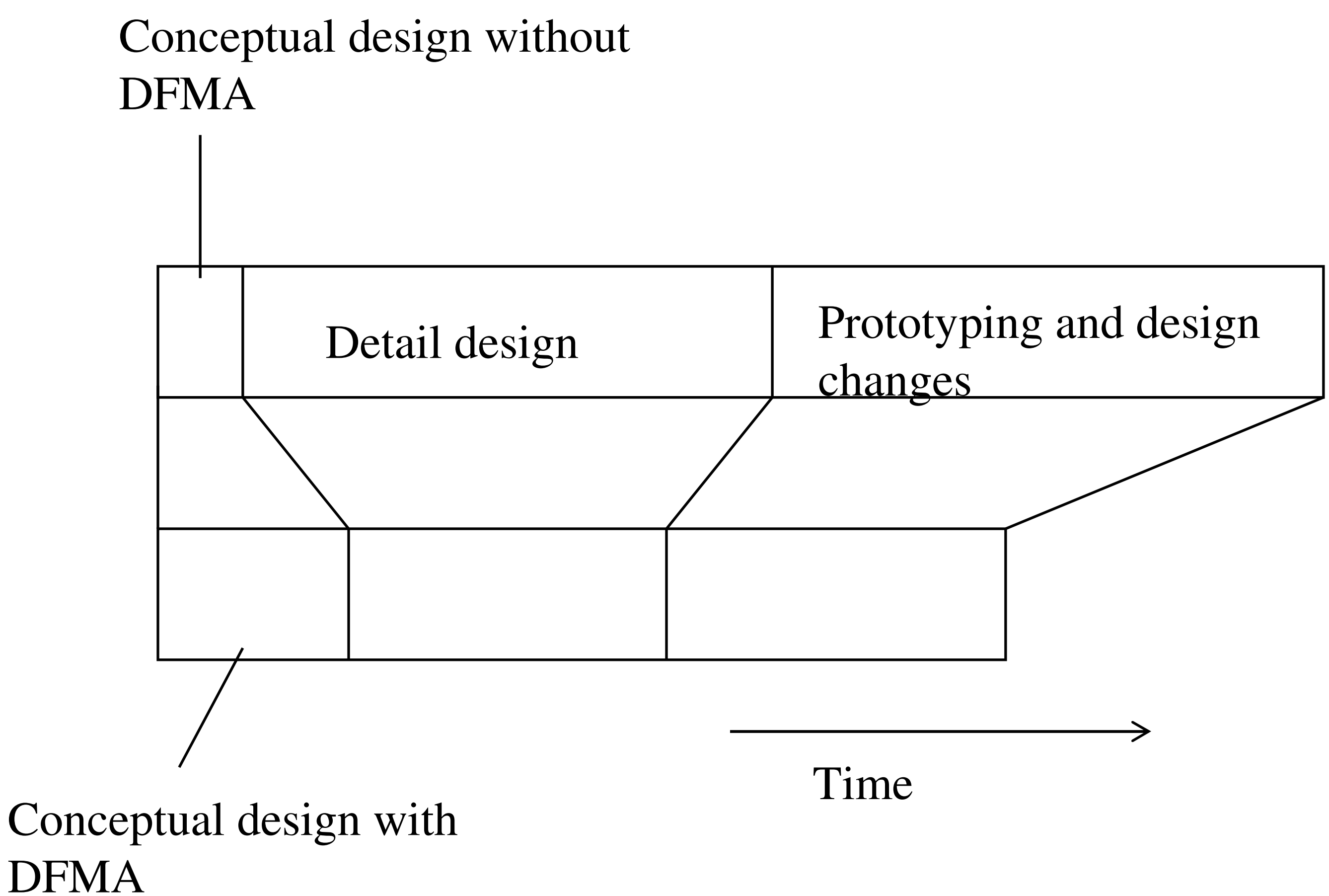
DFM

- Design for manufacture is the practice of designing products with manufacturing in mind so they can:
  - be designed in the least time with the least development cost
  - make the quickest and smoothest transition into production
  - be assembled and tested with the minimum cost in the minimum amount of time
  - have the desired level of quality and reliability
  - satisfy customers needs and compete well in the marketplace

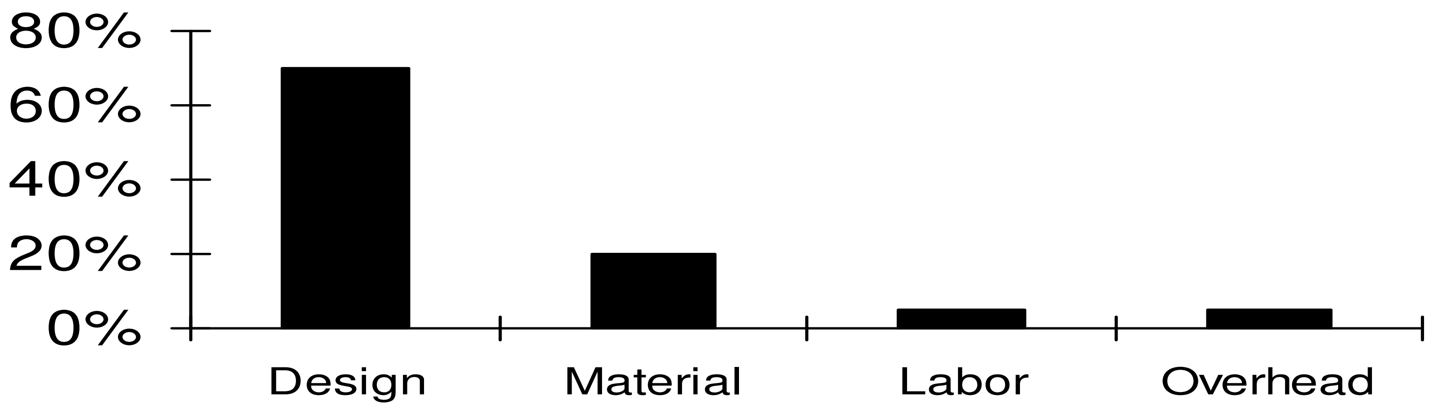
Design for Assembly

- Design for assembly minimizes the total product cost by targeting assembly time, part cost, and the assembly process at the design stage of the product development process.
- Problems without DFMA
  - Longer time to market
  - More equipment
  - Poor quality
  - Higher costs

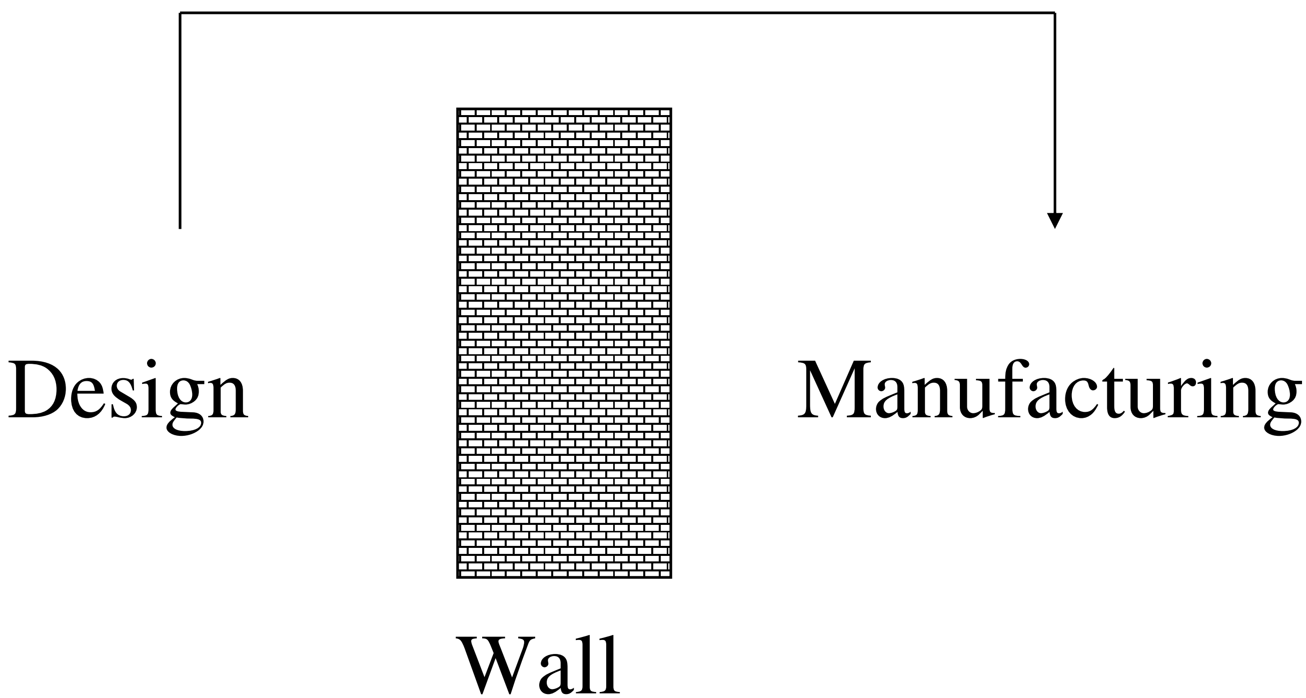
Production Times with DFMA



Designers' Influence on Final Part Cost



Tradition



Design for Assembly

- Minimum Part Assessment
  - During operation of the product, does the part move relative to all other parts already assembled?
  - Must the part be of a different material than or be isolated from all other parts already assembled?
  - Must the part be separate from all other parts already assembled because otherwise necessary assembly or disassembly of other separate parts would be impossible?

Design Efficiency

$$\text{Assembly Efficiency} = \frac{N_{\min}\left(t_{avg}\right)}{t_{act}}$$

where,

N_{min} = theoretical minimum number of parts

t_{avg} = average time to assemble one part

t_{act} = actual time to assemble all parts

DFMA Metrics

1. Commonality
2. Number of engineering change orders
3. Actual design cost
4. Actual product cost
5. Actual time-to-market
6. Input from the field
7. Subjective judgements
8. Design rule/guideline compliance

Failure Modes and Effects Analysis FMEA

- A FMEA is a living document which forecasts:
  - potential trouble areas
  - impact on the problem
  - solutions that will greatly reduce the negative effect in the design or process of the subject part
- DFMEA
  - Design FMEA
- PFMEA
  - Production FMEA

FMEA Reduces the risk of failures by:

- Aiding in the objective evaluation of design requirements and design alternatives.
- Aiding in the initial design for manufacturing and assembly.
- Increasing the probability that potential failure modes and their effects have been considered in the design process.
- Providing additional information to aid in the planning of design test and development programs.
- Developing a list of potential failure modes ranked by their effect on the customer establishing a priority system for design improvements.

Customer Defined

- The definition of customer for a FMEA should normally be the end user. However, customers can also be design engineers of higher level assemblies, and/or manufacturing engineers in activities such as manufacturing, assembly and service.

FMEA Chart

Part/Process Name Part Number	Part/Process Function	Potential Failure Mode	Potential Effect(s) of Failure		Potential Cause(s) of Failure	Current Controls	Occurrence	Severity	Detection	RPN	Recommended Action(s) Status	Actions Taken	Occurrence	Severity	Detection	RPN	Responsible Activity
10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**				

FMEA Procedure

10. Part/Process, Name, Part Number
    – part/assembly/system being analyzed
11. Part/Process Function
    – tasks that a component is intended to perform or may perform even if not intended
12. Potential Failure Mode
    – manner in which a component could potentially fail to meet the design intent
    – cracked, deformed, loosened, leaking, sticking, short circuited, oxidized, and fractured

FMEA Procedure

13. Potential Effects of Failure
    - effects of the failure mode on the function, as perceived by the customer
    - noise, erratic operation, poor appearance, unstable, intermittent operation, rough, inoperative, unpleasant odor, operation impaired
14. Critical Characteristics
    - Critical characteristics affecting regulatory compliance or safe product function are those product or process requirements which require special supplier, manufacturing, assembly, shipping, monitoring and/or inspection stations.

FMEA Procedure

15. Potential Cause/Mechanism of Failure
    - indication of a design or processing weakness, the consequence of which is the failure mode
    - incorrect material specified
    - poor mold form
    - insufficient lubrication
16. Current Controls
    - controls or design features which exist to either prevent the cause of failure from occurring or which are intended to detect the cause of failure

17. Occurrence

- Likelihood that a specific cause/mechanism exists and will result in a failure mode.

	Ranking	**Possible Failure Rate**
Remote	1	1 in 10,000,000
Low	2	1 in 20,000
	3	1 in 4000
Moderate	4	1 in 1000
	5	1 in 400
	6	1 in 80
High	7	1 in 40
	8	1 in 20
Very High	9	1 in 8
	10	1 in 2

18. Severity

- Assessment of the seriousness of the effect of the potential failure mode to next component, subsystem, customer etc.
- Minor 1
  - customer will probably not notice the failure
- Low 2-3
  - customer will notice a slight deterioration of the product
- Moderate 4-6
  - customer is uncomfortable or annoyed by the failure
- High 7-8
  - high degree of dissatisfaction.
  - does not compromise safety or government regulations
- Very High 9-10
  - failure effects safe operation and/or noncompliance with government regulations

19. Detection

- Assessment of the ability of the proposed type current controls to detect a potential cause(design weakness) or the subsequent failure mode before the component or assembly is released for production.
- Very High 1
  - almost certain detection of a potential design weakness
- High 2-3
  - good chance of detecting a potential design weakness
- Moderate 4-5
  - may detect a potential weakness
- Low 6-7
  - not likely to detect a potential weakness
- Very Low 8-9
  - probably will not detect a potential weakness
- Non-Detection 10
  - will/can not detect a potential design weakness

FMEA Procedure

20. Risk Priority Number (RPN)
    - RPN = Severity x Occurrence x Detection
    - RPN values should be used to rank order the concerns.
21. Recommended Actions
    - corrective action should be directed at the highest ranked items
    - reduce any one or all of the occurrence, severity, and detection rankings
    - revised test plan
    - revised design
    - revised material specification

FMEA Procedure

22. Actions Taken
    – brief description of the actual action and the completion date
23. Occurrence, Severity, Detection, and RPN
    – after the corrective action has taken place reassess the occurrence, severity, detection and RPN rankings

Value Analysis/Engineering

- An arrangement of techniques which:
  - identifies and makes clear the functions the user requires from a product, service, or organization
  - establishes a dollar value for each function

Why Unnecessary Costs Exist

1. Lack of concern about cost
2. Tradition
3. Short term pressures
4. Lack of knowledge about DFM
5. Wrong beliefs about cost
6. Lack of ideas

Comparison to Known Values Technique

- Compare your product to the competition
  - Cost/unit
  - Cost/sub-unit
  - Cost element as a % of total
    - cost of materials, processes, labor, etc.
  - Process Cost

Functional Analysis Technique

- Identify Function
  - find the most economical way to provide that function without sacrificing quality
- Evaluate Function
  - look for other ways for each function to be accomplished with less total cost

Group Technology

- Group technology is an approach to design and manufacturing that seeks to reduce manufacturing system information by identifying and exploiting the sameness or similarity of parts based on their geometrical shape and/or manufacturing process.

Advantages of Group Technology

- Eliminate tooling duplication and redundancy.
- Shorten design time and reduce effort by starting with a similarly designed part.
- Reduce part proliferation.
- Eliminate redundant part designs.

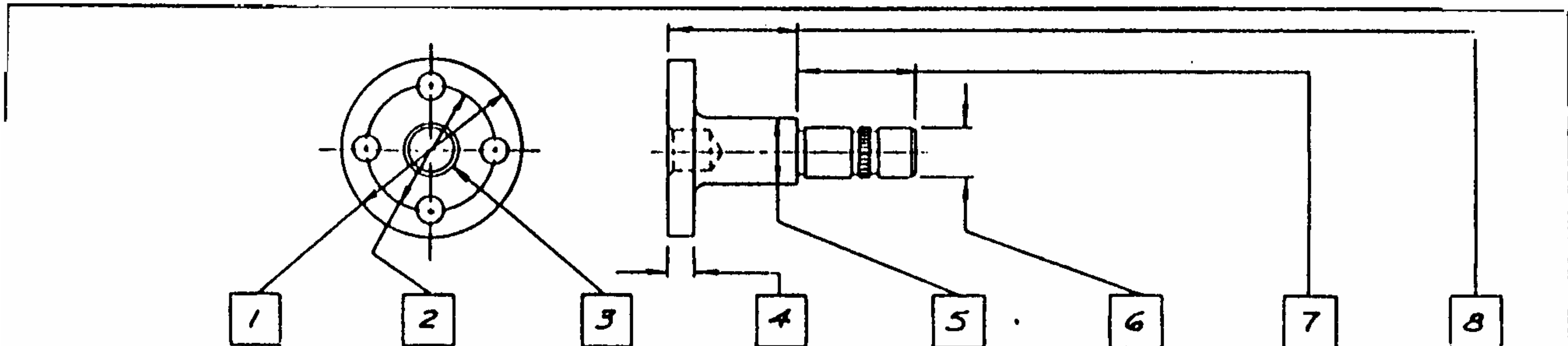
Grouping Strategies

- Visual Inspection
  - Visually inspecting each part or print to compare with other parts is difficult when a large number of parts is involved.
- Production Flow Analysis(PFA)
  - grouping products based on the operation sequence and routing through the plant
- Part Classification and Coding
  - parts are examined to identify features such as material and geometries using an agreed upon classification and coding system

Coding Systems

- Polycode (attribute)
  - identify individual part characteristics
  - each digit is independent of the other digits
- Monocode (hierarchical)
  - accepts and codes a wide variety of parts
  - each digit is related to the previous digit

Attribute Coding (polycode)



	OUTSIDE DIA.	BOLT CIRCLE	PILOT HOLE	FLANGE THICKNESS	FORGING DIA.	STEM DIA.	STEM LENGTH	SHOULDER LENGTH
1	2.50	1.75	.50	.20	.75	.50	.800	$\frac{1}{2}$ – 1
2	3.00	2.25	.625	.25	.875	.625	1.125	1 – 1 $\frac{1}{4}$
3	3.50	2.75	.750	.312	1.000	.750		1 $\frac{1}{4}$ – 1 $\frac{1}{2}$
4	4.00	3.25	DUAL	.437				1 $\frac{1}{2}$ – 1 $\frac{3}{4}$
5	OTHER	NONE	THREADED	.500				1 $\frac{3}{4}$ – 2
6			OTHER					2 – 2 $\frac{1}{4}$
7								2 $\frac{1}{4}$ – 2 $\frac{1}{2}$
8								2 $\frac{1}{2}$ & OVER

GROUP NUMBER □·□·□·□·□·□·□·□ + SEQUENTIAL PART NO. (I.E. 001, 002, 003.... 999)

NUMBER POSITION

Hierarchy Based Code (monocode)

GROUP NO. = ☐ ☐ ☐ ☐ + SEQUENTIAL PART NO. (I.E. 001, 002, 003 999)

PLACE WHERE NUMBER RESIDES

1		2		3		4	
NO.		NO.	DESCRIPTION	NO.	DESCRIPTION	NO.	DESCRIPTION
1	ROUND (e.g. BAR STOCK)	1	DIA. < 5"	1	LENGTH < 5"	1	MATERIAL HRS
						2	" CRS
				2	LENGTH > 5"	1	" HRS
						2	" CRS
		2	DIA. > 5"	1	LENGTH < 10"	1	" HRS
						2	" CRS
				2	LENGTH > 10"	1	" HRS
						2	" CRS
2	RECTANGULAR (e.g. BLOCK)	1	THICK < 2" WIDE < 4"	1	LENGTH < 6"	1	HRS
						2	" CRS
				2	LENGTH > 6"	1	" HRS
						2	" CRS
		2	THICK > 2" WIDE > 4"	1	LENGTH < 12"	1	HRS
						2	CRS
				2	LENGTH > 12"	1	" HRS
						2	" CRS
3	SHEET (e.g. SHEET METAL)	1	GAGE < 12	1	LENGTH < 60"	1	" HRS
						2	CRS
				2	LENGTH > 60"	1	HRS
						2	" CRS
		2	GAGE > 12	1	LENGTH < 80"	1	HRS
						2	" CRS
				2	LENGTH > 80"	1	" HRS
						2	" CRS
4	OTHER (e.g. IRREGULAR SHAPED CASTING)	1	LBS < 10	1	REQUIRES MILLING	1	" STEEL
						2	" CAST IRON
				2	REQUIRES DRILLING	1	" STEEL
						2	" CAST IRON
		2	LBS > 10	1	REQUIRES MILLING	1	" STEEL
						2	" CAST IRON
				2	REQUIRES DRILLING	1	" STEEL
						2	" CAST IRON

Quality Function Deployment (QFD)

- QFD is a planning tool for translating customer needs and expectations into appropriate company requirements.
- The intent of QFD is to incorporate the “voice of the customer” into all the phases of the product development cycle, through production and into the marketplace.

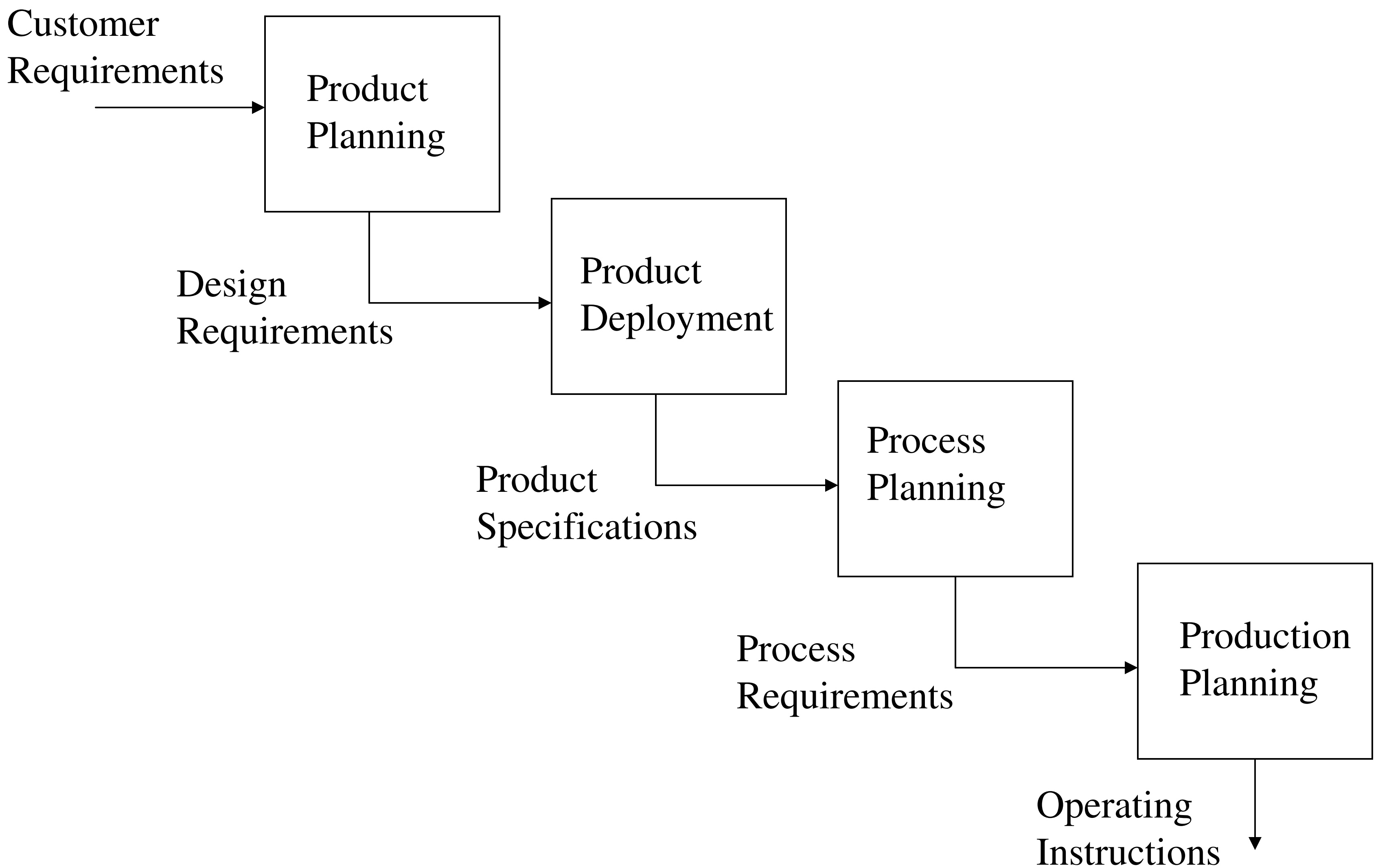
Basic Business Transaction

- When a company’s product matches the customers’ needs and expectations then there is no problem marketing the product.
- When a company’s product doesn’t match the customers’ needs and expectations then there additional marketing need to be implemented.
  - adjust price (offer rebates)
  - increase sales commissions
  - carry larger inventory
  - advertise the product
  - develop a public relations campaign

Benefits of QFD

- Happy, satisfied customers
- Shorter product development cycle
- Avoidance of a problem/redesign “spike” during production start-up
- Technical know-how and its relationship to customer demand is preserved and transferred to new employees or successors.

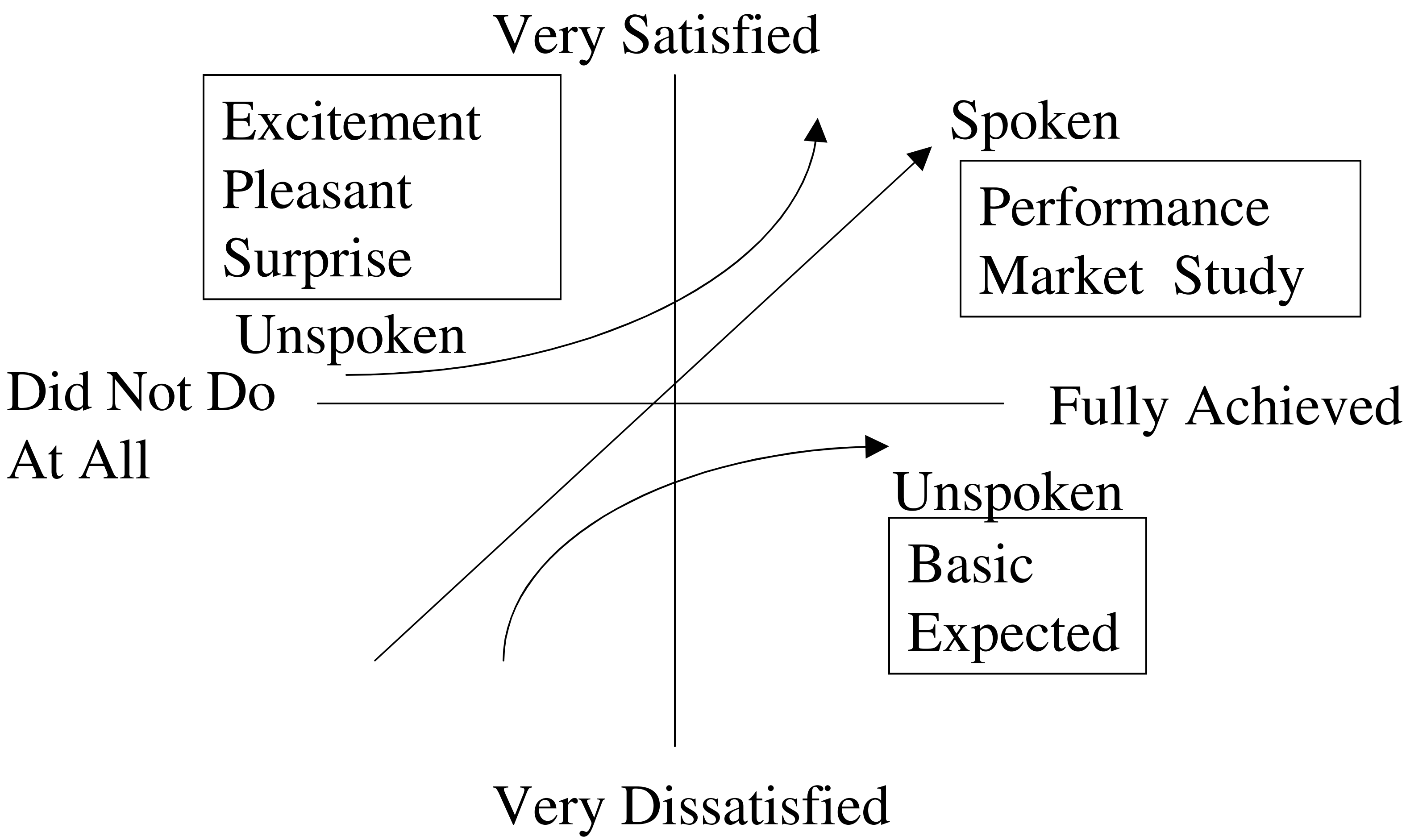
Four Phases of QFD



The WHATS

- By listening to the voice of the customer, a list of customer needs and expectations can be created.
- The list of WHATS should include all the items that customers want or expect from the product under construction.

Three Types of Quality Features

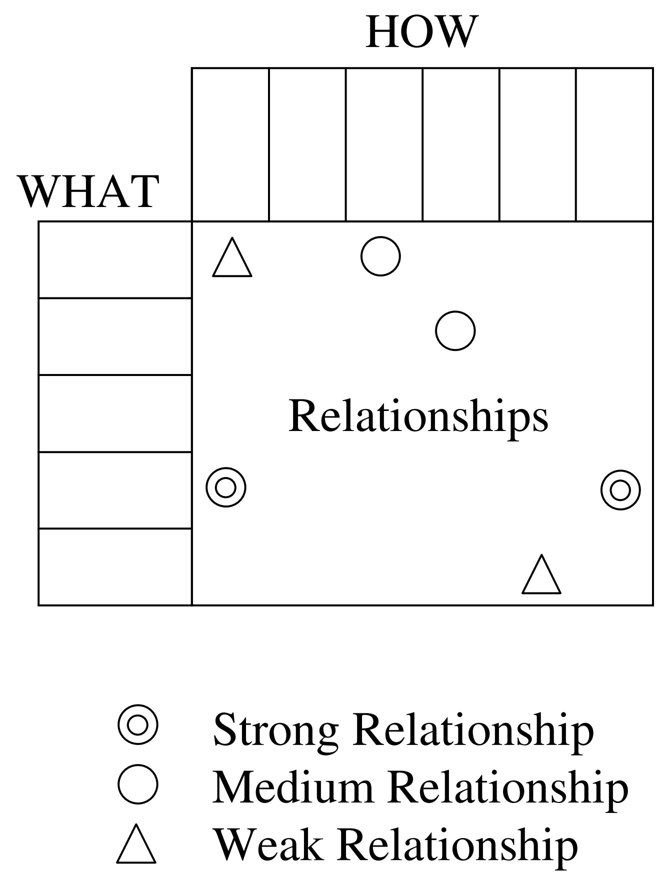


The HOWS

- The HOWS are a set of quality characteristics by which the WHATS can be realized.
- For example, a good ride can be achieved through dampening and stability requirements.

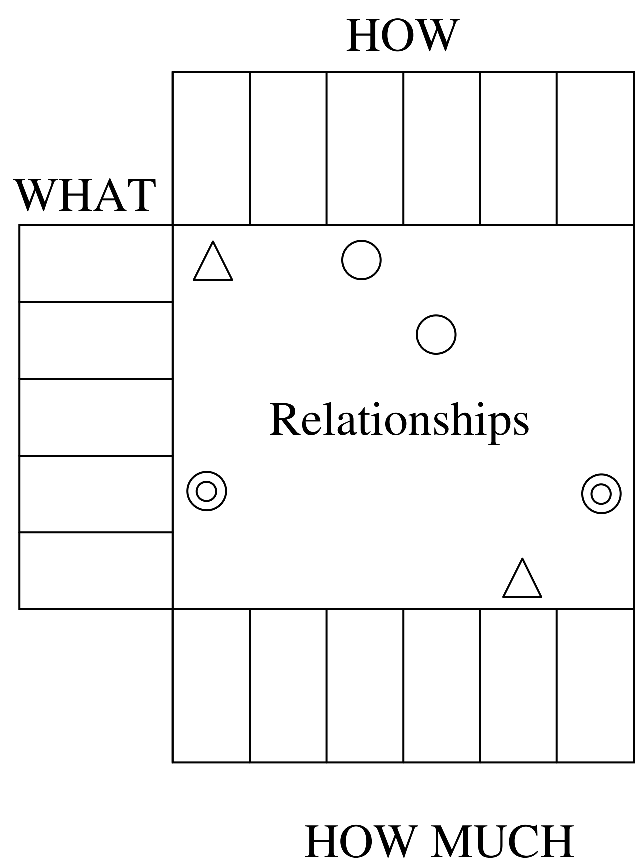
Relationship Matrix

- Since some of the HOWS can affect more than one what a relationship matrix is used to compare the interactions of the WHATS and HOWS.



How Much

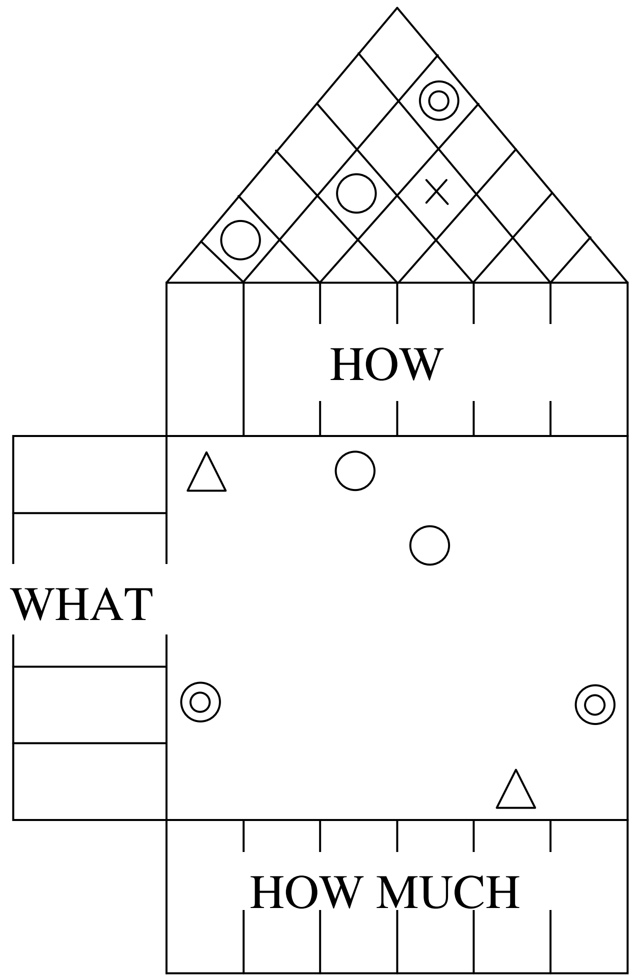
- For every how shown on the relationship matrix, a HOW MUCH should be determined. The goal is to quantify the customers' needs and expectations.



Correlation Matrix

- The roof of the house of quality identifies qualitative correlation's between the various HOWs.
- The correlation's help make trade-off decisions.
- A decrease in the 0-60 mph time has a negative effect on fuel economy.

◎ Strong Positive
○ Positive
× Negative
⨳ Strong Negative



Error Proofing/Mistake Proofing (poka-yoke)

- Error proofing and mistake proofing may have different meanings depending where you work.
- Error proofing
  - changes in the part and/or process to prevent errors from being made
  - creating part geometries to prevent incorrect assembly
- Mistake proofing
  - checking and warning system to indicate a mistake was made before it is shipped
  - vision system detects missing or reversed part

Rapid Prototyping

- Stereolithography (SLA)
  - a UV laser traces a thin cross section of the object onto a liquid resin surface, selectively hardening the polymer.
- Solid ground curing (SGC)
  - the prototype is built-up from a photocurable resin by exposing the resin to UV light through a mask
- Laminated object manufacturing (LOM)
  - produces 3-D parts directly form CAD data by successive deposition, bonding, and laser cutting of sheet or film materials

Rapid Prototyping

- Fused deposition modeling (FDM)
  - involves building successive layers of material through laminations using a filament of thermoplastic material or wax that is unwound from a spool and fed into a heated nozzle.
  - The accuracy of the prototype permits them to be investment cast
- Selective laser sintering (SLS)
  - similar to SLA except the part is not created in a liquid vat but from a heat-fusible wax or metal powder.
- Ballistic particle manufacturing (BPM)
  - droplets of wax are deposited by an ink-jet mechanism to build the required layers.

Part 3
Manufacturing Processes

Casting

- Casting is a process in which metal is poured or injected into a cavity and allowed to solidify to the shape of the cavity.
- The cavity is contained in a mold or die.
- Molds are generally made from:
  - green sand (sand, clay and water)
  - plaster
  - sand with resin binder
  - tool steel (die casting)
  - rubber

Casting Attributes

- Castings offer cost and performance advantages because their shape, molten metal is poured or injected and allowed to composition, structure, and properties can be tailored for a specific end product.
- Casting can produce parts with a complicated geometry.
- Casting can produce parts from metals that are hard to machine or form.
- Casting can produce parts with internal cavities.

Casting Disadvantages

- Castings have lower strength than machined or formed parts.
- Castings generally exhibit nondirectional properties.
- Wrought metals, on the other hand, usually are anisotropic—stronger and tougher in one direction than in another.
- Castings typically have a poor surface finish and poor dimensional accuracy (except for precision casting methods).

Casting Processes

- Multiple Use Pattern and Single Use Mold
  – sand casting
  – shell molding
- Single Use Pattern and Single Use Mold
  – lost foam (evaporative)
  – investment
- Multiple Use Pattern
  – die casting
  – squeeze casting

Green Sand Casting Characteristics

- Inexpensive molding material (sand, clay, and water).
- Green sand is recyclable.
- Patterns are reusable and relatively inexpensive to modify.
- Can be used with high melting temperature metals such as cast iron.
- Relatively poor surface finish due to sand.
- Relatively poor dimensional accuracy.
- One-time use molds and cores.
- Sand testing is required.
  – moisture content, permeability, strength, and active clay

Shell Molding

- A resin-coated sand is laid on a heated pattern so that the sand against the pattern bonds together to form a hardened shell. Two mating shells make a mold.
- Shell molds are harder, smoother and stronger than green sand molds.
- Shell molded parts generally have a better surface finish and dimensional accuracy than green sand casting.
- Shell molds are hard to recycle and expensive to throw away. The thermoset binder must be removed from the sand grains typically by heating which can cause emission problems.

Lost Foam Casting (Evaporative Casting)

- An expendable mold and pattern process where an expanded polystyrene pattern remains in the mold and is evaporated by the molten metal.
- The process eliminates the need for draft allowances, cores, coreboxes, parting lines, and many conventional foundry operations.
- Foam patterns are often coated with a ceramic coating or a alcohol/graphite wash increase rigidity and improve casting finish.
- The major drawback is the expense of part revisions. The molds used to produce the foam pattern are thin walled and therefore difficult to modify. Any revision results in new tooling.

Investment Casting (Precision Casting)

- An expendable mold and pattern process where an expendable pattern (usually wax) is coated with a refractory slurry that forms a hard shell.
- The wax is melted out and metal poured in.
- Very expensive due to the time consuming process.
- Produces high quality, intricate parts.
- The process eliminates the need for draft allowances, cores, coreboxes, parting lines, and many conventional foundry operations.
- Typically used to cast high temperature alloys for jet engines and corrosion resistant alloys such as stainless steel for valves.

Die Casting

- Die casting is variation of permanent mold casting where molten metal is injected into steel dies under pressure.
- Die casting produces a good surface finish and good dimensional accuracy.
- Die casting provides high volume output but with expensive tooling.
- Die castings highly susceptible to porosity.

Die Casting

- Porosity is caused by turbulence as the molten metal travels through the gating system at high velocity and by trapped air.
- Die casting is limited to low melting temperature alloys.
- Dies and cores are multiple use.
- Two types of die casting machines
  - hot chamber - magnesium and zinc
  - cold chamber - aluminum

Casting Design Issues

- Use fillets and rounds - no sharp changes in cross section.
- Use largest fillets as practical to increase fatigue life.
- Avoid or reduce the size of hot spots.
  - larger cross sections that solidify last and form shrinkage voids
- Use a riser to prevent shrinkage voids.
- Use a straight parting line when possible.

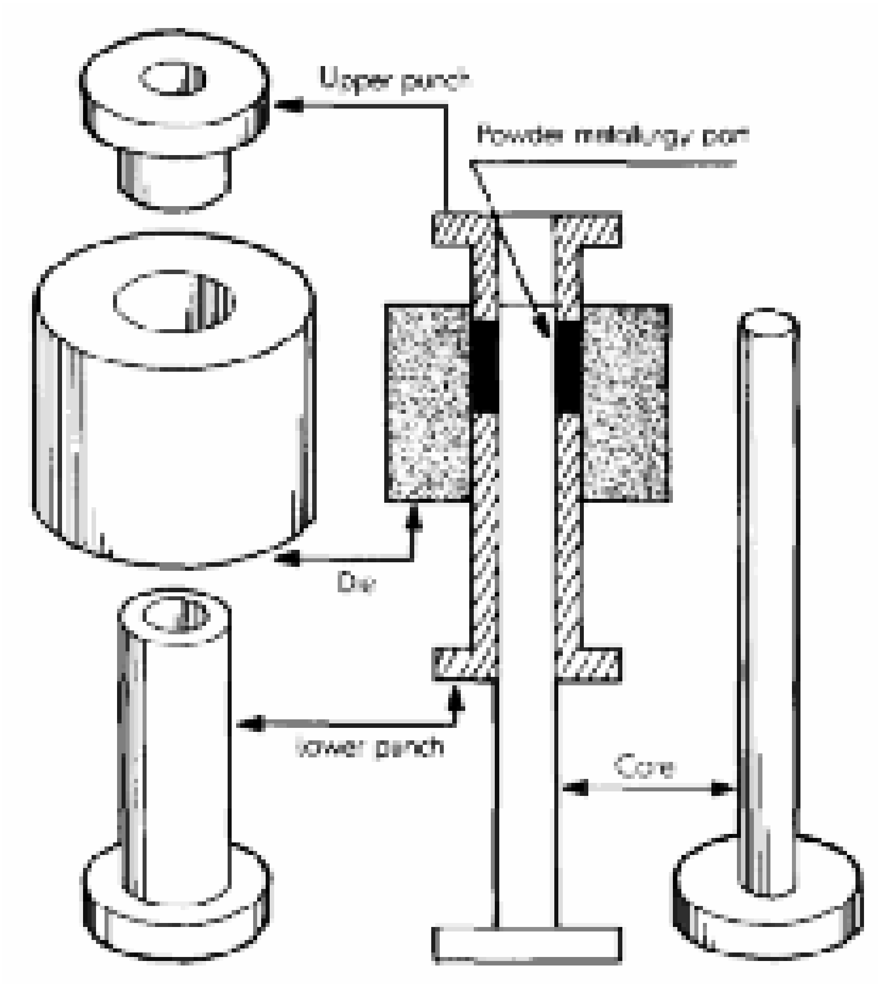
Casting Defects

Defect	Cause
Misrun	- metal solidifies before filling cavity
	- low pouring temperature
	- mold cross section too thin
	- slow pouring speed
Cold shut	- when two portions of metal flow together but not fuse
	- causes are similar to a misrun
Porosity	- network of small voids in the casting due to local solidification of the final molten metal in the dendritic structure
Shrinkage void	- void formed where the molten metal solidifies last

Casting Defects

Hot tear	- cracks in the casting when the mold prevents the solidifying casting from shrinking
Penetration	- when the fluidity of the metal is too high it penetrates the sand mold or core incorporation sand grains in the casting surface
Core shift	- due to the buoyancy of the molten metal the core may more creating thick and thin casting wall sections
Sand wash	- an irregularity in the casting surface due to erosion of the molding sand
Inclusion	- foreign material that becomes imbedded in the casting

PM Tooling



Powdered Metals (PM)

- Advantages of PM
  - can shape materials that are hard to machine (carbide inserts)
  - very little machining and scrap
  - can produce parts with less than 100% density
  - complex shapes (gears)
- Disadvantages of PM
  - parts are less than 100% dense
  - no negative draft
  - parts are less than 2 inches thick

Conventional (Mass Production) Powdered Metals Sequence

1. Powder Manufacture
   - melt atomization
   - grinding
2. Powder Blending
   - add binders and lubricants
   - separate oversize and fine particles
   - mix in alloy powders
3. Cold Compaction
   - form green compact
4. Sintering (inert atmosphere)
   - slow burn off of binders and lubricants
   - high temperature sintering
   - cool down
5. Secondary Processes
   - improve quality

Sintering

- Sintering is a three-step heat treating process to increase the strength of the green compact.
  - slow burn off
    - burns off binders and lubricants at a slow rate to prevent the compact from cracking during the high temperature step
  - high Temperature
    - 80% of the melting temperature
    - fuses all the metal particles together
  - cool down
- All three steps are done in an inert atmosphere (Argon) to prevent oxidation.

Secondary Processes

- Forging
- Coining
- Machining
- Steam treating
  - creates a blue/black corrosion resistant layer on ferrous PM parts
- Infiltration
  - low melting temperature metal is forced into the pores (or by capillary action) of a p/m part to improve its mechanical properties
- Impregnation
  - oil or other liquid is forced into the pores of a p/m part to make a self-lubricating bushing

Hot Isostatic Compressing (HIP)

- HIP combines compaction and sintering in one step.
- HIP is a low volume production process
  - Isostatic compressing refers to compressing a part from all sides not just the top and bottom.
- HIP parts are compacted and sintered in an autoclave.
- HIP produces higher quality parts than conventional PM.
- HIP is used to high temperature and/or corrosion resistant alloys.

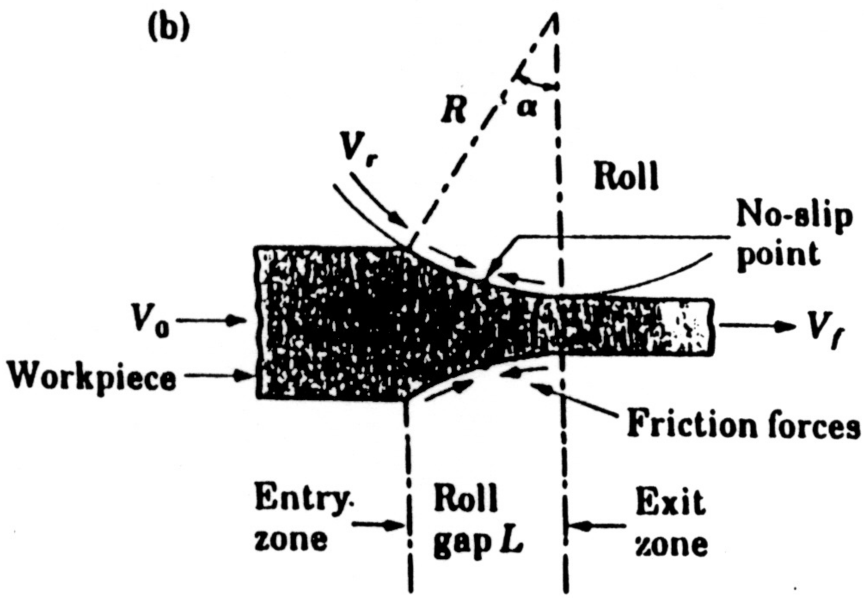
Forming Fundamentals

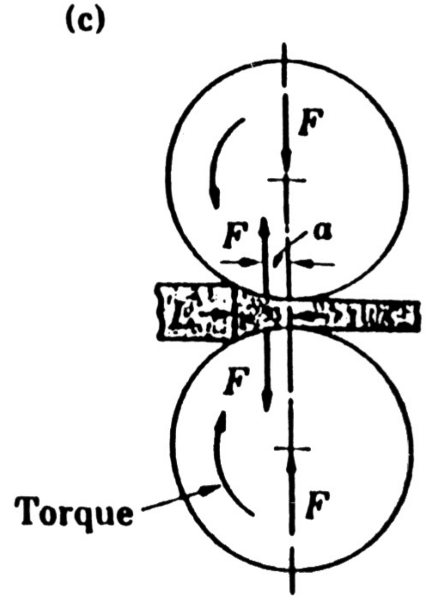
- Cold Forming
  - performed below the recrystallization temperature
  - part strain hardens
  - good surface finish
  - good dimensional accuracy
- Hot Forming
  - performed above the recrystallization temperature
  - part does not strain harden
  - poor surface finish
  - poor dimensional accuracy

Forming Fundamentals

- Warm Forming
  - sometimes above or below the recrystallization temperature
  - properties are between cold and hot forming

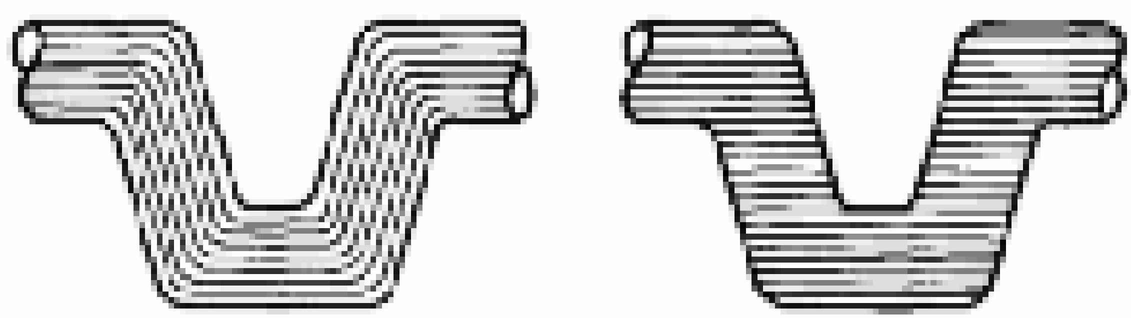
Rolling Fundamentals





Forging Fundamentals

- Forgings are stronger than castings.
  - due to the alignment of the grain pattern with the contour of the part: (a) forging, (b) casting

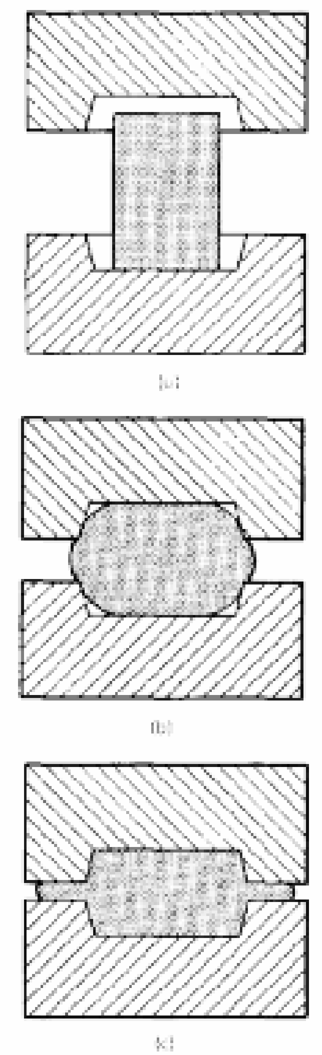


(a) (b)

  - due to the lack of porosity and other defects associated with casting

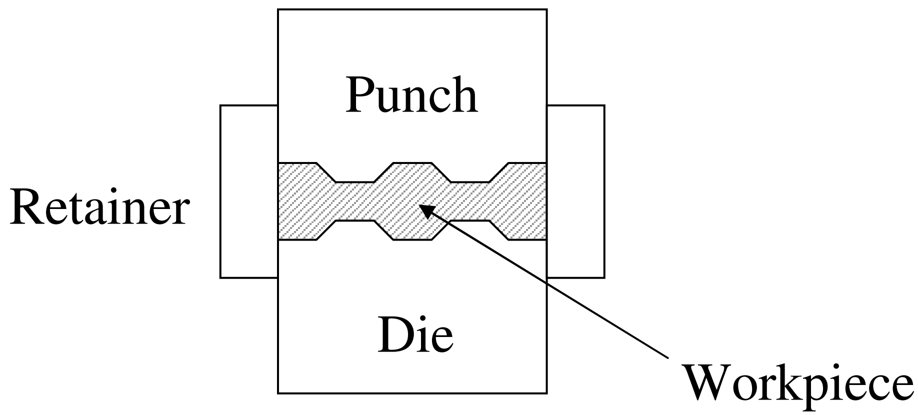
Closed Die Forging

- Dies contain the shape of the part to be produced.
- Excess metal(flash) squeezes out between the dies.



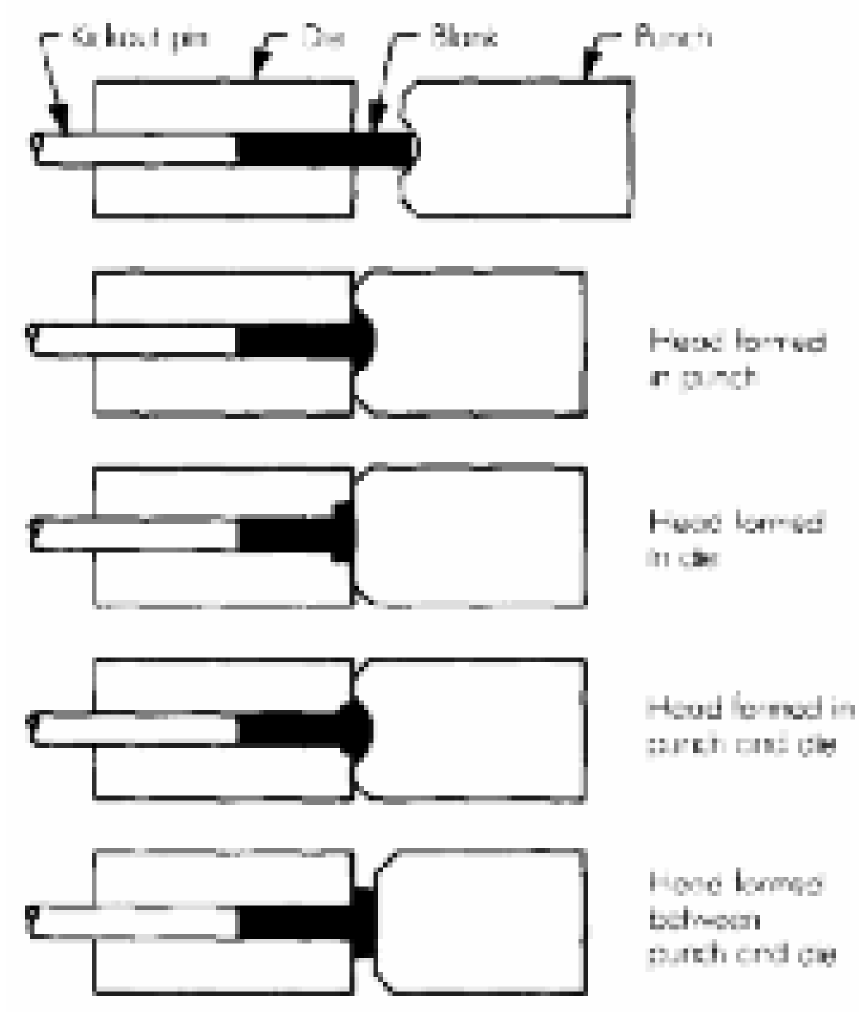
Coining

- Coining is a type of precision or flashless forging.
- There is literally no flash produced.
- Used for fine detail and finished dimensions.



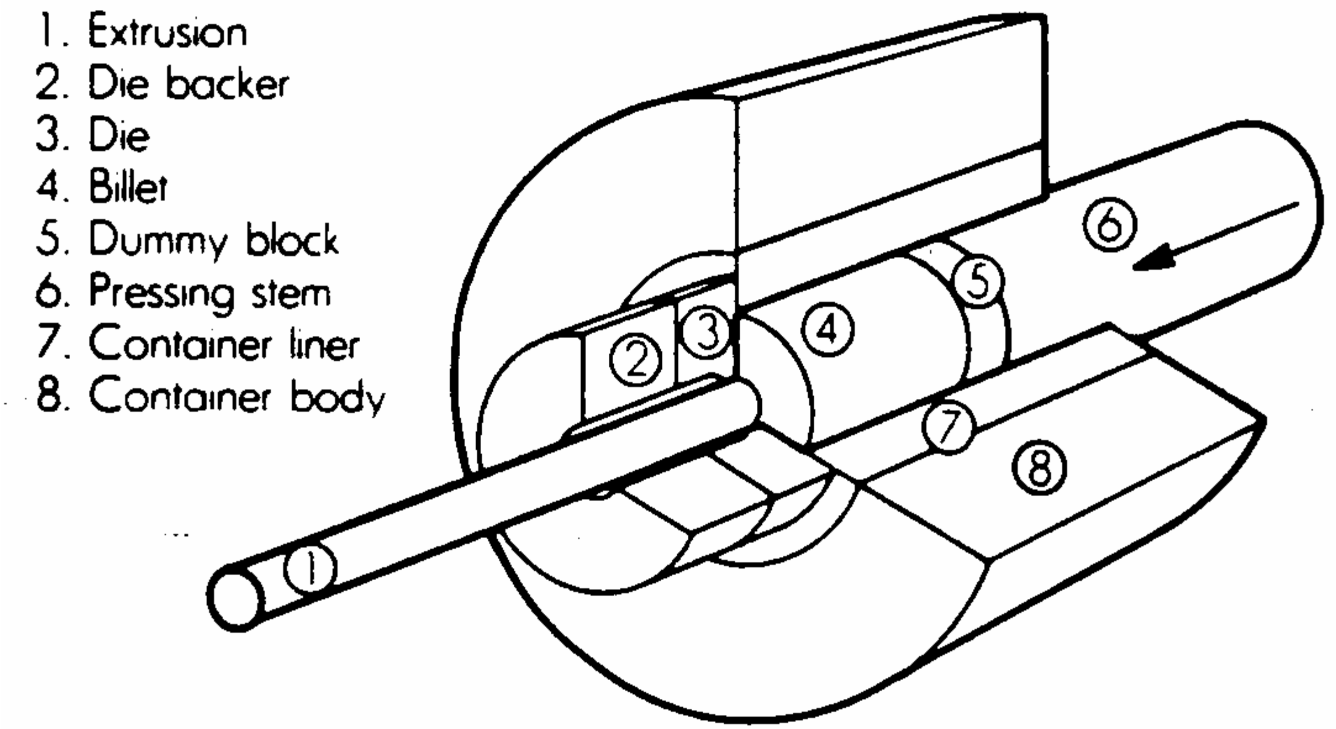
Heading (Upsetting)

- The length of unsupported metal that can be upset in one blow is three times the bar diameter or less.
- Lengths greater than three times the bar diameter can be upset provided the diameter of the die cavity is less than 1.5 times the bar diameter.



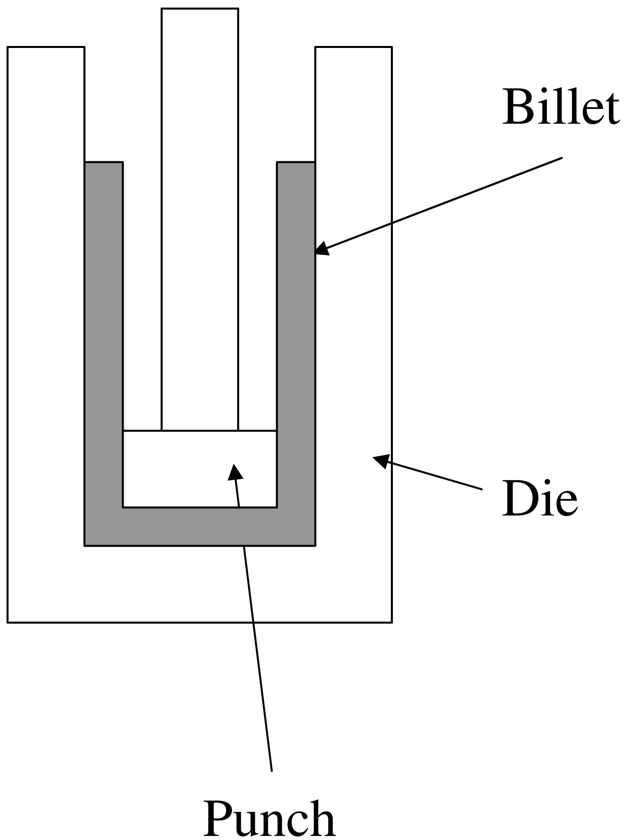
Forward (Direct) Extrusion

- Can extrude long lengths of aluminum or copper but not steel.



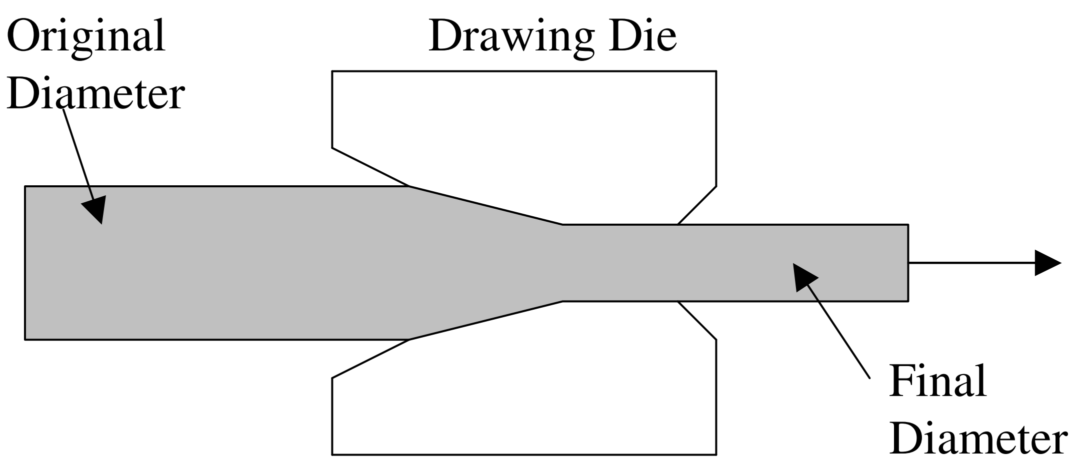
Indirect (Backward) Extrusion

- Produces hollow extrusions in shorter lengths.
- Typical feed stock includes steel, brass, aluminum, and copper.

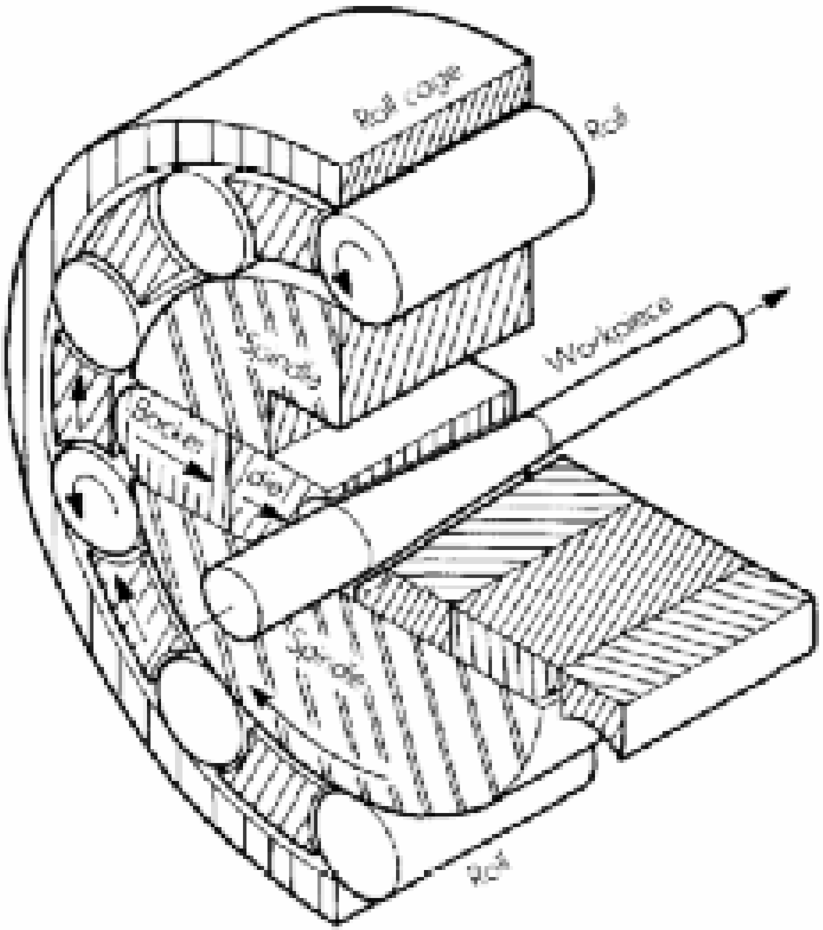


Wire and Tube Drawing

- Drawing pulls the metal through a die where extrusion pushes it.



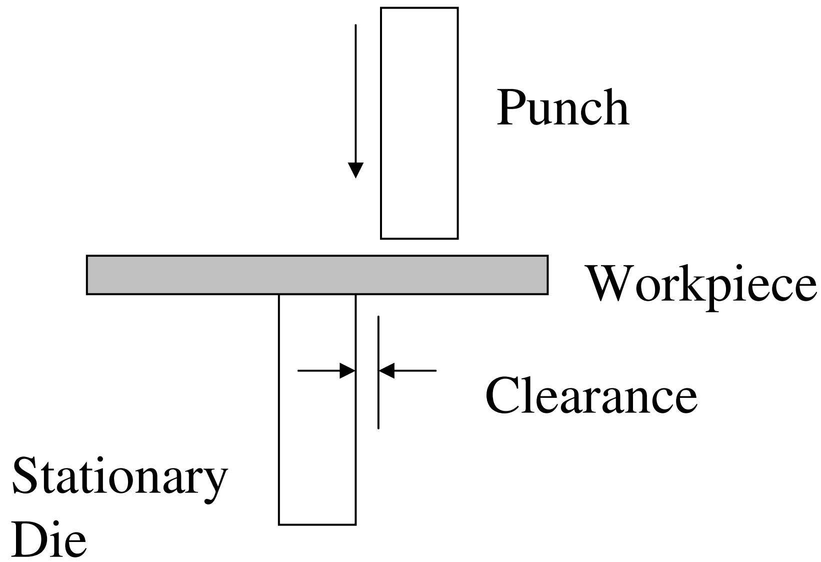
Swaging



- Impact blows are transferred to the work in rapid succession by dies in the machine.
- The contour built into the dies controls the cross section formed.
- Normally done cold but can be done hot.

Shearing

- The blades come together and contact the material being sheared, the blades penetrate the material until the tensile strength is overcome and a crack or tear, called the slip plane, develops from both sides.
- The punch is often angled rather than flat to reduce the cutting force required.



Clearance

- A tear occurs if the clearance is too great.
- A burnished edge develops as the punch penetrates the material.

$$c = at$$

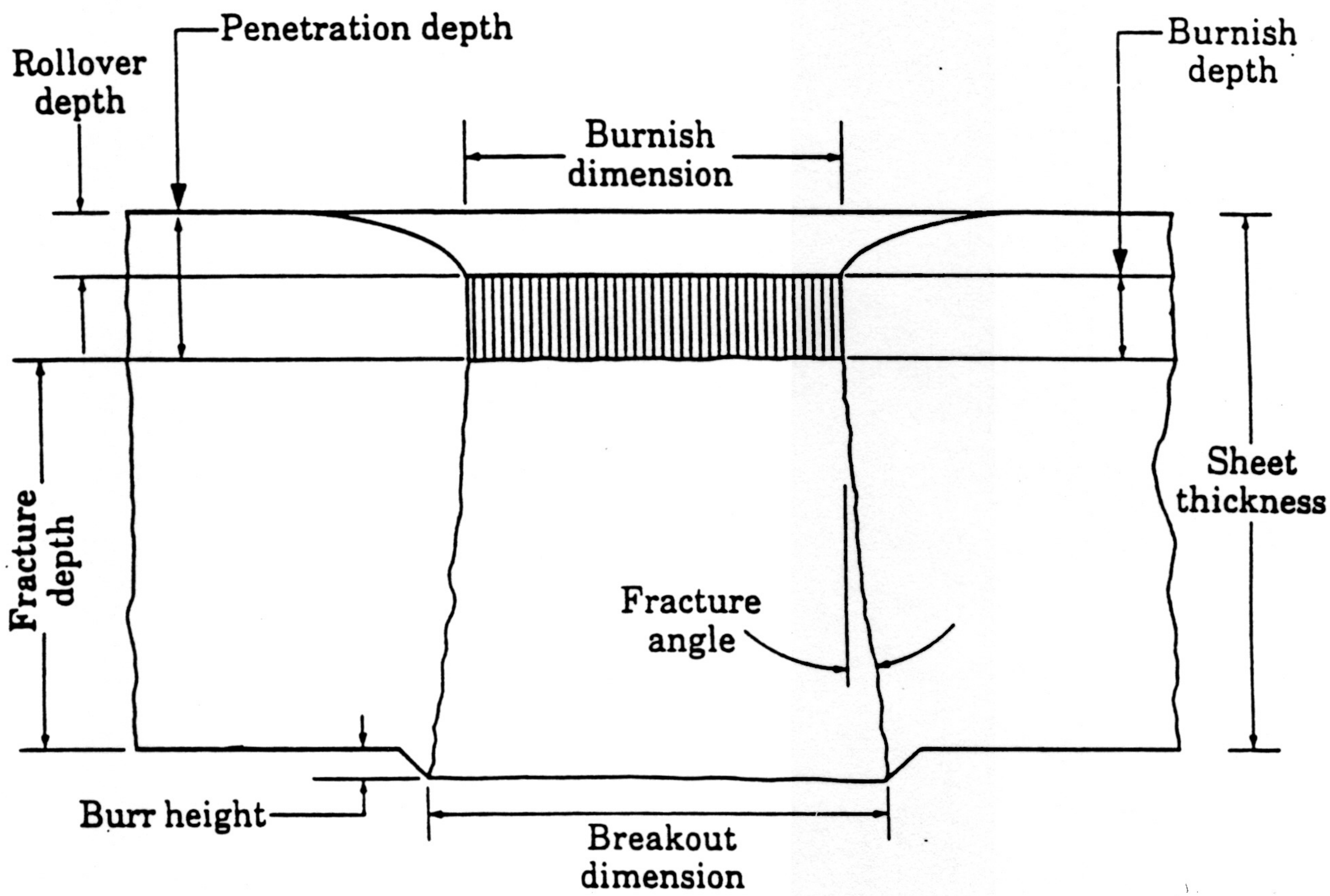
where

$c =$ clearance

$a =$ allownace %

$t =$ material thickness

Punching



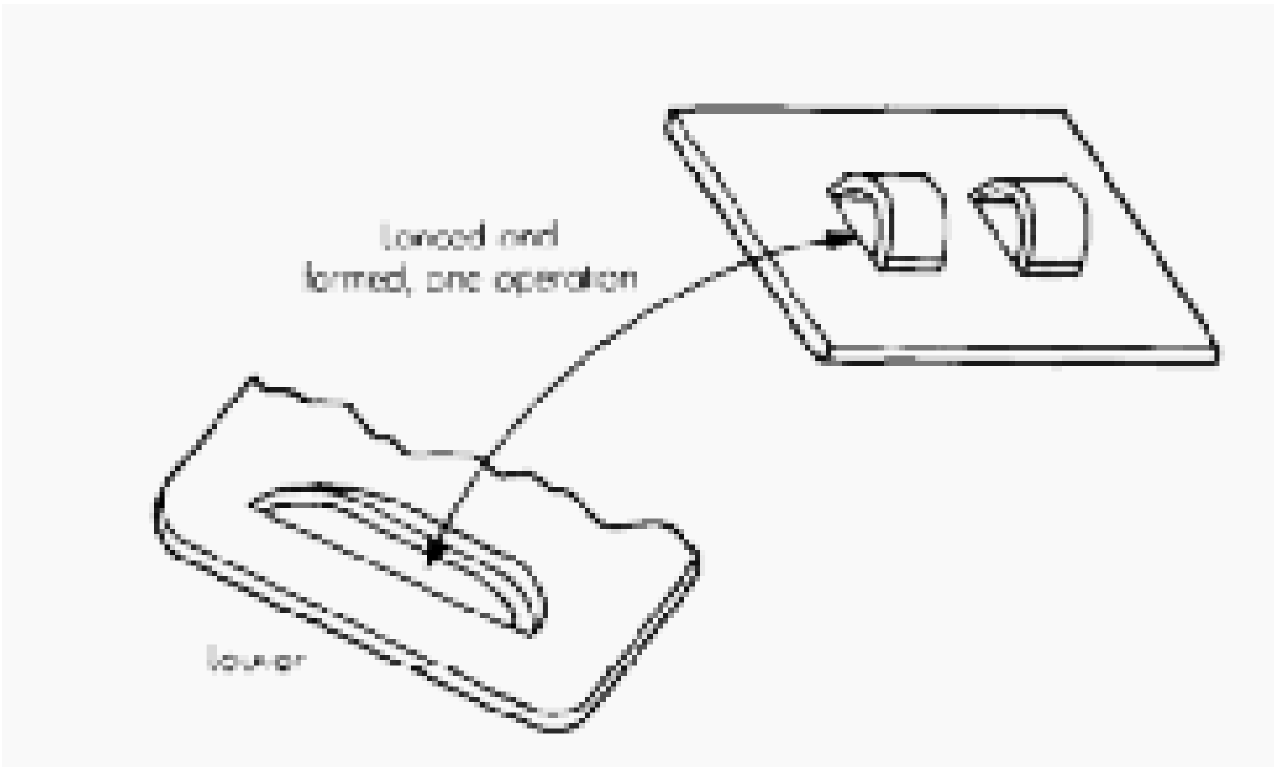
Penetration depth
Rollover depth
Burnish depth
Burnish dimension
Fracture depth
Sheet thickness
Fracture angle
Burr height
Breakout dimension

Shearing Processes

- Punching
  - the material removed is discarded
- Blanking
  - the material remove is saved for later operations
- Notching
  - removing a piece of metal from the edge of a strip

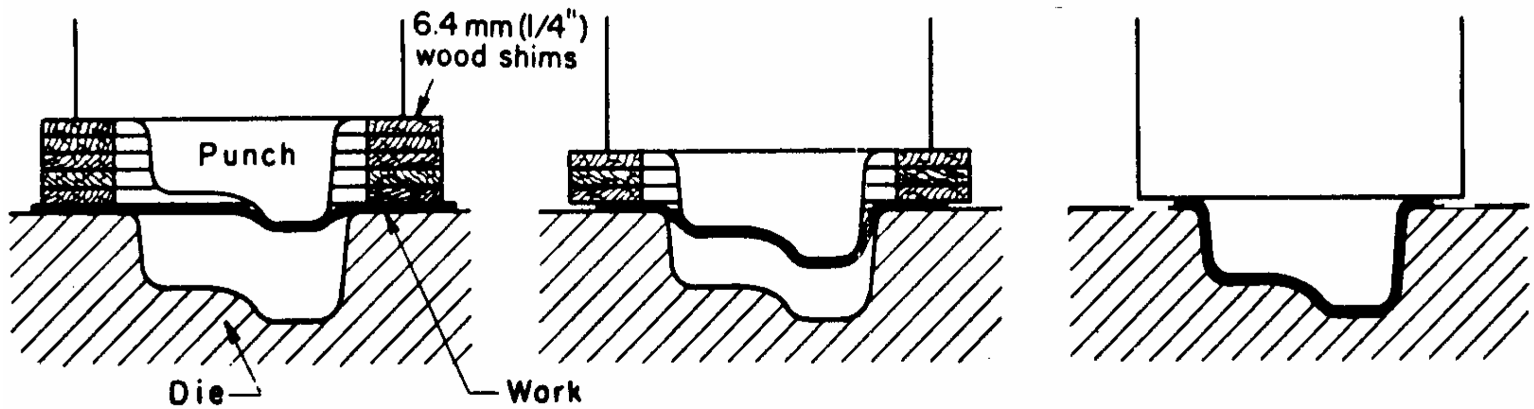
Lancing

- Lancing is cutting along a line in the product without freeing the scrap from the product.



Deep Drawing

- If the depth of the cup formed is equal to or more than the radius of the cup, the process is known as deep drawing.
- It requires a blankholder pressure to press the blank against the die to prevent wrinkling.
- Die design - final dies are perfected using circle grid analysis (CGA)



Spinning

- Spinning is a cold forming operation in which a rotating sheet metal disk is forced against a the contour of a rotating mold.
- Spinning is a technique for forming conical, hemispherical, or cylindrical cup shapes.

Presses and Dies

- Presses are classified by one or a combination of characteristics:
  - source of power
  - number of slides
  - types of frames
  - construction.
- A slide or ram is the main reciprocating member of a press, guided in the press frame, to which the punch or upper die is fastened.
- The source of power for press operation can be manual, mechanical, hydraulic, pneumatic, or pneumatic/ hydraulic.

Press Components

- Punch Holder
  - fixture used for mounting the punch
- Punch
  - male member of the punch and die configuration
- Stripper
  - plate designed to surround the punch
  - strips the sheet metal stock from the punching members during the withdrawal cycle
- Die
  - female member of the punch and die configuration

Press Components

- Die shoe
  - plate or block upon which the die is mounted
  - functioning primarily as a base for the complete die assembly
  - bolted or clamped to the bolster plate
- Bolster
  - plate attached to the top of the bed of the press
  - contains numerous drilled holes and/or T-slots for attaching the die shoe

Quick Die Change

- Internal tasks
  - those elements of the procedure that must be performed while production is halted
  - unclamping the die, adjusting shut height, etc
- External tasks
  - tasks that can and should be performed before production stops
  - positioning new dies and stock in the area
  - To improve die set efficiency, external tasks must be performed externally, and as many internal tasks as possible should be converted to external tasks.

Tool Material Characteristics

	High-Speed Steel	Cast-Cobalt Alloys	Carbide	Coated Carbide	Ceramic	Cubic Boron Nitride	Diamond
Impact Strength	Good	Good	Fair	Fair	Poor	Poor	Very Poor
Wear Resistance	Poor	Poor	Fair	Fair	Good	Good	Very Good
Cutting Speed	Low	Low	Moderate	Moderate	High	High	Very High
Depth of Cut	Light to moderate	Light to heavy	Light to heavy	Light to heavy	Light to heavy	Light to heavy	Very light
Finish Obtainable	Rough	Rough	Good	Good	Very Good	Very Good	Excellent
Cost	Low	Low	Moderate	Moderate	High	High	Very High

Tool Materials

- High-Speed Steels
  - M series - molybdenum + carbon + tungsten + vanadium + chromium + (sometimes cobalt)
  - T series - tungsten + carbon + vanadium + chromium + (sometimes cobalt)
- Coated Carbide
  - titanium carbide (TiC) (introduced in 1969)
  - titanium nitride (TiN)
  - aluminum oxide-ceramic (Al_2O_3)
  - This process mainly done through chemical vapor deposition (CVD).
- Coated High-Speed Steel
  - titanium nitride (TiN) (introduced in 1981)

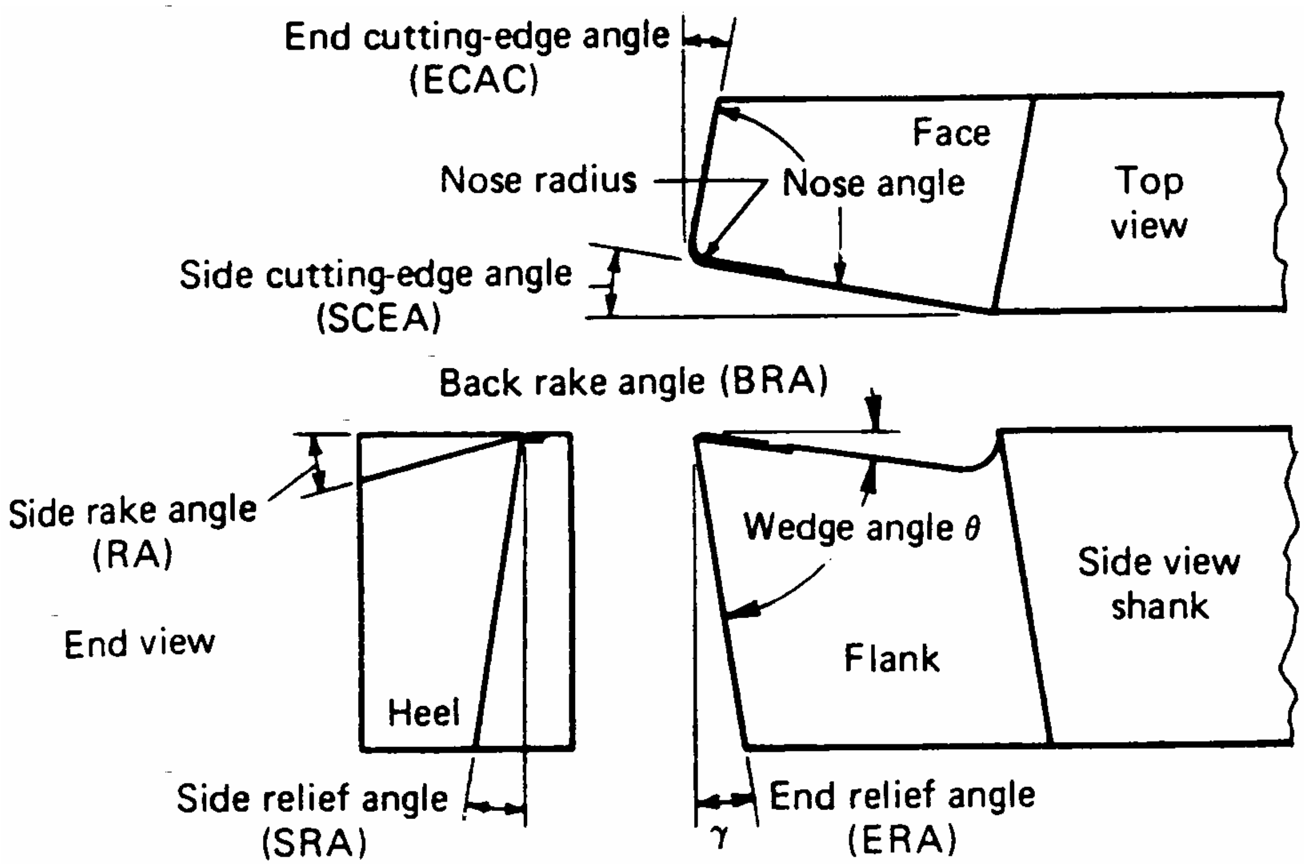
Cutting Fluid Functions

- Coolant
  - Fluids with a high specific heat and high thermal conductivity draw heat away from the tool or part.
- Lubricant
  - reduces the effects of friction at the tool-chip interface

Cutting Fluids

- Cutting Oils
  - based on oil derived from petroleum or other sources
  - good lubrication but poor cooling
- Emulsified Oils
  - oil droplets suspended in water
  - combine cooling and lubrication
- Chemical Fluids
  - chemicals in a water solution
  - good cooling but poor lubrication

Tool Angles


End cutting-edge angle
(ECAC)
Face
Nose radius
Nose angle
Top
view
Side cutting-edge angle
(SCEA)
Back rake angle (BRA)
Side rake angle
(RA)
End view
Heel
Wedge angle θ
Side view
shank
Flank
Side relief angle
(SRA)
γ
End relief angle
(ERA)

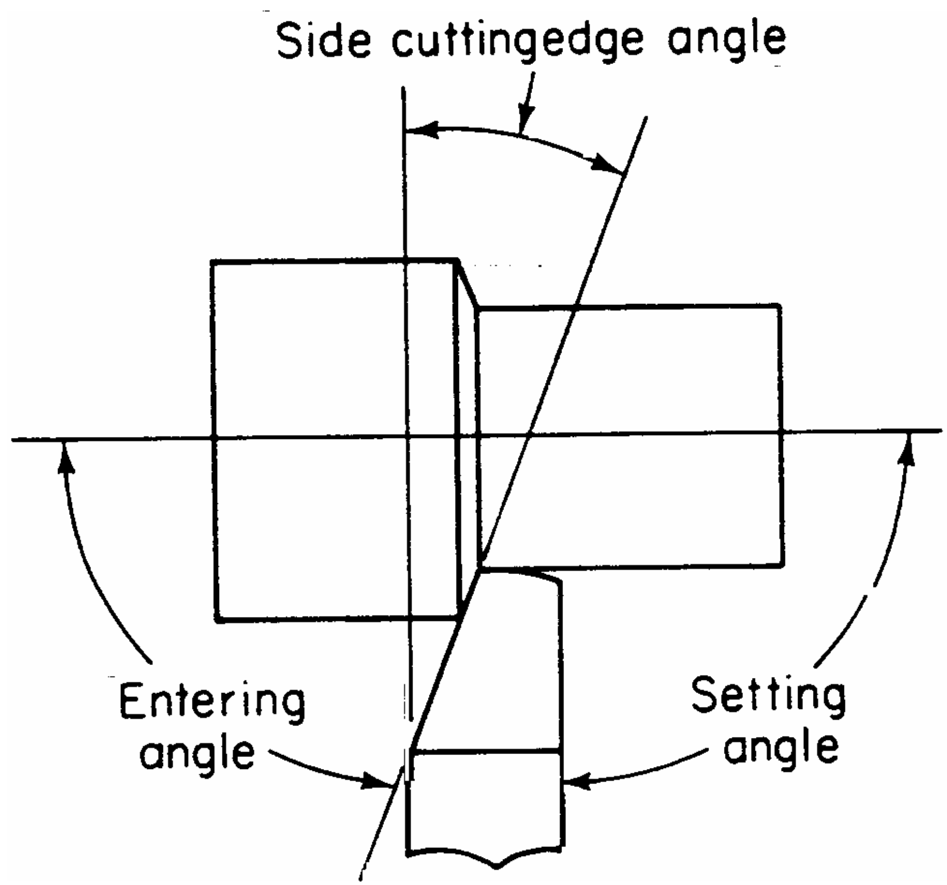
Tool Angles

- Positive Rake
  - inclination of the tool face makes the cutting edge keener or more acute than when the rake angle is zero
  - the previous figure illustrates positive rake
  - decreases the cutting force and temperature and extend tool life

Tool Angles

- Negative Rake
  - inclination of the tool face makes the cutting edge less keener or less acute than when the rake angle is zero
  - requires more cutting force and create higher temperature thus reducing tool life
  - strengthens the cutting edges
  - recommended for hard materials and heavy interrupted cuts

Working Angles



Tool Wear

- Crater Wear
  - crater that forms on the rake of the tool face as the chip slides slides against the surface
- Flank Wear
  - occurs on the flank of the tool as a result of rubbing between the newly generated surface and the flank face adjacent to the cutting edge

Taylor Tool Life Equation

$$C = VT^{n}$$

- V = cutting speed (fpm or m/min)
- T = cutting time between resharpening or replacement (minutes)
- n = constant related to tool material
- C = numerically equal to the cutting speed that gives a tool life of 1 min (fpm or m/ min).

Typical n Values

Material to be Machined	Carbide	HSS Tool Steel
Steel	0.3	0.15
Cast Iron	0.25	0.25
Light Metals	0.41	0.41
Brass and Cast Brass		0.25
Copper		0.13

Taylor Tool Life Example

Find the tool life for carbide when V = 90 fpm

n = 0.2

C = 150

$$C = VT^n$$

$$150 = 90T^{0.2}$$

$$\ln\frac{150}{90} = \ln T^{0.2}$$

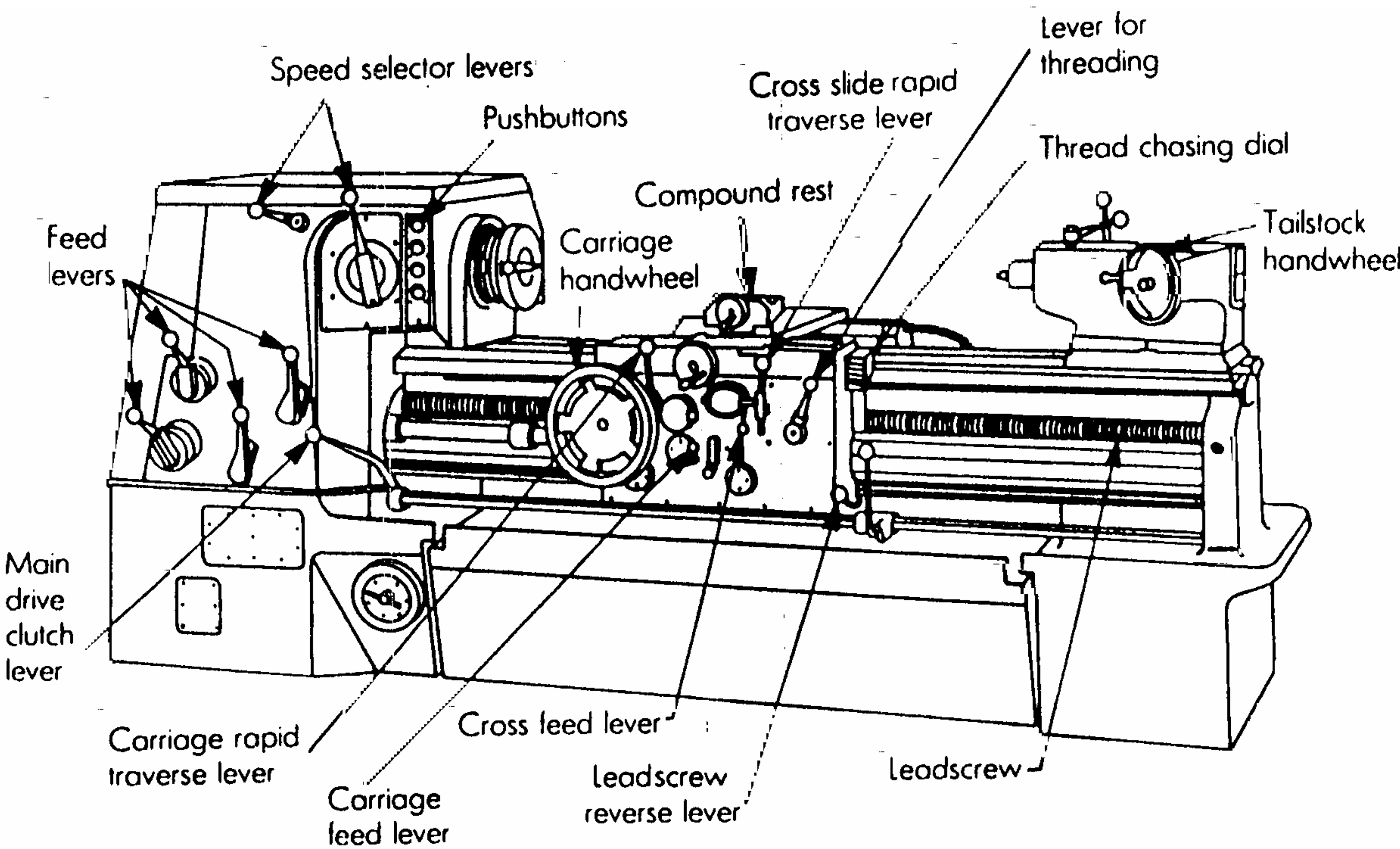
$$0.51 = 0.2\ln T$$

$$2.55 = \ln T$$

$$e^{2.55} = e^{\ln T}$$

$$\underline{12.8\text{ minutes} = T}$$

Parts of the Lathe



Work Holding

- Lathe Dog
  - turning between centers
- Collet
  - most precise (no runout)
  - many different sizes required
- Three Jaw Universal Chuck
  - easy to use
  - all three chuck jaws move simultaneously
  - not as precise as others (runout)

Work Holding

- 4 Jaw Independent Chuck
  - all four jaws move independently
  - irregular shaped objects
- Face plate
  - mounting large irregular shaped parts
- Mandrel
  - tapered mandrel used to hold cylindrical part by their internal feature
  - mandrels are then turned between centers
  - part outer diameter is concentric with an inside diameter

Turning Calculations

$$N = \frac{V_c \times 12}{\pi \times D} \text{ (English)}$$

$$N = \frac{V_c \times 1000}{\pi \times D} \text{ (Metric)}$$

$$Q = 12 \times d \times f_r \times V_c \text{ (English)}$$

$$Q = 1000 \times d \times f_r \times V_c \text{ (Metric)}$$

$$P_m = \frac{P_s}{E}$$

$$U = \frac{P_s}{Q}$$

N = spindle rpm

V_c = cutting speed (ft/min [m/min])

D = workpiece diameter (in.[mm])

Q = metal removal rate (in.^{3}/min [mm^3/min])

d = depth of cut (in.[mm])

f_r = feed rate (in./rev [mm/rev])

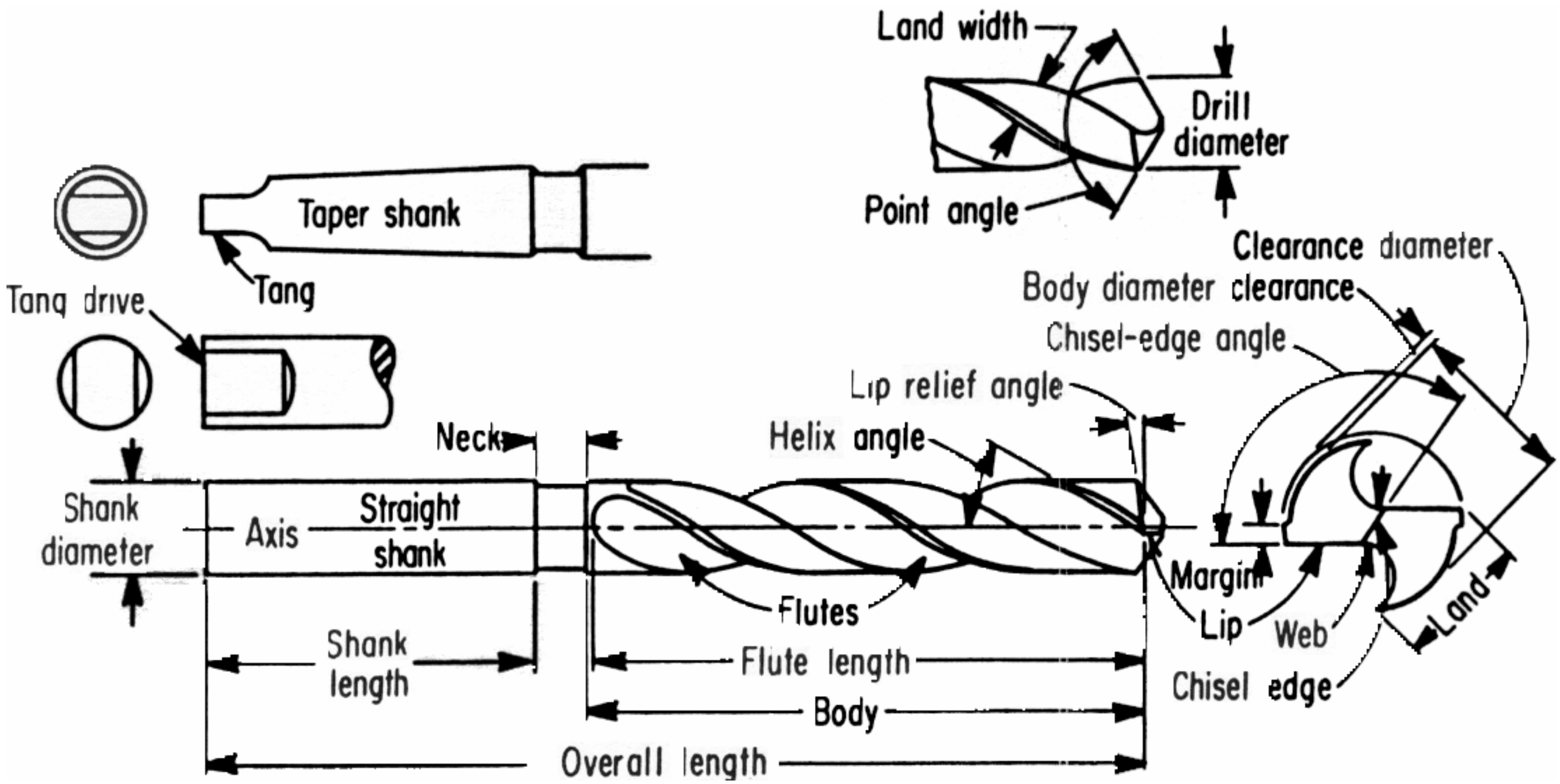
P_m = power at motor (hp [W])

P_s = power at spindle (hp [W])

U = unit power (hp/in^3/min [W/mm^3/min])

E = efficiency of spindle drive

Parts of a Twist Drill



Drilling Calculations

$$N = \frac{V_c \times 12}{\pi \times D} \text{ (English)}$$

$$N = \frac{V_c \times 1000}{\pi \times D} \text{ (Metric)}$$

$$Q = \frac{\pi}{4} \times D^2 \times f_r \times N$$

$$P_m = \frac{P_s}{E}$$

$$U = \frac{P_s}{Q}$$

N = drill rpm

V_c = cutting speed (ft/min [m/min])

D = drill diameter (in.[mm])

Q = metal removal rate (in.^{3}/min [mm^3/min])

f_r = feed rate (in./rev [mm/rev])

P_m = power at motor (hp [W])

P_s = power at spindle (hp [W])

U = unit power (hp/in^3/min [W/mm^3/min])

E = efficiency of spindle drive

Up and Down Milling

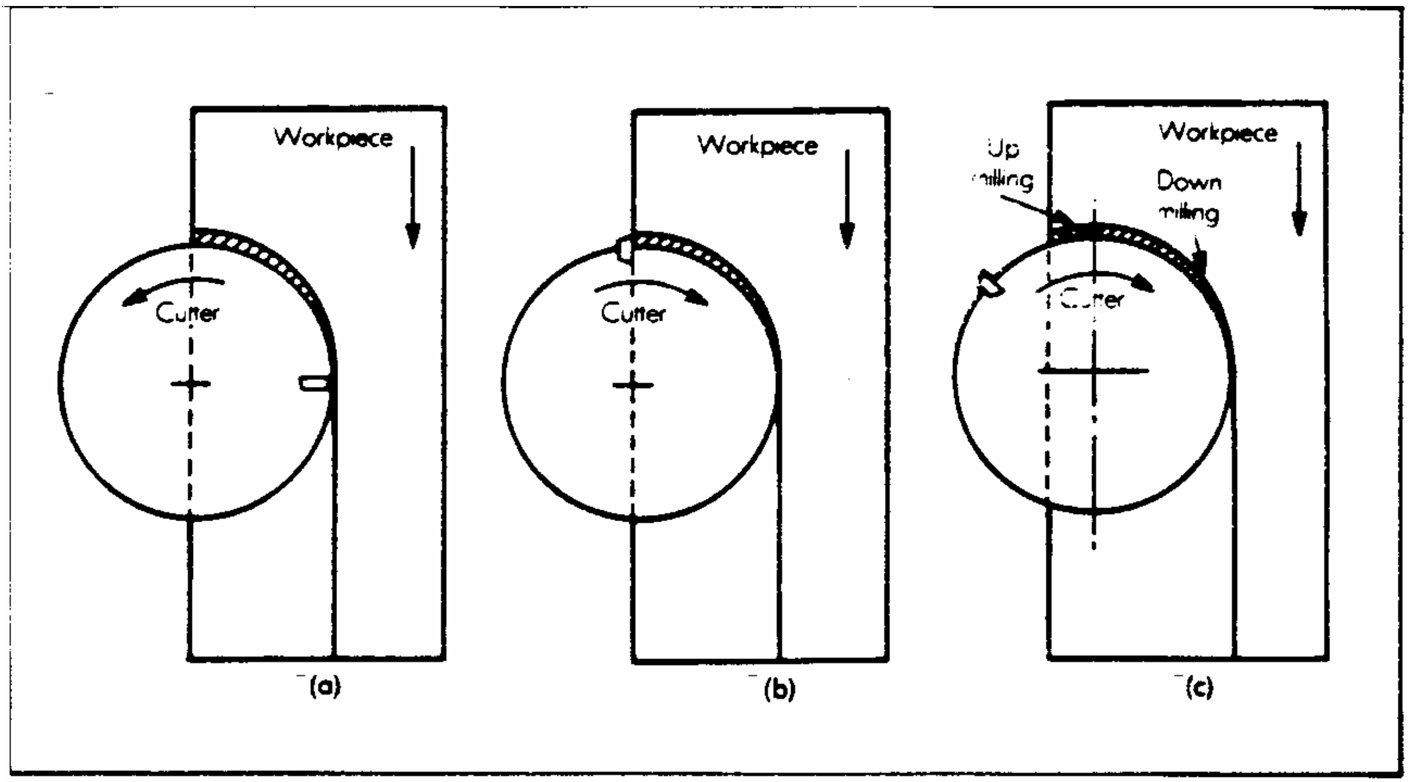


Figure 19.8 (a) Up Milling, (b) Down Milling, (c) Combination Up and Down Milling.

Types of Milling

- Up Milling
  - when the milling cutter is spinning in the opposite direction of workpiece travel
  - used on flame cut surfaces or when large variations in the amount of stock to be removed exist
- Down Milling(climb)
  - when the milling cutter is spinning in the same direction of workpiece travel
  - requires less cutting force and may extend tool life

Milling Calculations

$$N = \frac{V_c \times 12}{\pi \times D} \text{ (English)}$$

$$N = \frac{V_c \times 1000}{\pi \times D} \text{ (Metric)}$$

$$F = f_t \times n \times N$$

$$Q = w \times d \times f_t \times n \times N$$

$$P_m = \frac{P_s}{E}$$

$$U = \frac{P_s}{Q}$$

N = cutter rpm

V_c = cutting speed (ft/min [m/min])

D = cutter diameter (in.[mm])

Q = metal removal rate (in.^{3}/min [mm^3/min])

w = width of cut

d = depth of cut (in.[mm])

F = table feed rate (in./min [mm/min])

f_t = feed per tooth (in./tooth [mm/tooth])

n = number of teeth

P_m = power at motor (hp [W])

P_s = power at spindle (hp [W])

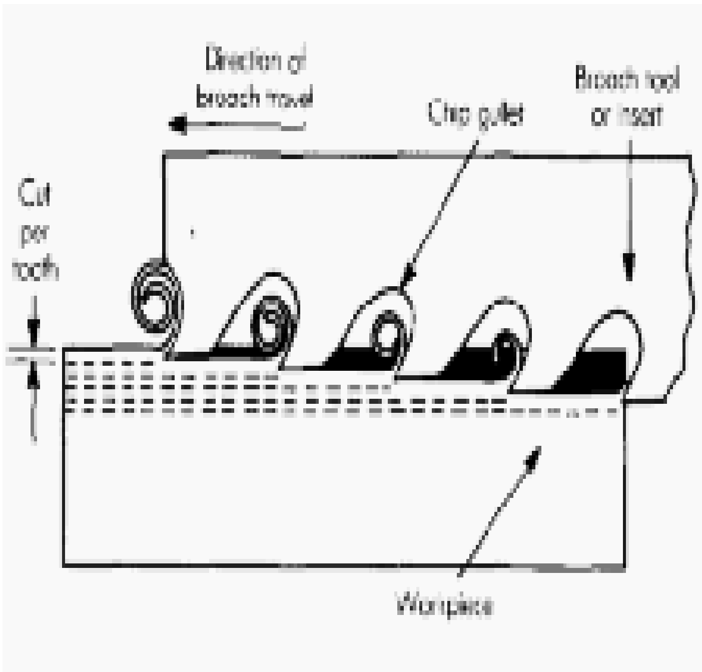
U = unit power (hp/in^3/min [W/mm^3/min])

E = efficiency of spindle drive

Boring

- Jig Boring
  - precise vertical-type boring machine used for making jigs and fixtures
- Production precision boring machines
  - built for precision machining parts in mass production
  - typically light cutting
- Horizontal and vertical boring machines
  - very versatile and useful in machining large parts
  - capable of heavy cutting

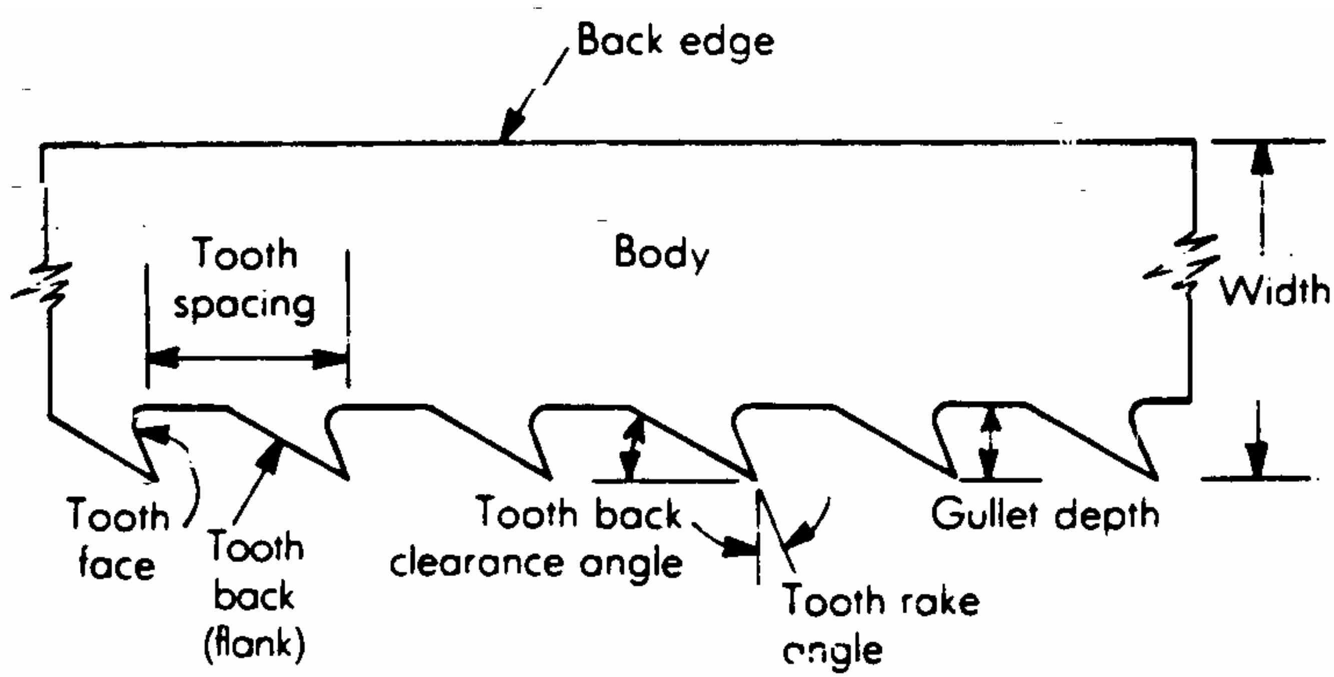
Broaching



- Advantages
  - fast
  - good finish and accuracy
  - roughing and finishing are done with separate teeth on the same broach
- Disadvantages
  - costly to make and sharpen
  - can not broach if there is an obstruction across the broach travel path
  - large broaching forces can deform the part

Bandsawing

- Bandsaw Terminology



Bandsawing

- Tooth Geometries
  - standard
  - skip
  - hook teeth
- Pitch
  - number of teeth per inch
- Tooth Set
  - projection of the teeth from the sides of the band to prevent binding

Thread Cutting

- Tap and die
  - too great a thread percentage throws a strain on the teeth of the tap and serves no useful purpose
  - the greater the percentage, the more power required to tap, the more difficult to hold size, and the greater the amount of tap breakage
  - generally, the harder and tougher the material, the lower the percentage of thread that should be required
- Chasing (lathe)

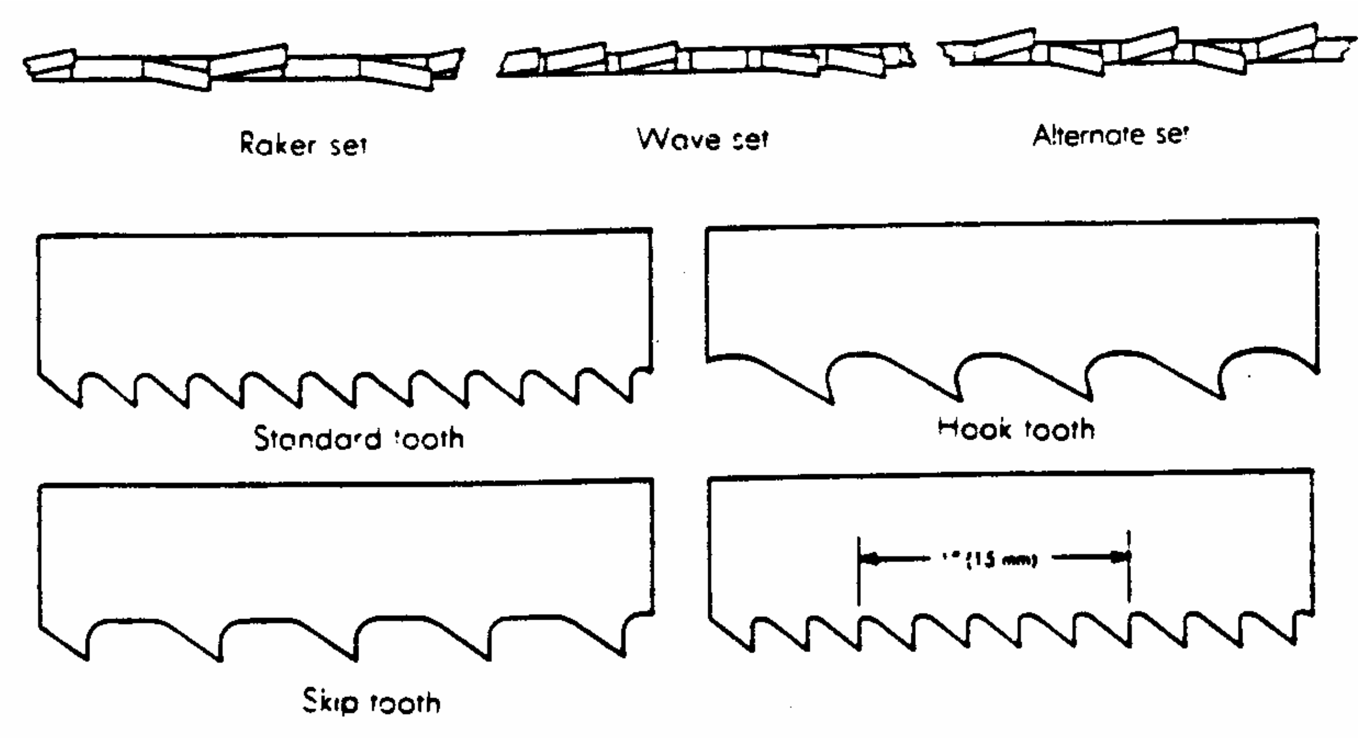
Thread Forming

- Rolling
  - superior to cutting for strength, wear and finish
  - no metal is cut away
  - cold formed which stain hardens the metal
- Casting
- Plastic molding

Threads Classes

- Class “A” for screws and Class “B” for nuts.
- Class 1A and 1B are for a loose fit, where quick assembly and rapid production are important and shake or play is not objectionable.
- Class 2A and 2B serve for most commercial screws bolts and nuts.
- Classes 3-5 provide for closer fits and for interference fits.

Tooth Geometries



Grinding Wheels

- Abrasive Materials
  - aluminum oxide
    - ferrous alloys
  - silicon carbide
    - nonferrous alloys, cast iron and stainless
  - diamond
  - cubic boron nitride
- Grain Size
  - smaller grain size (grit) provides a better finish
  - larger grain size provides a faster material removal rate but a poor finish

Wheel Marking System

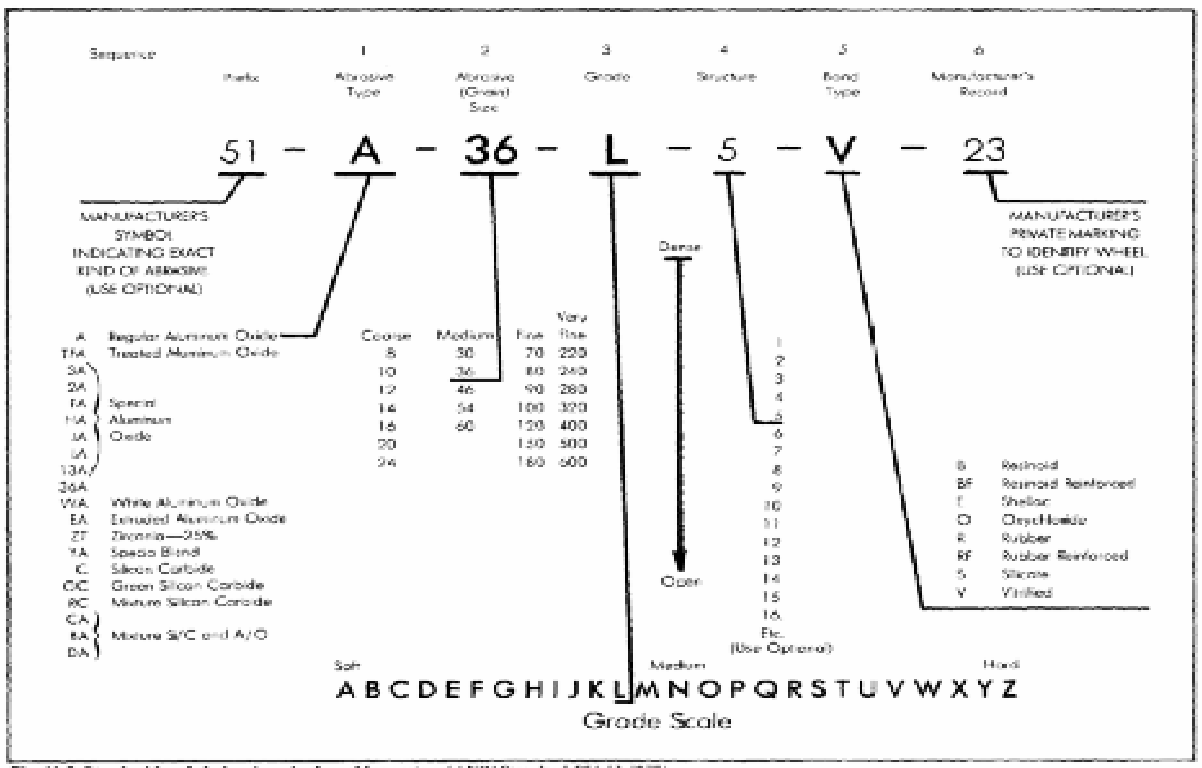


Fig. 11-8 Standard bonded-abrasive wheel-marking system *(ANSI Standard B74.13-1977).*

From Left to Right

Prefix(51)

1 Abrasive type (A)

2 Grain size (36)

3 Grade (L)

4 Structure (5)

5 Bond type (V)

6 Manufacturer's record (23)

Grinding Wheel Bonds

- Vitrified Bond
  - baked clay and ceramics
  - common for grinding wheels
- Silicate Bond
  - sodium silicate bond
  - minimizes heat generation
- Rubber Bond
  - flexible
  - cut off wheels
- Resinoid Bond
  - rough grinding
  - soften with prolonged exposure to water
- Shellac Bond
  - high finishes on rolls and cutlery grinding
- Metallic Bond
  - bond for diamond and cubic boron nitride wheels
  - abrasive material is usually only on the outside of the wheel
  - ceramic and carbide grinding

Grinding Wheels

- Wheel grade
  - measure of the wheels strength in retaining the abrasive grits during cutting
  - soft wheels lose grains readily.
  - hard wheels are used for high material removal rates and soft materials

Grinding Wheels

- Structure
  - measure of the relative spacing of the abrasive grains in the wheel
  - dense structures are used for a better surface finish and dimensional control

Grinding Wheel Wear

- Grain Fracture
  - part of a grain fractures leaving the remainder attached to the wheel
- Attritious Wear
  - dulling of the individual grains
- Bond Fracture
  - individual grains are pulled out of the bonding material
- Wheel Loading
  - chips or other material become clogged in the pores of the wheel

Nontraditional Machining

- Water Jet Cutting
  - high velocity water stream
  - narrow kerf
  - cuts textiles, flooring, composites
- Electrochemical Machining
  - material removed from an electrically conductive workpiece by anodic dissolution
  - the workpiece shape is formed by formed electrode
- Electrical Discharge Machining (EDM)
  - sparks from a formed electrode or wire travel through a dielectric medium(nonconductive) and selectively erode the workpiece

Dielectric Fluid

- The fluid must insulate until the required conditions are achieved between the electrode and workpiece, and then it must act as a conductor.
  - Insulates until sufficient voltage is applied across the spark gap to break the dielectric strength and then to ionize (become an electrical conductor), allowing a current (spark) to flow to the workpiece.
  - Characterized by high dielectric strength, the measure of maximum voltage that can be applied to a given material before ionization takes place.
- The fluid must cool the workpiece, electrode, and “chips.”
- The fluid must flush the particles out of the spark gap.

Welding

- Oxyfuel Gas Welding and Cutting
  - gas welding and cutting
  - brazing
  - soldering
- Arc Welding
  - SMAW
  - GMAW
  - GTAW
- Electric Resistance Welding
  - spot and seam
- Solid State Welding
  - ultrasonic welding
  - inertia welding
- Unique Processes
  - electron beam
  - laser
  - spray

Oxyfuel Welding

- Oxygen and Fuel Gas (acetylene)
- Advantages
  - inexpensive
  - portable
  - good heat source
- Disadvantages
  - low temperature
  - can’t be automated
  - low volume production

Types of Flames

- Carburizing
  - excess fuel gas
- Neutral
  - complete combustion
- Oxidizing
  - excess oxygen

Brazing

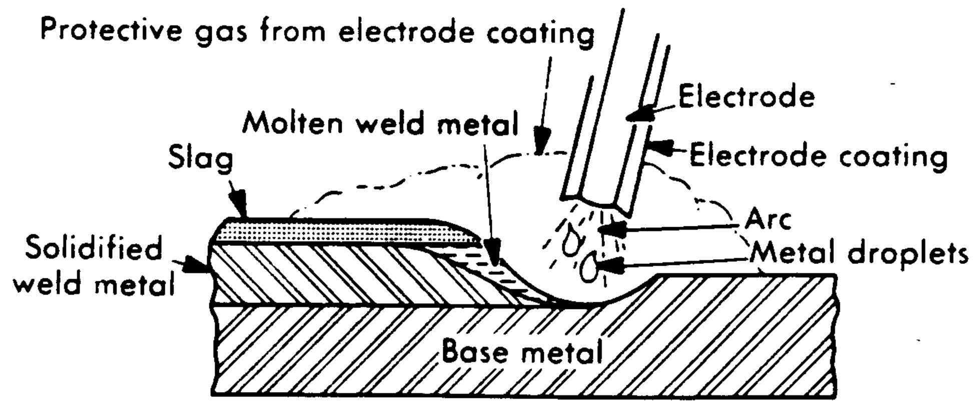
- "A group of welding processes which produces coalescence of materials by heating them in the presence of a filler metal having a liquidus above 840° F (450° C) and below the solidus of the base metal.
- Brazing materials include BCuP (Copper, Phosphorous, and Silver) and BAg(Copper, Silver, Zinc and sometimes Cadmium)
- Advantages
  - low temperature/low distortion
  - join dissimilar metals
  - capillary action
  - leak tight joints
- Disadvantages
  - lower strength than welding
  - requires a reducing atmosphere to prevent oxidation

Soldering

- "A group of welding processes which produce coalescence of materials by heating them to a suitable temperature and by using a filler metal having a liquidus not exceeding 840° F (450° C) and below the solidus of the base material.
- Solder applications
  - plumbing and electrical
- Solder materials
  - for plumbing, usually 95-5 (Tin -Silver no lead allowed)
  - for electrical, usually 60-40 (Tin - Lead)

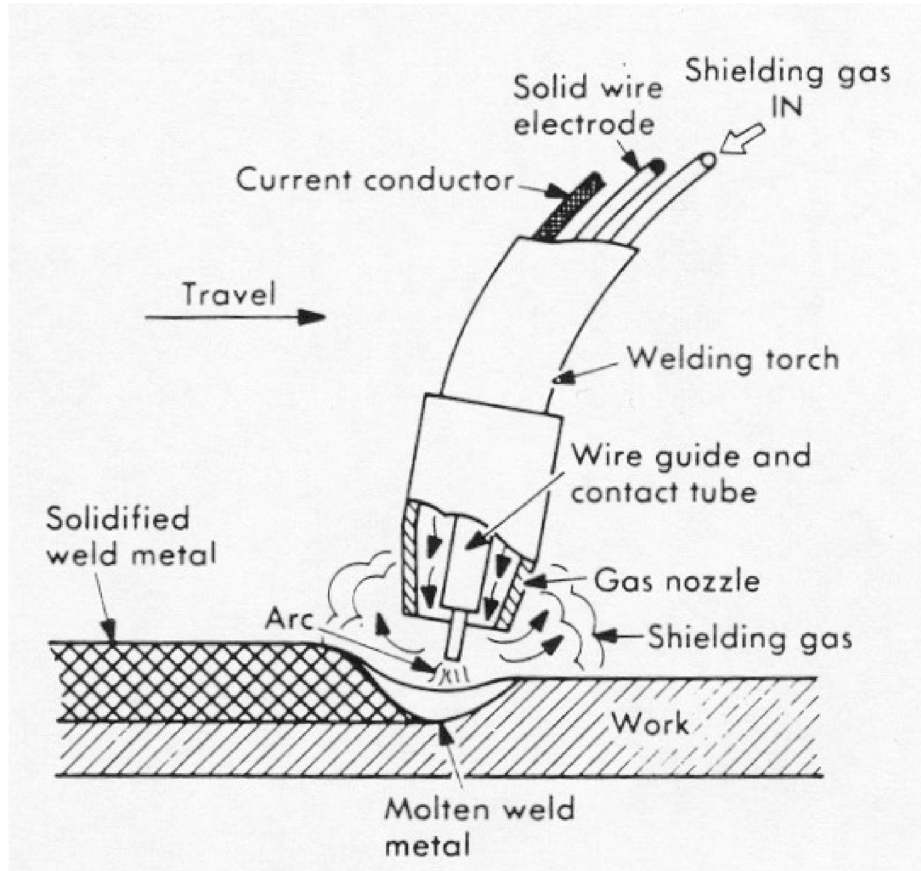
SMAW Welding

- SMAW (Shielded Metal Arc Welding)
- Also known as stick welding
- Advantages
  - high penetration (12,000 F arc)
  - versatile
- Disadvantages
  - difficult to automate
  - electrode waste
- Short arc lengths provide higher penetration and a lower voltage drop.



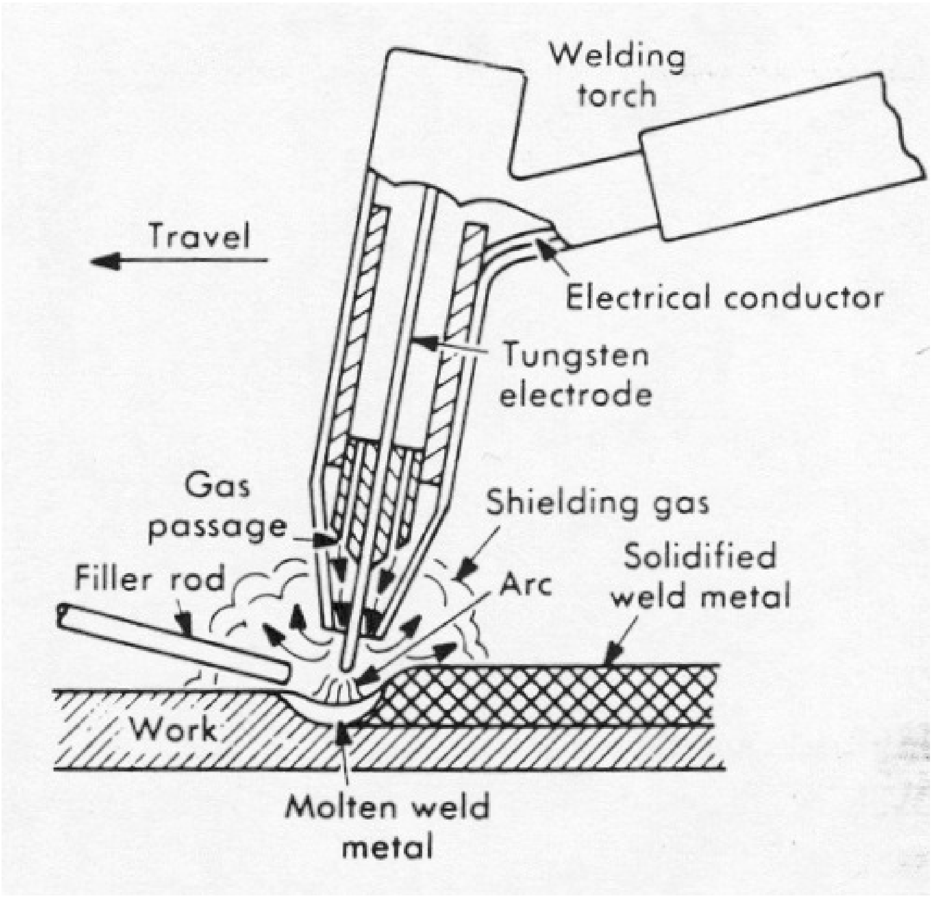
GMAW

- GMAW - Gas Metal Arc Welding
- Also known as MIG welding or wire feed welding
- Uses an Argon/CO_2 shielding gas in place of flux
- Advantages
  - can automate
  - no flux to chip off
  - less heat distortion
- Disadvantages
  - less penetration than stick



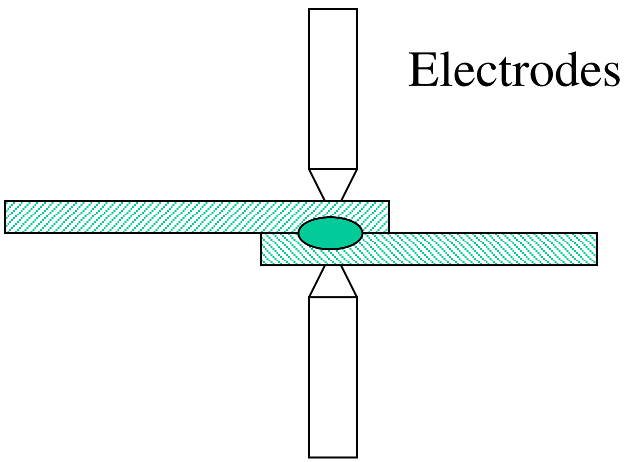
GTAW

- Gas Tungsten Arc Welding
- Also known as TIG of Heliarc welding
- Uses an Argon shielding gas in place of flux
- Advantages
  - clean, precise weld
  - deep penetration
- Disadvantages
  - difficult to automate with the exception of orbital welders
  - highly skill oriented



Resistance Spot Welding

- Electricity is passed from one electrode through the workpieces(forming a weld nugget between the faying surfaces) and through the other electrode and back to the power supply to complete the circuit.
- Advantages
  - quick
  - low temperature/low workpiece distortion
- Disadvantages
  - limited to a lapp joint
  - small weld area



Ultrasonic Welding

- Ultrasonic welding is a solid state process that vibrates two components together at a high frequency.
- Can join a variety of metallic and nonmetallic materials including dissimilar metals.
- Limited to lap-joints and relatively thin materials.

Electron Beam and Laser Welding

- Electron Beam Welding
  - Under a vacuum, a narrow beam of electrons penetrates the surface of a butt or lap weld creating a deep and narrow weld.
  - The heat affected zone is very small.
  - Must be done in a vacuum and generates harmful x-rays.
- Laser Beam Welding
  - Utilizes a high-power laser beam to produce a fusion weld.
  - Laser welds have a greater depth-to-width ratio than electron beam welding.
  - Narrow heat affected zone.
  - Is not done in a vacuum and does not generate x-rays.

Adhesives

Adhesive Category	Characteristics	Specific Adhesives	
Chemically reactive	Undergo a curing or crosslinking reaction within the adhesive. Epoxies and phenolics are heat and solvent resistant	Epoxies Polyeurethanes Phenolics	Silicones Anaerobics Cyanoacrylates
Evaporative	Curing occurs with the loss of solvent or water. Water-based adhesives are more environmentally friendly than other adhesives.	Vinyls Acrylics	Polyeurethanes
Hot melt	Bond forms rapidly and can join most materials. Variable joint gaps can be filled.	Polyolefins Polyamides	Polyesters
Delayed tack	Nontacky solids that are heat-activated to produce a state of tackiness that is retained upon cooling for periods up to several days.	Polystyrenes Polyvinyl acetates	Polyimides
Film	Must be supplied on a flexible cloth or tape. They have a controlled glue line thickness. Easy to apply	Nylon-epoxies Vinyl-phenolics	Elastomer-epoxies
Pressure sensitive	Bond formation occurs by the brief application of pressure. Poor solvent resistance.	Natural rubber Styrene-butadiene rubber Butyl rubber	

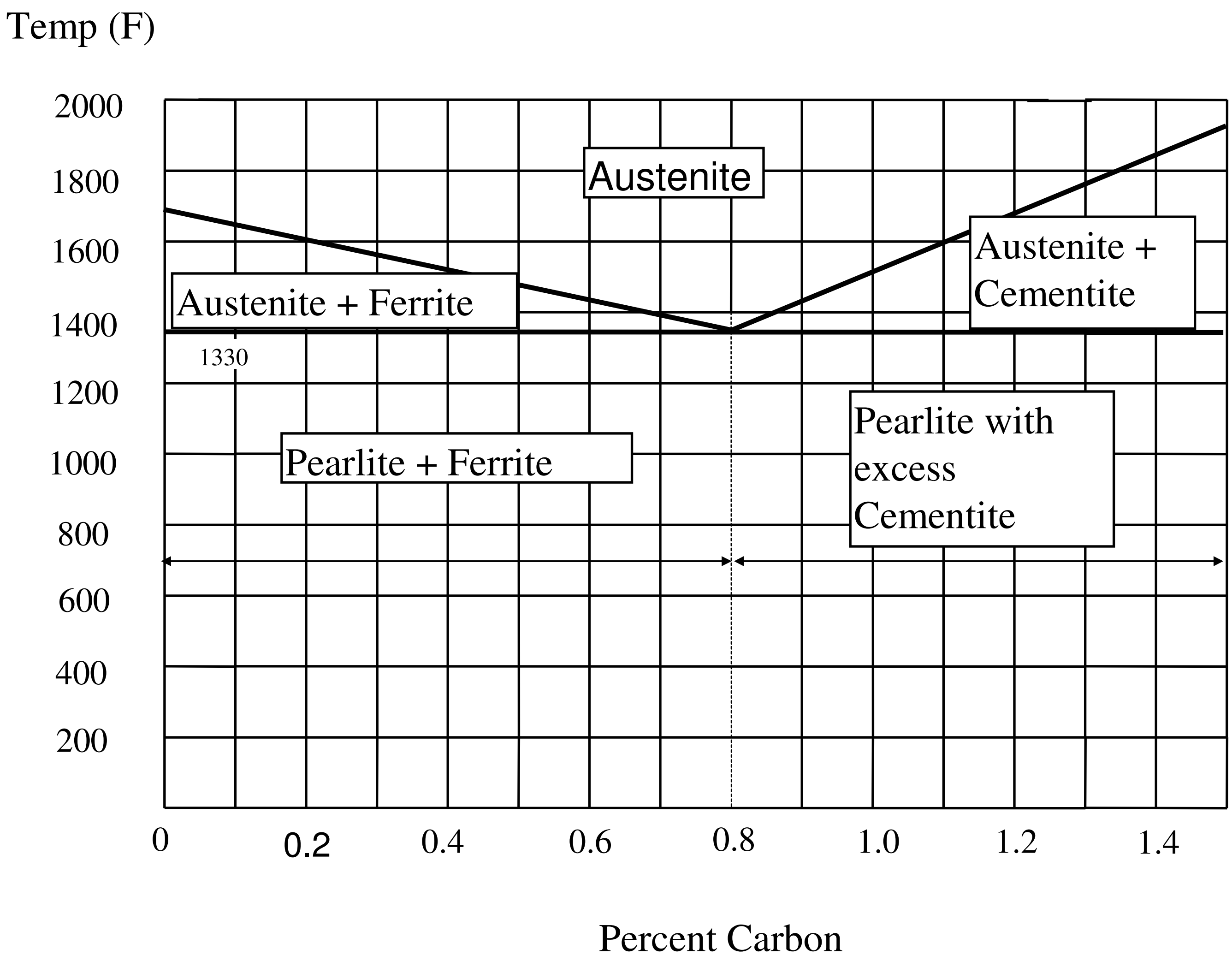
Adhesives

- Advantages
  - stresses are uniformly distributed over a large area
  - dissimilar materials can be joined
  - some improve fatigue life
  - reduced assembly weight
- Limitations
  - careful selection of adhesive type
  - critical surface preparation
  - disassembly is difficult
  - joints have high shear strength and lower tensile strength

Secondary Metal Working Operations

- Heat treating
  - carbon steel
  - nonferrous metals
- Deburring and Finishing
- Plating
- Painting

Iron-Carbon Phase Diagram



Definitions

- Ferrite
  - iron
- Pearlite
  - mixture of iron and iron carbide
- Carbide
  - compound or carbon and another element
- Iron Carbide
  - compound of carbon and iron
  - Fe_3C
- Cementite
  - iron carbide

Definitions

- Austenite
  - solid solution of iron and carbon
- Martensite
  - supersaturated solution of iron and carbon
  - formed by quenching austenite
  - hard and brittle
- Bainite
  - similar to pearlite but with a needle like carbide structure rather than plates
  - harder than pearlite

Definitions

- Lower Critical Temperature
  - minimum temperature for hardening
- Upper Critical Temperature
  - minimum temperature for achieving maximum hardness
- Hypereutectoid steels have more than 0.77% carbon.
- Hypoeutectoid steels have less then 0.77% carbon.

Pearlite Formation

- Most heat treatment involves the formation of pearlite in a controlled way.
- Furnace Cooling
  - coarse pearlite (15 Rockwell C)
- Air Cooling
  - medium pearlite (25 Rockwell C)
- Oil Quench
  - fine pearlite (38 Rockwell C)
- Higher hardness numbers indicate higher hardness.

Martensite Formation

- To achieve hardness higher than a 38 Rockwell C water or brine(salt water) must be used to quench the steel.
- When carbon trapped in austenite the result is called martensite.
- Martensite (55 Rockwell C) is very hard and brittle.

Quench Media

Relative Severity	**Quench Media**
5	agitated brine
1	still water
0.3	still oil
0.02	still air

Agitated brine can cool an austenitized steel 250 times faster than still air.

Hardenability

- Refers to the depth and distribution of hardness induced by quenching not to the maximum hardness that can be attained in a given steel.
- Metals having low hardenability require faster cooling rates and can only be hardened to relatively shallow depths.
- Those with high hardenability can be hardened more deeply or completely through the material with slower cooling rates.
- Jominy end-quench test determines hardenability.

Through Hardening

- Harden the part all the way to its center.
- Primarily with tools and knives (items that need to be sharpened or refurbished)
- Difficult to do since the cooling rate is slower on the inside than the outside
- Possible with tools steels that have alloying elements which require a slower cooling rate to form martensite.

Case Hardening

- Case hardening provides a wear resistant surface and a soft ductile core.
- Carburizing
  - starts with an inexpensive low carbon steel
  - the steel is heated above the upper critical temperature and placed in a carburizing flame or carbon powder
  - the surface absorbs the carbon
  - after quenching the outside becomes harder because of the higher carbon content and the inside remains unchanged

Case Hardening

- Induction hardening
  - starts with a medium to high carbon steel
  - the part is place in an induction coil where the outside is heated without heating the inside
  - after quenching the outside becomes harder because it was heated above the upper critical temperature
- Nitriding
  - generally used on tools and dies without producing any distortion
  - the parts are heated in an ammonia atmosphere for 10 hrs at 900 F.
  - nitrides build up on the surface increasing its hardness

Softening

- Full Annealing
  - heating above the upper critical temperature and slow cooled (slower than air)
  - ultimate softness
- Normalizing
  - heating above the upper critical temperature and air cooling
  - faster but not at soft
- Tempering
  - heat from 100 F to 800 F and quench
  - remove some of the hardness
  - also know as drawing

Softening

- Stress Relieving
  - heat to 1000 F for 2 hours to remove the residual stress from welding or casting
- Recrystallization
  - heat into the recrystallization range to remove the effect of cold working (strain hardening)
- Spheroidizing
  - used on medium to high carbon steels to form the cementite (iron carbide) network into spheres
  - carbide spheres increase the metals ductility

Nonferrous Metals

- Nonferrous metals such as aluminum, copper and brass do not contain carbon and therefore do not form martensite when heated and quenched.
- Hardening
  - solution heat treating
  - strain hardening (cold working)
  - age hardening (precipitation)
- Softening
  - annealing (recrystallization)

Aluminum Heat Treatment

- Strain hardening
  - When a metal is deformed below its recrystallization temperature, it becomes harder.

Aluminum Solution Heat Treatment

- Solution treatment involves creating a solid solution of aluminum and an alloying element by heating and quenching.
- For example, if the aluminum-copper alloy 2017 is heated at 950 °F (510 °C) for 12 hours, a solid solution of aluminum and copper will form.
- The supersaturated solution is then formed by rapid quenching.
- The aluminum in this state has higher corrosion resistance and ductility however its hardness may be increased by a process known as precipitation hardening or aging.

Aluminum Precipitation(Aging) Hardening

- Precipitation hardening or aging takes solution heat treatment one step further.
- Precipitation hardening increases the aluminum hardness by the precipitation of very fine $CuAl_2$ particles after the aluminum-copper alloy is solution heat treated.
  - natural aging means that the precipitation of the $CuAl_2$ occurs at room temperature.
  - artificial aging implies that the precipitation occurs at an elevated temperature.
  - Overaging is possible if the aging time or temperature is too high and results in a lower strength and corrosion resistance.

Annealing Aluminum

- After aluminum has been strain hardened, annealing, or more specifically recrystallization, will return it to a soft and ductile condition.
- For example, heating 1100 aluminum at approximately 650 °F (345 °C) and quenching will restore its softness and ductility.
- The quenching rate is not important for pure aluminum.
- For wrought aluminum alloys of the precipitation hardening grades, 2017, the cooling rate must be 50 °F (10 °C) per hour or less to achieve the annealed condition.

Heat Treating Defects

- Scaling
  - Formation of surface oxides.
  - Requires machining, grinding, cleaning, or other methods of descaling.
  - Scaling can be minimized by using protective atmospheres in the heating furnaces.
- Residual Stresses
  - Can cause distortion, cracking, or breakage, especially after quenching and before tempering.
  - Result from the nonuniform contraction of heated parts during cooling, expansion during transformation, or a combination of the two.

Heat Treating Defects

- Quench Cracking
  - As the carbon content of a steel increases, the tendency to crack increases.
  - Steels with coarser grain size are more susceptible to cracks than fine-grained steels.
  - Severe cooling media, such as water or brine, may sometimes result in more cracking than quenching in a slower cooling medium, such as oil.

Heat Treating Defects

- Retained Austenite
  - Austenite that is not transformed during the heat treating cycle is soft and weak, and lowers the overall hardness of the steel if excessive in amount.
  - Cold treating—cooling the quenched parts to temperatures below freezing where transformation of austenite to martensite proceeds to completion.

Heat Treating Defects

- Decarburization
  - Steel parts are often decarburized to some extent during heating for hot forming operations, such as rolling, extruding, and forging.
  - The loss of surface carbon may prevent attaining full hardness in the finished parts.
  - Decarburization during heating can be eliminated by using protective atmospheres in the furnaces.

Deburring

- Hand Deburring
  - files
  - brushes
  - rotary burrs
- Automatic Deburring
  - chamfering
  - barrel tumbling
  - chemical deburring
  - liquid honing
  - thermal vaporizing

Plating

- Electroplating
  - electrolytic process in which metal ions in an electrolyte are deposited onto a cathodic workpiece.
  - 0.002 in thickness
- Electroforming
  - same as electroplating except the metal ions are deposited onto a pattern until a certain thickness is reached

Inorganic Coatings

- Chemical conversion coatings
  - a thin film of oxide, phosphorous or chromate is formed on a metallic surface by chemical reaction
- Anodizing
  - electrolytic treatment that produces a stable oxide layer on a metal surface
  - the work is the anode and the tank is the cathode
  - 0.0001 to 0.003 in.
- Hot dipping
  - zinc hot dipping of galvanizing dips chemically cleaned metal into molten zinc
  - 0.0016 to 0.0035 in.

Inorganic Coatings

- Chemical vapor deposition
  - involves the interaction between a mixture of gasses and the surface of a heated substrate causing a chemical decomposition of some of the gas constituents and formation of a solid film on the substrate

Organic Coatings

- Coating components
  - polymer (binder)
  - solvent (adjust the viscosity)
  - pigment (add color)
  - additives (thickeners, etc.)
- Powder coating
  - applied as dry pulverized particles that are melted onto a part’s surface and then solidify into a dry coating
  - thermoset or thermoplastic powders
  - electrostatic spraying or fluidized bed application

Painting Terminology

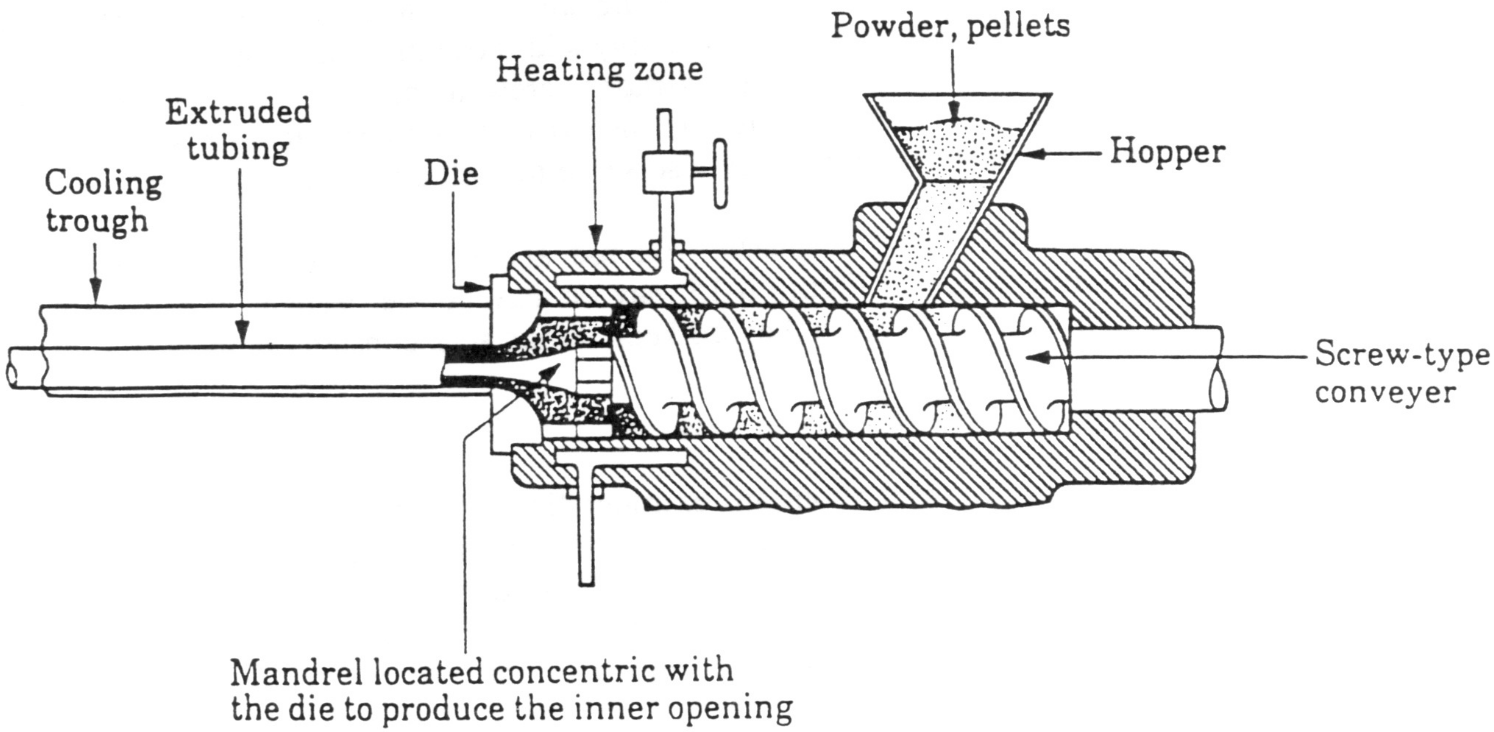
- Orange peel is a term descriptive of a surface finish where the coating has not flowed out or "leveled" to a perfectly smooth finish, leaving the paint with the pebbled appearance of the skin of an orange.
- Runs and sags are areas where excess coating has been applied to quickly and the liquid has run down in sheets.
- Holidays are small bare spots left by oily or greasy surface spots.
- Fish eyes are small, under 0.1“ (3 mm) diameter, raised or crater like areas around a central thin spot caused by a tiny oil drop or surface contamination from silicones.

Plastic Processing

- Extrusion
- Blow molding
- Injection molding
- Reaction injection molding
- Thermoforming sheet and film
- Rotational molding
- Casting
- Compression and transfer molding

Extrusion

- Extruders are sized by the diameter of the screw and the horsepower of the drive motor.

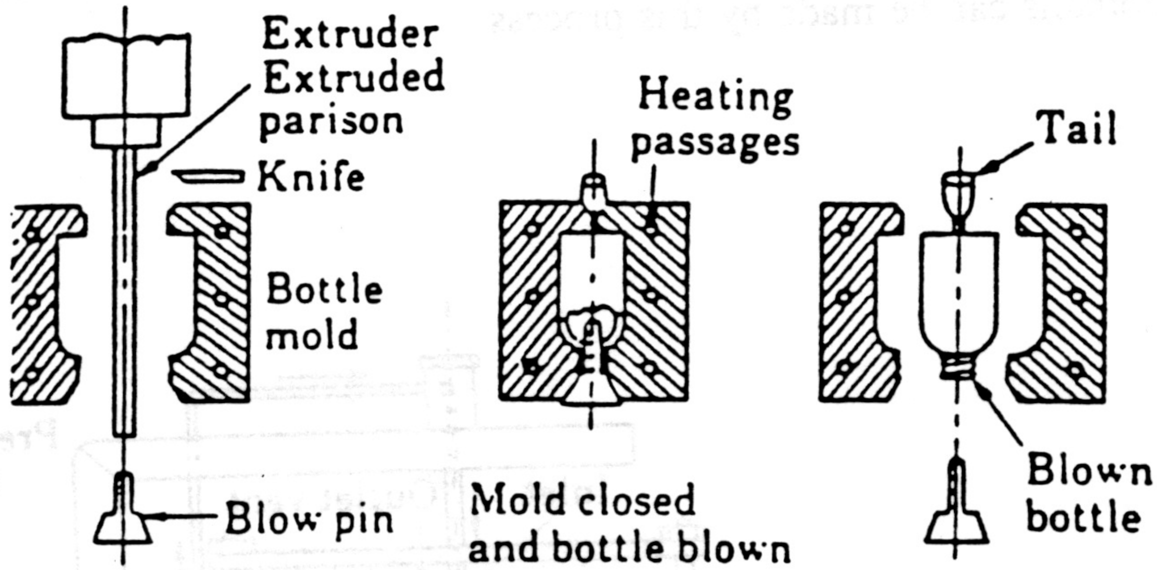


Extrusion Products

- Extrusion processes are categorized by the general shape of the products.
  - profile extrusion
  - pipe extrusion
  - sheet extrusion
  - film extrusion
  - filament extrusion
  - wire coating.
- The most commonly extruded materials are rigid and flexible vinyl, ABS, polystyrene, polypropylene, and polyethylene.

Extrusion Blow Molding

- The process can be identified by the line across the bottom of the container which shows where the parison was pinched-off.



Injection Blow Molding

- In injection blow molding, a parison is created by injection molding.
- Extrusion blow molding can not produce threads that are strong enough and accurate enough to hold the pressure exerted by the carbonation.
- Precision, strong threads are injection molded into the parison, and then the blowing process creates the major shape of the bottle.

Injection Molding

- Injection molding is a versatile process for forming thermoplastic and thermoset materials into molded products of intricate shapes, at high production rates, and with good dimensional accuracy.
- The basic injection molding process involves injecting, under high pressure, a metered quantity of heated and plasticized material into a relatively cool mold-in, which is solidified by the plastics material.

Injection Molding Machines

- Injection molding machines are described by the shot size and the clamp tonnage.
  - Shot size is the maximum amount of material the machine can inject per cycle.
  - Clamp tonnage is the amount of force the machine can generate to squeeze a mold together.
  - If the clamp is not great enough, the mold will open slightly when the plastic is injected, creating flash around the parting line.

Reaction Injection Molding

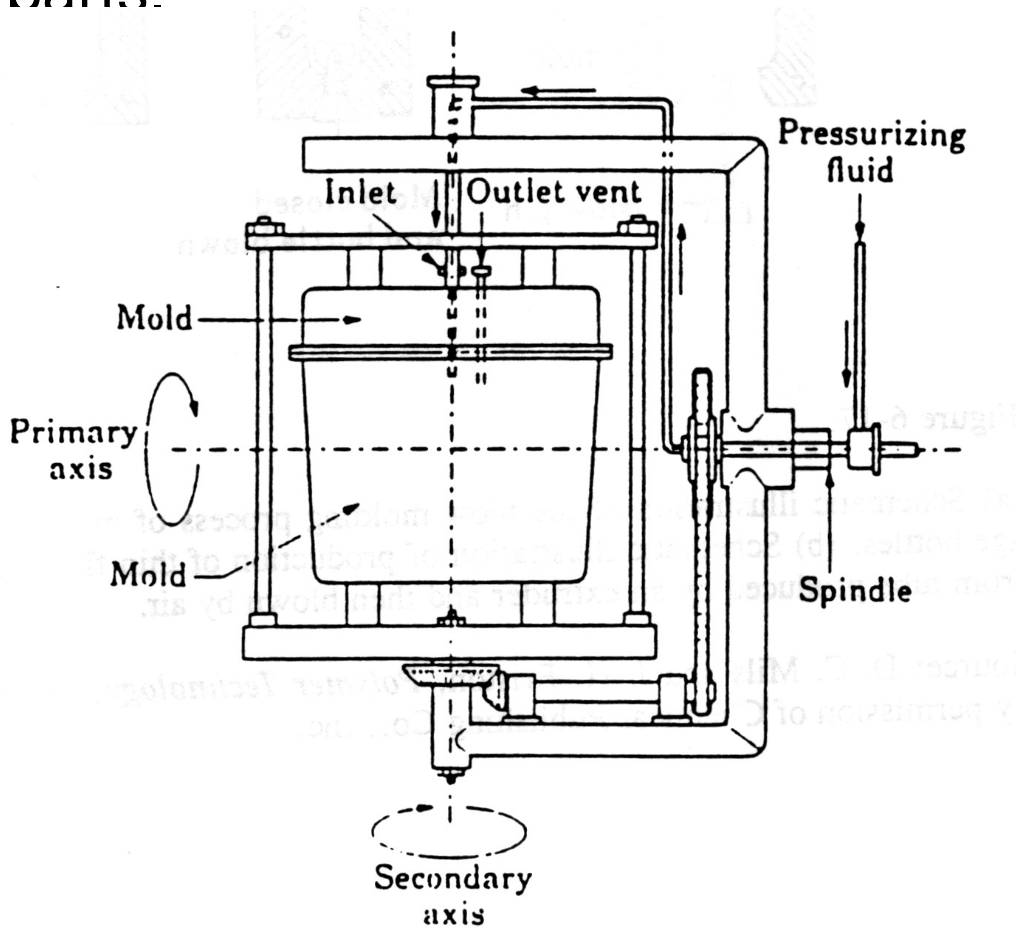
- Reaction injection molding (RIM) is a form of injection molding that brings temperature and ratio-controlled, liquid reactant streams together under high-pressure to form a polymer directly in the mold.
- A chemical reaction produces the plastics as it forms the part.

Thermoforming Sheet and Film

- Thermoforming consists of heating a thermoplastic sheet to its processing temperature and forcing the hot, flexible material against the contours of a mold.
- Capability of forming light, thin, and strong parts for packaging and other uses.
- Capability of making large, one-piece parts with relatively inexpensive machinery and tooling.

Rotational Molding

- Rotational molding is a process for forming hollow plastics parts.



Compression Molding

- Thermoset molding compounds, when placed within the confines of a mold (generally hardened steel), are subjected first to heat to plasticize and cure the material then to pressure to form the desired shape.

Transfer Molding

- Transfer molding is an extension of compression molding.
- In transfer molding unpolymerized material is placed in a transfer pot and melted.
- A plunger forces the molten plastic into a die cavity.
- Temperature and pressure are maintained until the resin has cured.
- This process produces thin-walled, intricate shapes similar to injection molding.

Composite Fabrication

- Continuous Fibers
  - hand lay-up
  - laminating
  - resin transfer molding
  - filament winding
  - pultrusion
- Short Fibers
  - injection molding
  - spraying

Laminating

- Advanced composites are typically used in the form of laminates and are processed by starting with a prepreg material (partially cured composite with the fibers aligned parallel to each other).
- A pattern of the product's shape is cut out, and the prepreg material is then stacked in layers into the desired laminate geometry.
- A final product is obtained by curing the stacked plies under pressure and heat in an autoclave.

Filament Winding

- Fibers or tape are drawn through a resin bath and wound onto a rotating mandrel.
- Filament winding is a relatively slow process, but the fiber direction can be controlled and the diameter can be varied along the length of the piece.
- With both the fiber and tape-winding processes, the finished part is cured in an autoclave and later removed from the mandrel.
- Filament winding is used to produce round or cylindrical objects such as pressure bottles, missile canisters, and industrial storage tanks.

Pultrusion

- In composites technology, pultrusion is the equivalent of metals extrusion.
- Pultrusion (also called pultruding), consists of transporting a continuous fiber bundle through a resin matrix bath and then pulling it through a heated die.
- The process can be used to make complex shapes; however, it has been limited to items with constant cross sections, such as tubing, channels, I-beams, Z-sections, and flat bars.

Resin Transfer Molding

- In the conventional RTM process, two-piece matched cavity molds are used with one or multiple injection points and breather holes.
- The reinforcing material, either chopped or continuous strand mat, is cut to shape and draped in the mold cavity.
- The mold halves are clamped together, and a polyester resin is pumped through an injection port in the mold.
- Compared with the spray-up method, RTM permits faster cycle times and usually requires less labor.

Clay Processes-Slip Casting

- Slip Casting requires the clay to be prepared as slip which is a suspension of clay in water.
- Slip casting involves pouring or pumping slip into a porous mold, most commonly made of plaster.
- The plaster molds rapidly draw the water out of the slip, leaving a uniform layer of clay on the surface of the mold.
- For large, hollow shapes, the slip is emptied out of the mold once the desired wall thickness has been achieved.
- When the clay has dried to a leathery consistency, the mold is removed and product finished.

Clay Processes-Plastic Forming

- Throwing involves the use of a potters wheel. While some thrown products are hand-thrown, mechanical devices have partially automated this process.
- Jiggering is a process that forms one side of a clay product, such as a plate, with a plaster mold and the other side using a metal template.
  - as the blank of clay rotates on the mold, the profile is determined by the template
- Extrusion is a process used in the manufacture of clay pipe and drainage tiles.
  - an auger or ram forces the clay through a tubing die

Clay Processes-Dry Powder Pressing

- Similar to powdered metals, dry powder pressing compacts clay powder with a very low moisture content (4%) between two dies.
- Dry powder pressing works very well for the continuous production of dimensionally accurate products such as plates.

Crystalline Ceramic Processing

- Crystalline ceramics are very hard and brittle and have very high melting points.
- They are compacted as powder into the desired shape.
  - dry pressing with a ram
  - isostatic pressing
  - hot-isostatic pressing
- Isostatic pressing, which involves the use of a flexible cover and pressurized hydraulic oil, is that the pressure compacts the powder in all directions.
- Automotive spark plugs are an example of isostatic pressing.

Printed Circuit Boards

- Fabrication
  - schematic capture of an electronic design that meets specifications
  - with a CAD program and component selection the schematic is transformed into a board layout with component placements and conductor pathways or traces
  - circuit boards are made from copper laminated to a fiber glass substrate
  - circuit traces are produced by selectively etching the copper

Component Placement

- Through-Hole Technology (THT)
  - component sequencing
  - auto insertion
  - wave solder
- Surface Mount Technology (SMT)
  - component pads on the circuit board are coated with solder paste by stencil printing
  - components are placed by a pick-and-place robot
  - reflow soldering heats the board and components untill the solder melts and secures each component

Part 4
Production Systems

Production Environments

- Manufacture to stock
  - Customer orders are typically filled from existing stocks and production orders are used to replenish those stocks.
  - Examples of manufacture-to-stock products are consumer goods such as televisions, power hand tools, lunch boxes,

Production Environments

- Assemble to order
  - Where a product can be assembled after receipt of a customer's order.
  - The key components used in the assembly or finishing process are planned, and possibly stocked, in anticipation of a customer order.
  - Examples of assemble-to-order products are automobiles, office furniture, and retail display units.

Production Environments

- Manufacture to order
  - A product can be made after receipt of a customer's order.
  - As a rule, this environment relies heavily on standard components and often on simple, custom variations of similar parts.
  - Industrial punch presses, vehicle chassis, and standard conveyor systems are typically made-to-order.

Production Environments

- Engineer to order
  - Products whose customer specifications require unique engineering design or significant customization.
  - Each customer order results in a unique set of part numbers, bills of material, and routings."4
  - Examples include products such as custom-designed capital equipment, stamping dies, plastic molds, and space shuttles.

Traditional Production Planning and Control Elements

- Forecasting
- Aggregate production planning
- Master production scheduling
- Rough-cut capacity planning
- Final assembly scheduling
- Process planning

Forecasting

- Forecasting is predicting future demands.
- The shorter the forecast period the more accurate the forecast.
- Total company forecast can be more accurate than a specific product line forecast.
- Forecast error is always present.
- No single forecast method is best.

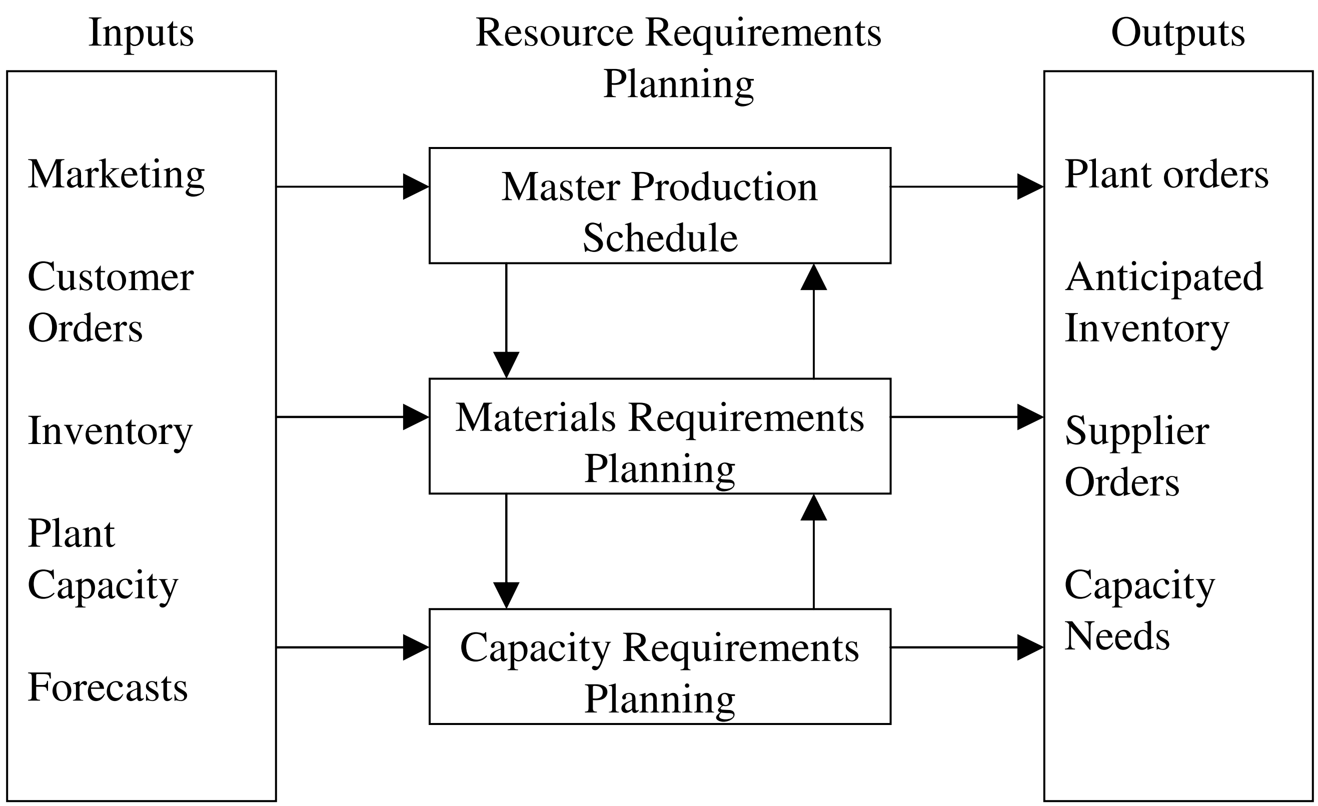
Aggregate Production Planning

- Monthly or quarterly production requirements for product groups or families that will meet the estimated demand.
- A sport-shoe manufacturer may consider broad product lines such as tennis shoes, aerobic shoes, and high-top basketball shoes in developing an aggregate production plan.
- Forecasting drives the aggregate production plan.

Master Production Schedule (MPS)

- The master production schedule is the time phased requirements for individual products.
- Typically weekly requirements over a 6-12 month horizon.
- The MPS translates the aggregate plan into a separate plan for individual items.

Master Production Scheduling



Planning Horizons in MPS

- Frozen
  - cannot be changed
- Firm
  - not quite frozen
- Full
  - costs would be minimal if orders were changed
- Open
  - capacity is not fully allocated

Material Planning

- Time-Phased Planning
  - thought of as “batch” manufacturing
  - results in higher capacity utilization, however, it generates high overhead and work-in-process costs
  - MRP (Material Requirements Planning) is an example of a time-phased planning system
  - also known as a “push system”
- Rate-Based Planning
  - decreases overhead and work-in process costs, however, it decreases capacity utilization.
  - just-in-time (JIT) is a rate-based system
  - also know as a “pull system”

Material Planning

- The purpose of material planning is to answer these questions:
  - what do we need?
  - how much?
  - when?
- Quantity Based Approach
  - reorder points
  - two-bin system
- Time Phased Approach
  - material requirements planning (MRP)

Reorder Points

- Reorder points are determined by calculating the average demand during the replenishment lead time, plus safety stock.
- The resulting figure is compared against available daily inventory, which is the sum of stock on hand plus existing schedules.
- Whenever the re-order point is equal to or greater than the available inventory, a message to replenish is generated.
- Safety stock is used as protection against two types of uncertainties: forecast inaccuracy (representing uncertainty of demand) and unreliable completion of schedules (representing uncertainty of supply).

Two-Bin System

- Does not require daily inventory transactions to be recorded.
- It separates inventory into two locations, and whenever one becomes empty, it triggers a reorder for more material.
- The second bin must contain adequate inventory to satisfy the average demand during the replenishment lead time, plus safety stock.

Material Requirement Planning (MRP)

- MRP determines the requirements and schedule for (1) manufacturing the components and subassemblies, and/or (2) purchasing the materials needed in order to meet the requirements of the master production schedule.
- The purpose of MRP is to ensure that materials and all individual parts and subassemblies are available in the right quantities and at the right times.

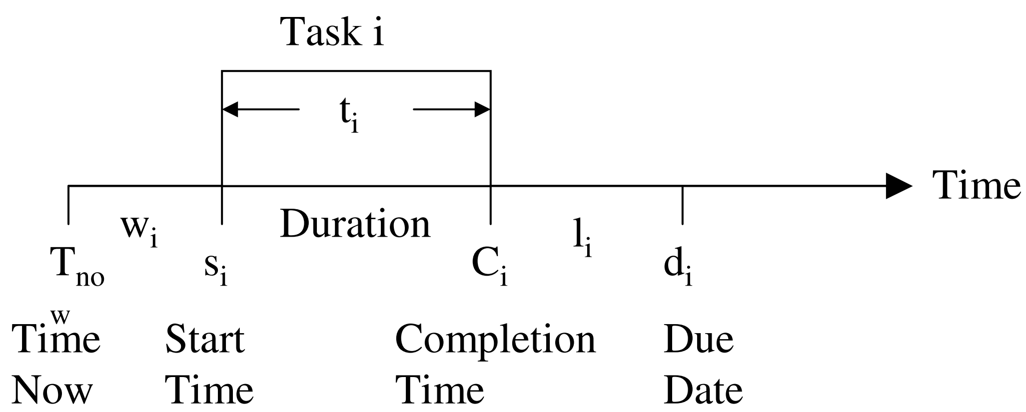
MRP Data Sources

- Inputs to the MRP process include:
  - inventory balances
  - bills of materials(product structure record)
  - process routings
  - shop-order status by operation
  - purchase order status by item and date
  - customer order data
  - forecasting and master schedule
  - work center data

Job Shop Scheduling

- Task
  - also called an operation, requires only one resource
- Job
  - consists of a number of tasks

Scheduling Time Line



- T_{now}, time now
- w_i, wait time
- s_i, start time for task i
- t_i, task duration
- C_i, Completion time
- l_i, lateness
- d_i, task due date

Scheduling Rules

- Assumptions
  - all jobs are independent
  - raw material is always available
  - no interruptions
  - no downtime

Schedule Evaluation

- Mean Wait Time (MW)
  - how long do jobs wait before they are performed
- Mean Flow Time (MF)
  - how long has the job spent in the system
- Mean Lateness (ML)
  - can be zero if half the jobs are early and half are late
- Mean Tardiness (MT)
  - mean of only the jobs that were late

Scheduling Rules

- Shortest Processing Time (SPT)
  - minimizes MF, ML, and MW
- Earliest Due Date (EDD)
  - minimizes max lateness (XL) and max tardiness (XT) but increases ML
- Shortest Slack Time (SLT)
  - addresses amount of remaining work
- Critical Ratio (CR)

$$CR_i = \frac{\text{due date - time now}}{\text{lead time remaining}} = \frac{d_i - T_{now}}{(s_i + t_i) - T_{now}}$$

Capacity Planning

- After the master production schedule has been formulated, rough-cut capacity planning is done to determine its feasibility and where bottlenecks will occur.
- Limitations in machine capacity, labor capacity, and supplier capacity may require changes in the master production schedule to be made.
- A much more detailed capacity plan can be generated using capacity requirements planning (CRP).

Capacity Requirements Planning (CRP)

- CRP differs from rough-cut capacity planning in that it uses time-phased information from the MRP system.
- CRP considers work-in-process when calculating workcenter capacities.
- CRP also includes the demand not accounted for in the MPS such as replacement parts.

Physical Capacity

- Physical capacity is plant capacity.
- Physical capacity depends on:
  - product mix
  - scheduling
  - equipment

Resource Utilization

$$\text{Utilization} = \frac{\text{Busy Time}}{\text{Total Time}}$$

- If utilization < 1, then resource is underutilized (over capacity).
- If utilization = 1, then resource is at capacity.
- If utilization >1, then resource is overutilized (under capacity).

Manufacturing Resource Planning (MRP II)

- Approach for planning and scheduling all of the resources that manufacturing companies need.
  - aggregate planning
  - master scheduling
  - material planning
  - capacity planning
  - shop scheduling
  - supplier scheduling

Process Planning

- determining the processes to be used
- development of operation flow charts
- production layouts
- routings
- operation (process) sheets
- setup charts and machine tool layouts
- equipment selection and sequence
- material handling details
- tooling requirements
- inspection plans for quality assurance and quality control
- production cost analysis

Process Planning

- In process planning the general characteristics of the part, such as the general part configuration, material, surface finish, and tolerances, must be determined first.
- These characteristics will effect:
  - part handling
  - type of tooling
  - type of machines
  - sequence of operations
  - assembly
  - rate of production

Tolerance Stacks

- A tolerance stack is when acceptable tolerances on individual dimensions combine in such a way as to create an unacceptable part or assembly.
  - Design tolerance stacks are created by the designer and found on the part print.
  - Process tolerance stacks are the result of improper processing.

Process Selection

- Process selection is dependent on
  - wall thickness
  - symmetry
  - draft, cavities
  - surface finish
  - tolerances
  - material
- Fundamentally, the best process is the one that meets the requirements with the least amount of money.
- In reality, many other constraints such as capability, versatility, and maintenance etc. confound the issue.

Equipment Selection

- General-Purpose Machines
  - less expensive, more flexible, require less maintenance, and require less debugging time than special purpose machines
  - drill presses, milling machines, etc.
- Special-Purpose Machines
  - create unique part geometries faster and with higher quality than general-purpose machines

New Machine Acquisition and Installation Factors

- The position should facilitate the manufacturing process and maximize machine utilization.
- Minimize
  - material handling
  - direct and indirect labor
  - work in progress
  - equipment investment
- Some flexibility should be maintained.
- A safe and convenient workspace should be created.

Computer-Aided Process Planning

- Variant
  – Develops a process plan by modifying an existing plan that is selected using group technology principles, namely coding and classification.
- Generative
  – The database includes a body of manufacturing logic, the capacities of existing machinery, standards and specifications.
  – Based on the part description (geometry and material) and finished specifications, the computer then selects from this stored knowledge the optimum method of producing the part and automatically generates the process plan.

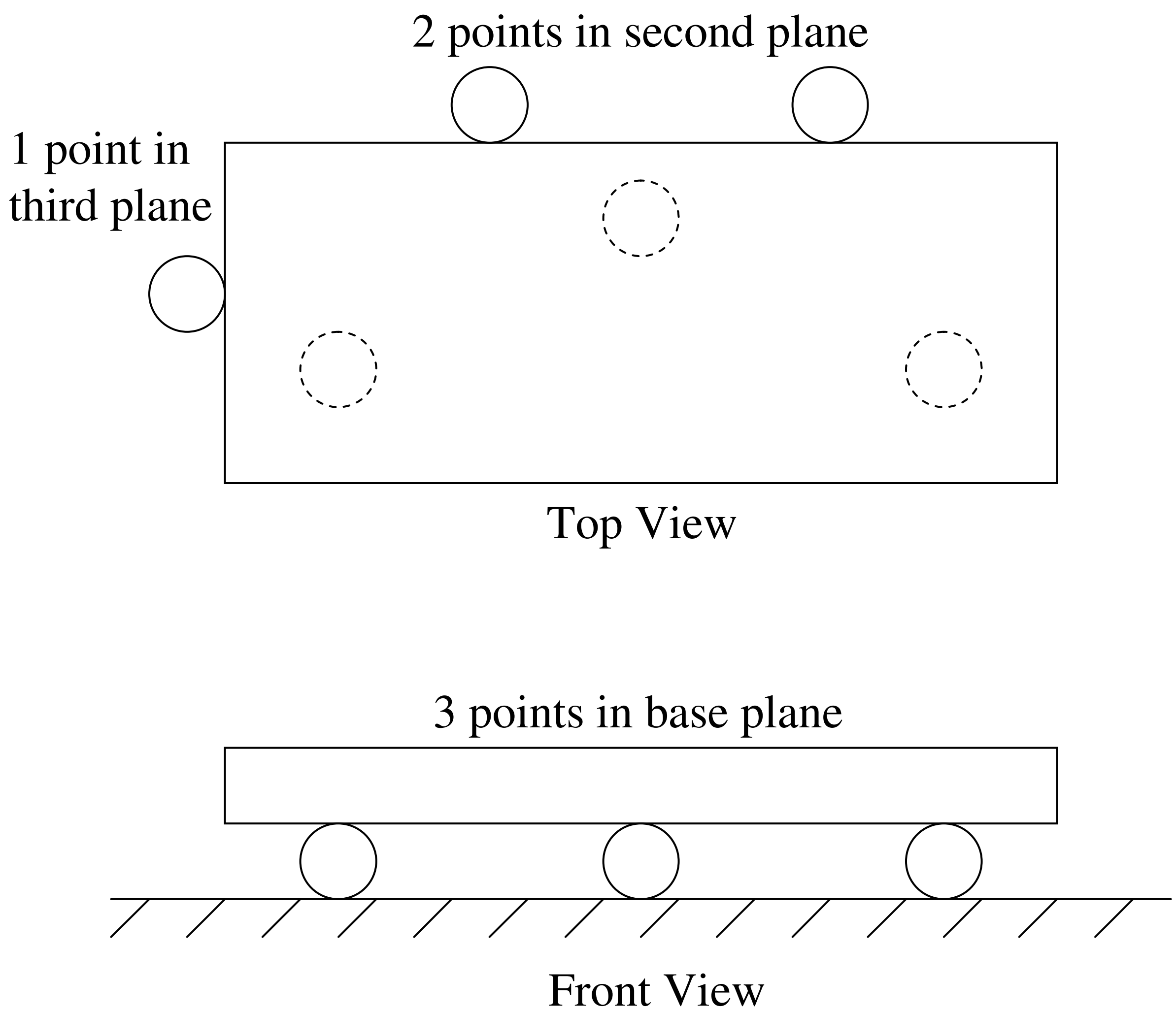
Jigs/Fixtures/Locating

- Jig
  - a device for locating and holding a workpiece while guiding or controlling a cutting tool
- Fixture
  - locating and holding device only

Fixtures

- 3-2-1 Principle
  - to completely confine a part one plane must located with 3 points, the second with 2 points and a third with one point
- Fixtures must confine a part through six degrees of freedom, 3 linear and 3 rotational.

3-2-1 Principle



Locating Principles

- Cutting forces should be directed toward the part locators.
- Locating points should be spread out as far as is practical to provide a stable locating surface.
- Part locators should be designed and placed in such a manner as to ensure the repeatability of the part's location from one workpiece to the next.
- Locators should always contact a workpiece on a solid and stable point.

Locating Devices

- Machined surface on the fixture
  - hardened rest buttons can also be used
- Pins
  - pins can be shortened or have three flats cut to form a diamond pin for reducing jamming
- V-blocks

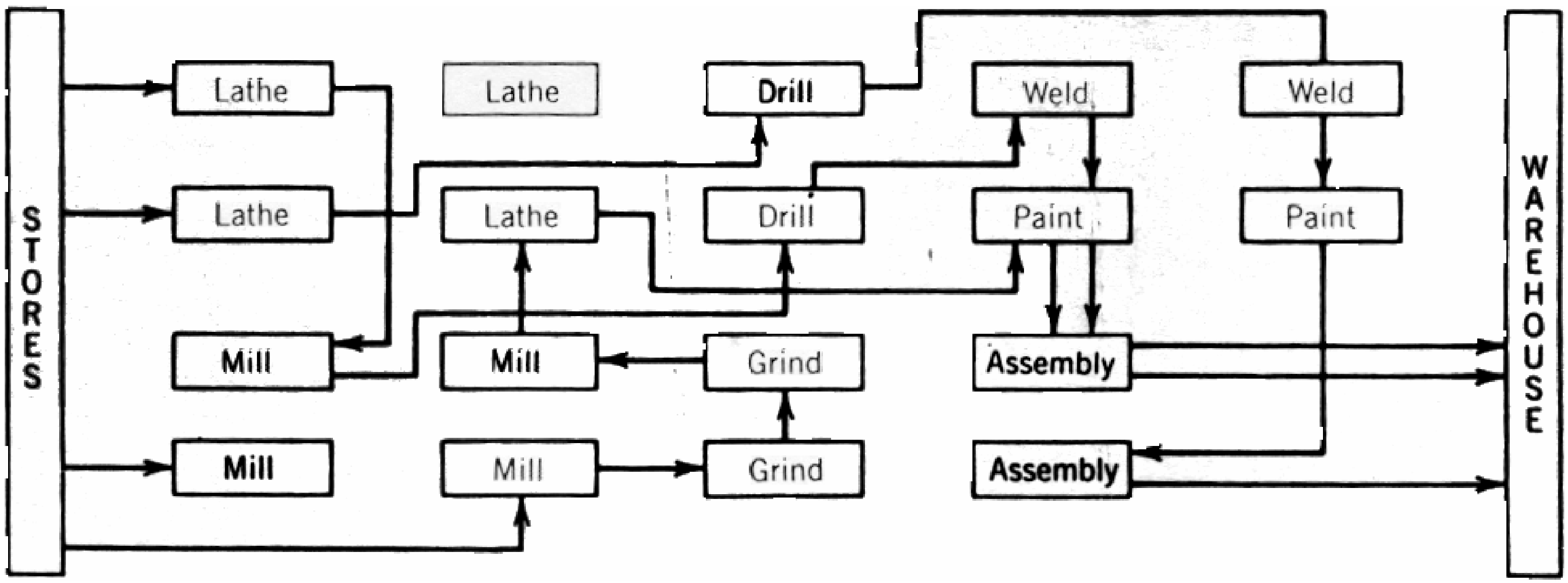
Clamps

- Clamping force should be transmitted through a fixed support point on the workpiece in a manner that does not distort the workpiece.
- Clamps should be in line with the action forces of the cutting tool as much as possible.
- Clamps should be integral parts of the device
- Types of clamps
  - screw, cam, level
  - toggle, wedge, latch

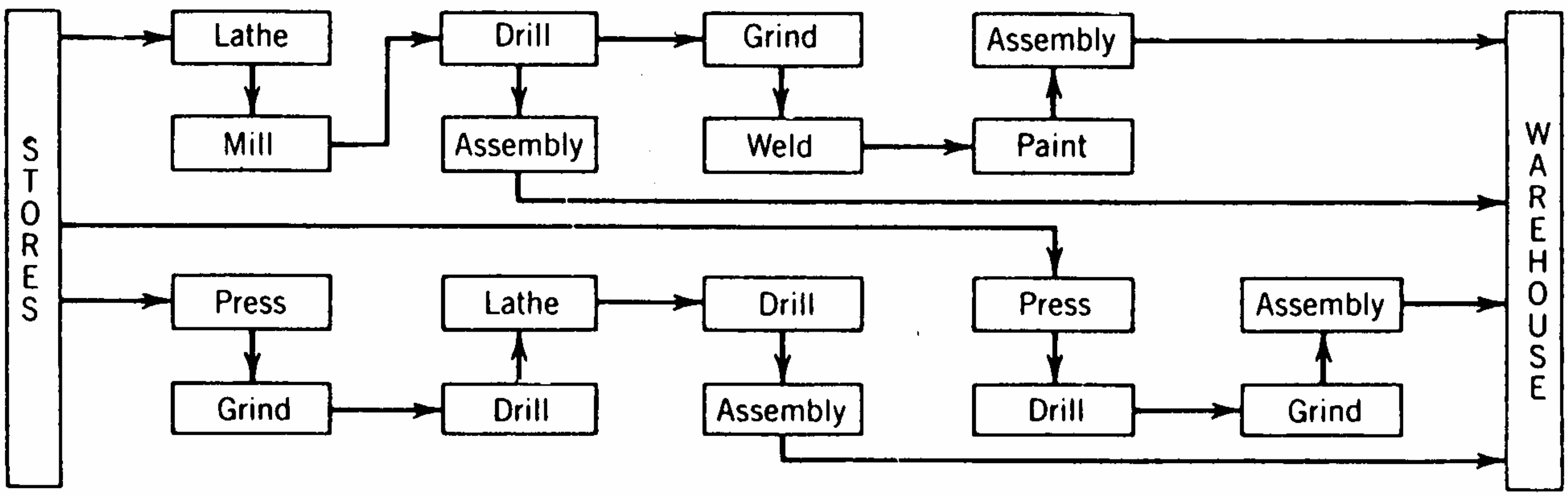
Assembly

- Single-Station Assembly
  - specific operation performed many times on one or a few parts
- Synchronous Assembly (indexing)
  - all workpieces are moved at the same time and the same distances
  - high volume
- Nonsynchronous Assembly
  - floating or free pallets or workpieces are moved independently
  - the times required to perform different operation vary greatly
- Continuous-motion Assembly
  - assembly operations are performed while the pallets or workpieces are moving at a constant speed

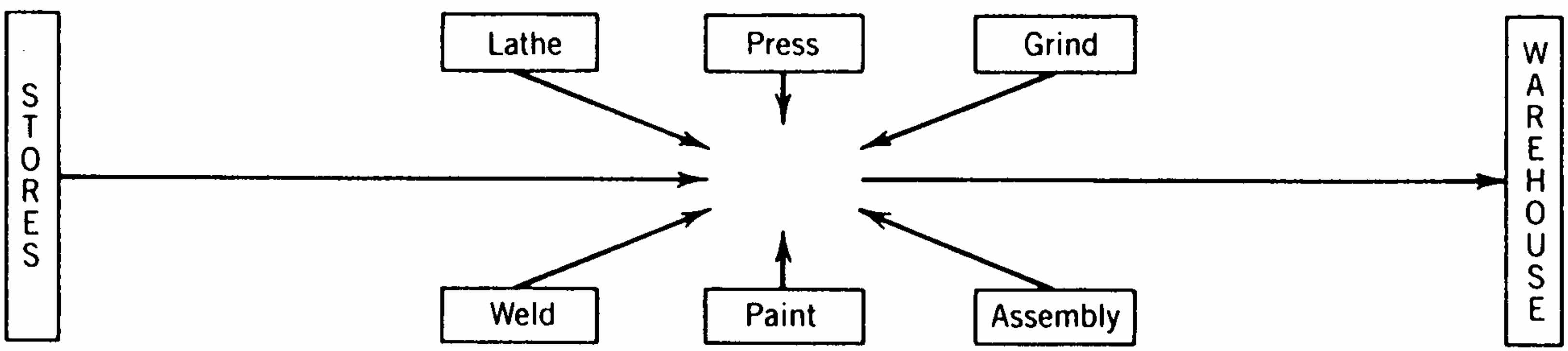
Process Layout



Product-Process (Cellular) Layout



Fixed Production Layout



Total Productive Maintenance

- Total productive maintenance is a management technique that involves everyone in a plant or facility in equipment or asset utilization.
- Is it possible to produce quality products on poorly maintained equipment?
- Can a JIT program work with equipment that is unreliable or has low availability?

Total Productive Maintenance

- Can employee involvement programs work for long if management ignores the pleas to fix the equipment or get better equipment so a "'World Class" product can be delivered to the customer on a timely basis, thus satisfying the employee concerns and suggestions?

Total Productive Maintenance (TPM)

- Corrective maintenance (reactive)
  - complete repairs when something breaks down.
- Preventative maintenance
  - scheduled maintenance to prevent future break downs
- Predictive maintenance
  - utilization of sensors to predict future break downs and make repairs just prior to a breakdown

Overall Equipment Effectiveness (OEE)

Equipment Effectiveness = Availability x Performance Rate x Quality Rate

Availability

$$\text{Availability} = \frac{\text{required availability - downtime}}{\text{required availability}}$$

- The required availability is the time production is to operate the equipment, minus the miscellaneous planned downtime, such as breaks, scheduled lapses, meetings, etc.
- The downtime is the actual time the equipment is down for repairs or changeover.

Performance Rate

$$\text{Performance Rate} = \frac{\text{design cycle time} \times \text{output}}{\text{operating time}}$$

- The design cycle time will be in a unit of production, such as hours per part.
- The output will be the total output for the given time period.
- The operating time will be the availability from the previous formula.

Quality Rate

$$\text{Quality Rate} = \frac{\text{production input - quality defects}}{\text{production input}}$$

- The product input is the unit of product being fed into the process or production cycle.
- The quality defects is the amount of product that is below quality standards after the process or production cycle is finished.

Example OEE Calculation

- The press was scheduled to operate 15 8-hour shifts per week.
- This gave a total possibility of 7200 minutes of run time per week.
- Planned downtime for breaks, lunches, and meetings totaled 250 minutes.
- The press was down for 500 minutes for maintenance for the week.
- The changeover time was 4140 minutes for the week.
- The total output for the operating time was 15,906 pieces.
- The design cycle time was 9.2 pieces per minute.
- There were 558 rejected pieces for the week.

Example OEE Calculation

- Gross time available $8 \times 60 \times 15 = 7200\,\text{min}$
- Total down time $250 + 500 + 4140 = 4890\,\text{min}$
- Availability $\dfrac{7200 - 4890}{7200} \times 100 = 33\%$
- Design cycle time $\dfrac{1}{9.2} = 0.109$
- Performance rate $\dfrac{0.109 \times 15,906}{7200 - 4890} \times 100 = 75\%$

Example OEE Calculation

- Quality rate $$\frac{15,906-558}{15,906}\times 100=97\%$$
- OEE $$(0.33\times 0.75\times 0.97)\times 100=24\%$$

Inventory Management

- Inventory management consists of three components:
  - management of raw materials and purchased parts
    - purchasing, receiving and retrieval
  - management of finished goods
    - packaging and shipping
  - management of materials during the conversion process
    - handling and storage of work in progress materials

Major Costs of Inventory

- Procurement Costs
  - cost associated with ordering and obtaining parts
- Carrying Costs
  - opportunity cost
  - warehouse cost
  - cost of spoilage, obsolescence, etc.
  - insurance

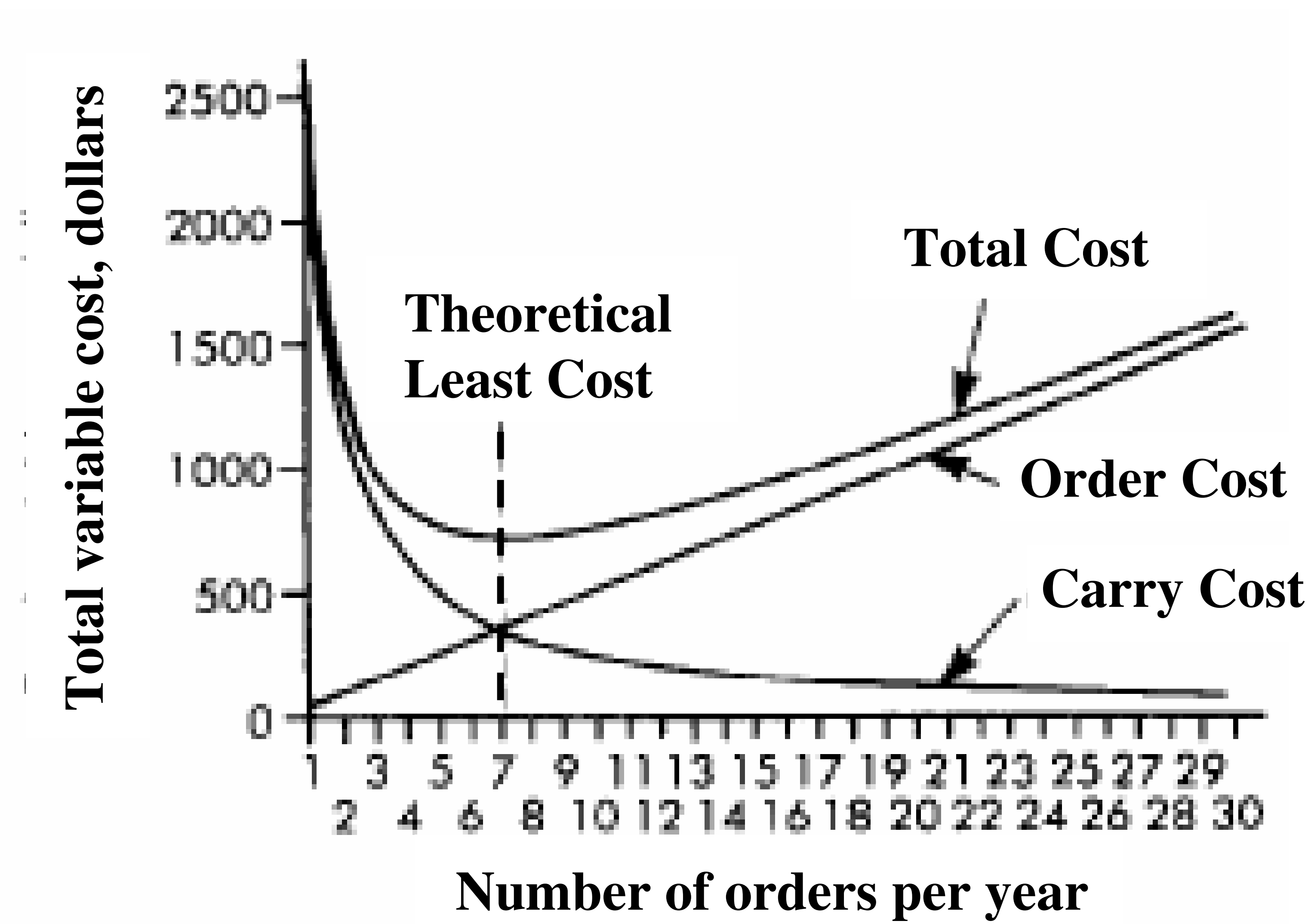
Inventory Management

- Independent demand is unrelated to the demand for other items.
- Dependent demand is derived from the demand for other items.

Inventory Management

$$\text{Inventory turns} = \frac{\text{Annual inventory usage \$ at cost}}{\text{Average inventory \$at cost}}$$

Economic Order Quantity (EOQ)



Economic Order Quantity (EOQ)

- EOQ attempts to balance inventory carrying costs with ordering costs.

  A = Annual usage

  S = setup and order costs per order

  i = interest and storage cost percentage

  c = unit cost of one part

$$EOQ = \sqrt{\frac{2AS}{ic}}$$

ABC Analysis

- Requires sorting of items by the amount of dollar demand (at cost) recorded over some past period.
- Based on Pareto analysis, it is usually observed that only about 20% of the items in any inventory will be involved in 80% of the usage measured by dollars.
- If this top 20% is managed carefully, the lower dollar items can be handled less often with little effect on the total dollar investment.
- The result of such policies and procedures is that the high dollar volume items get the most attention.

ABC Analysis

- Basing inventory policies on the ABC analysis results in items being given replenishment rules like the following:
  - Review A items weekly, and order one week's supply when less than a lead time plus one week's supply remains.
  - Review B items biweekly, and order four weeks' supply when less than a lead time plus two weeks' supply remains.
  - Review C items monthly and order 12 weeks' supply when less than a lead time plus 3 weeks' supply remains.

ABC Analysis

Number of Parts	Cost	Percent	Inventory Category
6	680,000	68	A
16	200,000	20	B
80	120,000	12	C

Material Handling

- Basic Elements of Material Handling
  - motion of materials
  - time to move materials
  - quantity of materials
  - space in which the materials are moved
- Material Handling Impacts
  - quality of the product
  - facility requirements
  - safety
  - productivity

Types of Loads

- Unit Load
  - large parts
  - quantity of smaller pieces combined on a pallet
- Bulk Load
  - materials handled by conveying systems, bins or hoppers

Symptoms of Inefficient Material Handling

- Disorganized storage
- Material stored in the aisles
- Long hauls
- Excessive walking
- Repetitive handling
- Lack of parts and supplies

Lean Production

- Lean (as opposed to mass) production uses less of everything:
  - half the human effort in the factory
  - half the manufacturing space
  - half the investment in tools
  - half the engineering hours to develop the product in half the time
  - inventory levels are far lower as are defect rates

Lean Production

- “Lean” inventory levels are continually reduced to deliberately reveal flaws in the system.
- Lean production employs teams of multiskilled workers at all levels of the organization
- Lean uses highly flexible machines to produce high volumes and high variety.

Mass Production

- Mass production uses narrowly skilled professionals to design products made by semiskilled workers tending expensive, single purpose machines at high volumes;
- Changes are expensive and infrequent and production buffers are needed to smooth production;
- Mass production yields low costs to consumers for standard designs.
- Mass production sets "acceptable " level for defects while lean systems set their sights on perfection.
- Mass production systems are relatively static once launched while lean systems are dynamic and intent on continuous improvement.

Lean Components

- Value Stream Analysis
  - set of all the specific actions required to bring a specific product through the three critical management tasks:
    - problem solving: running from concept through detailed design and engineering to production
    - information management: running from order taking through detailed scheduling to delivery
    - physical transformation: proceeding from raw materials to a finished product in the hands of the customer

Lean Components

- Value stream analysis will help to identify:
  - unambiguous value-adding steps
  - steps which do not add value but which are unavoidable
  - steps which create no value and are immediately avoidable
- Takt Time
  - (Takt = rhythm or beat in German) How often you should produce your product based on the rate of sales to meet customer requirements.
  - Takt time is your available work time per shift divided by customer demand rate per shift.

Lean Components

- Kanban (Card system)
  - The type and quantity of units are written on a tag-like card that is sent from workers of one process to workers of the preceding process.
  - When all the parts in a lot have been used, the card becomes the mechanism for reorder.
- Kaizen
  - Ongoing improvement involving everyone, both managers and workers.

Lean Components

- Visual Control
  - A worker uses his/her eyes to monitor the state of the line and the flow of production.
  - The operator either seeks help or “closes the loop” if an abnormality appears.
  - Visible inventory/kanban tickets, foolproofing by paint color or light, and Andon or call lights.
- Total Productive Maintenance
  - Machines must be in safe operating condition, have predictable process capability and uptime.
  - Proactive, preventative (total) maintenance programs use both operators and skilled trades to achieve these goals.

Lean Components

- One-Piece Flow
  - A worker completes a job within a specified cycle time; the introduction of one unit is balanced by the completion of another unit of finished product.
  - This flow reduces inventory, reduces lead-time, and attunes production mix and volume to sales.
- Error Proofing (poka-yoke)
  - One-piece flow and autonomation in response to kanban pull requires that the system prevent errors.
  - Using techniques such as visible control and mistake-proof part loading, error proofing attempts to eliminate mistakes by making it impossible to do a job incorrectly.

Lean Components

- Standardization
  - The standard operation shows the sequential routine of various operations taken by a worker who handles multiple kinds of machines as a multi-functional worker.
  - Jobs are standardized across operators and shifts.
- Autonomation
  - Autonomation means to build in a mechanism to prevent mass-production of defective work.
  - Autonomation is the autonomous check of the abnormal in the process.

Lean Components

- Production Leveling
  - Producing too much is waste, producing too little does not meet customer needs.
  - Overtime and fatigue cause waste.
  - Production leveling (reduced to takt time for each process per unit) assures a constant flow from suppliers and appropriate utilization of workers.

Lean Components

- Problem Solving Circles
  - Work groups run cells or work areas.
  - Problem-solving circles are made up of work groups and/or anyone who can help solve the problem.
  - They meet outside of production time to solve specific problems identified by circle members or management.
  - The very best lean systems elicit 50-100 suggestions per employee per year with a 90% implementation rate and 90% of employees with at least one suggestion.

Lean Components

- Five S’s
  - Basic principles of industrial housekeeping
  - The Five S’s in Japanese translate as:
    - sort - clutter free work area
    - straighten - orderly work area
    - shine - clean work area
    - standardize - standard best practices
    - sustain - discipline to maintain the 5sS strategy

Just-in-Time (JIT)

- Just-in-time is a philosophy that has the elimination of waste as its objective.
- Waste may appear in the form of:
  – rejected parts
  – excessive inventory levels
  – interoperation queues
  – excessive material handling
  – long set-up and changeover times

Just-in-Time (JIT)

- Just-in-time highlights the need to match production rate to actual demand and eliminate non-value-adding activities.
- Changeover and setup are both nonvalue adding activities. JIT philosophy requires a minimal number of changeovers with a minimal setup time.
- JIT philosophy requires manufacturing processes be designed to accommodate a fairly mixed set of products without building inventory to level the capacity requirements.

Just-in-Time (JIT)

- JIT is also a very visual process. Remembering sets of instructions and procedures is difficult.
- JIT requires workers to be cross-trained in a variety of jobs to accommodate production surges.
- Visual cues can reduce the number of innocent mistakes.

Pull System

- Pull systems do not allow parts to be produced until “authorization (pull signal)” is received from the subsequent operation.
- Over-lapped pull system
  - utilize empty space as the pull signal or communication device between production operations
- Linked pull system
  - utilize a pull signal (or kanban) to trigger the production of components from operation to previous operation

Learning Curves

- Learning curves predict the amount by which the production time decreases as additional units are successively built.
- The percentage associated with a learning curve specifies the amount by which the production time per unit is reduced each time the quantity produced is doubled.
- For example, with a learning curve of 50%
  - first part = 60 sec
  - second part = 0.5(60 sec) = 30 sec
  - fourth part = 0.5 (30 sec) = 15 sec

Types of Learning Curves

- Unit curve
  - production time is expressed in hours per unit to build the Xth unit
- Cumulative average curve
  - production value is expressed as the cumulative average time in hours per unit to fabricate a total of X units.

Part 5
Automated Systems and Control

Criteria for Automation

- Improve product quality
- Improve production efficiency
- Improve quality of work life
  - Replacement of labor is not a rationale for automation since direct labor only accounts for a small percentage of the final product cost.
- Improve product development time
- In terms of agile manufacturing, automation must improve flexibility

Simulation

- Simulation is the process of experimenting with a model of a real system by changing the structure, environment or underlying assumptions.
- Manufacturing simulation
  - computer/network performance
  - CNC programs
  - product performance
  - kinematics of work cells
  - manufacturing systems
  - continuous processes

3-D Applications

- Wireframes
  - stores geometry of a 3-D model as edges and points
  - the points on the surface are implied
- Surface modeling
  - adds varying degrees of accuracy as compared to a wireframe model
- Solid modeling
  - provides CAD/CAM systems with a wealth of topological information
  - CAM functions can be executed faster from solid models

Networks

- The computer networks consist primarily of local area networks (LAN).
- LANs can also be joined to form enterprise wide computing (EWC) or corporate intranets.
- An intranet is similar to the internet except only people within the company or organization can access it.

Networks Specifications

- Computer networks are specified by
  – architecture
    - organized combination of protocols and standards
      – token ring (IBM)
      – Appletalk
      – ethernet (most popular)
  – access protocol
  – bandwidth
    - the number of signals that can be carried simultaneously on the same conductor
  – cable, distance, and cost

Network Components

- The four components to a network
  - servers (file, client, communications, print, and web)
  - transmission medium (cable or wireless)
  - network interface cards (NIC)
  - network operating system

Servers

- File Server
  - the centerpiece of networks, stores program or data files for shared use
  - stores the network operating system
  - controls user access and security
  - performs periodic backup of data and program files

Servers

- Client Server
  - The client server (also called a database server) is important for real-time access by multiple users to any file, but most commonly databases or CAD documents.
  - From a file server, the entire file is downloaded to the client's workstation and only that user has access to it at that time.
  - Client servers retain the files and allow multiple users to access portions of the file simultaneously.
- Web servers, required for intranet or internet posting of an organization's web files, are a specific type of client server.

Cabling

- Variety of copper conductors
  - thick coaxial cable
  - thin coaxial cable
  - unshielded twisted pair (UTP) cable
    - common media for local area networks in environments that are relatively free of EMI that come from motors, transformers and fluorescent lights.
  - shielded twisted pair (STP) cable
- Fiber optics is the most secure medium, since the light does not have the electromagnetic fields inherent with wire or wireless communications, and it is the least susceptible to electromagnetic interference (EMI).

Cabling

- The cable category determines:
  – the bandwidth and distance the cable is capable of transmitting
  – number of twists per foot
  – capacitance
  – frequency
  – attenuation
  – pair-to-pair near end crosstalk
- Cross talk occurs when the signal from one wire in the twisted pair cable induces a random signal in an adjacent wire.

Network Interface Card (NIC)

- The network interface card (NIC) connects the computer motherboard to the cabling.
- Internal network interface cards are used with desktop computers while laptops use an NIC that connects to the laptop by the PCMCIA port.

Remote Access

- Plain old telephone system (POTS) lines and modems
  - least expensive and lowest performance level (56 Kbps)
  - bandwidth is low
- T1 lines (1.544 Mbps)
  - while T1 lines are leased and costly, they provide the opportunity for even greater exchanges of data, voice, and video conferencing.
  - T3 line is fiber optic cable (44.736 Mbps)
  - T1 and T3 lines are expensive because of the installation of cabling to the corporation by the telephone company and the leasing the 24 hour access and line control.

Remote Access

- Integrated Services Digital Network Lines (ISDN)
  - developed to provide an intermediate solution to the high performance and high cost of the T1 line and low performance of the modem on a POTS line
  - ISDN has never been universally available and its performance has been questioned.
  - 144 Kbps - 155 Mbps depending on type

Remote Access

- Digital Subscriber Lines (DSL) and Digital Data Service (DDS)
  - developed to use conventional four wire telephone lines in a digital mode
  - since it is digital, a modem is not necessary
  - DSLs were intended to transmit data at high speed over low cost telephone lines.
  - 64 Kbps - 1.54 Mbps depending on type

Remote Access

- Limitations of a DSL
  - the distance from the telephone company’s communications equipment to one’s local office or manufacturing plant
  - the type of cable used between the communications equipment and the manufacturing plant
  - the services that have been sold to other subscribers that are running on adjacent lines

Operating System

- An operation system is the software that interfaces the user with the network and off of its components.
- Common operating systems that support ethernet architecture include:
  - Novell Netware
  - Windows NT
  - Unix

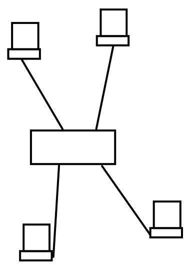
Network Equipment

- Repeaters
  - do not do error control, flow control, address correction or process the signal
- Bridges
  - link identical LANs to increase user access to a greater range
- Routers
  - support communication between dissimilar LANs using the same protocol
- Gateways
  - connect networks of different architectures and protocols by translating the protocol from one to the other

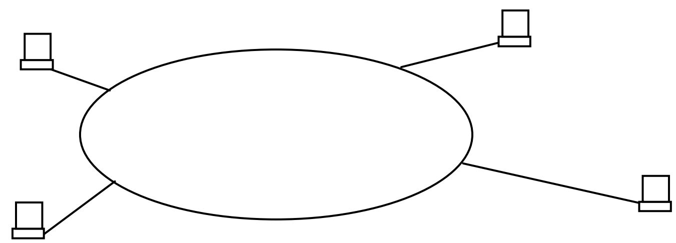
Physical Topologies

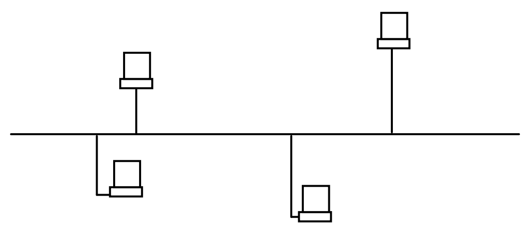
- Physical topology refers to how users are connected to the network.

Star



Ring





Bus

Protocols

- Protocol is the procedure by which a node on the network is allowed to access the network.
- Common protocols
  - carrier sense multiple access with collision detection (CSMA/CD) (used by ethernet)
  - token ring
  - token passing

CSMA/CD

- To communicate with the server a node,
  - waits for a pause in the transmission of data
  - check that no other node has tried to transmit at the same time
  - begins transmission
  - if a data collision occurs from two nodes transmitting at the same time both nodes will cease transmitting
  - each node will wait a prescribed time based on a random number generated
  - each node will check for a clear line before transmitting again

Token Passing

- Token passing allows a workstation to transmit data (e.g. save a file on the server) when the workstation holds the token.
- The token can be directed to the specific addresses of specific workstations more frequently than others.
- A signal is passed to the next node on the ring.

Token Ring

- Token ring messages pass through the multiple workstations, being received and re-transmitted, until the message or data arrive at the designated workstation.

Internet and Intranet

- The internet and intranet both require transmission control protocol/internet protocol (TCP/IP) protocol suite.
- TCP is used to transfer data between two internet devices.
- Virtual ports are used to make these connections and TCP monitors the flow of data.
- The internet protocol (IP) addresses the data and directs it to the appropriate destination.
- Each internet device has an IP number composed of four segments of one to three digits separated by decimal points (e.g. 198.109.68.194).

Internet and Intranet

- The domain name system (DNS) permits names to be coupled to the IP address.
- For example, www.sme.org may be used instead of 198.109.68.194 to locate the web page for the Society of Manufacturing Engineers.
- Dynamic IP addresses that are captured by a user at login to the network or internet reduce the total number of addresses required at a specific time.
- Dynamic IP addresses are managed by a dynamic host configuration protocol (DCHP) server.

Internet and Intranet

- If one wishes to download or upload a specific file from a server, file transfer protocol (FTP) is used. Hyper text transfer protocol (HTTP) is used to transfer information from web servers to web browsers.

Advantages of Internet and Intranet over LANs

- Multiple user real-time access of multimedia
- Personal appointment data, e-mail
- enterprise wide computing information that is both text and graphic, access from the internet, and videoconferencing
- Worker collaboration uses groupware software on both the internet and intranets to allow groups of people to work together.
- Both the internet and intranets are key components in MEI wheel level 3 “shared knowledge systems”.

Programmable Logic Controllers PLCs

- PLCs are used for:
  - relay replacement
  - control of analog and digital closed loop systems
  - manufacturing cell control
  - control servo operations
  - proportional-integral-derivative (PID) systems
  - drive stepper motors
  - automatic data collection
  - communication with other networks

PLC Cell Control

- As cell control PLCs offer several advantages
  - increase control capability
  - faster processing of the robotic program
  - simpler robotic programs
  - If the robot controller is not functioning other functions will still be controlled by the PLC.

PLC Components

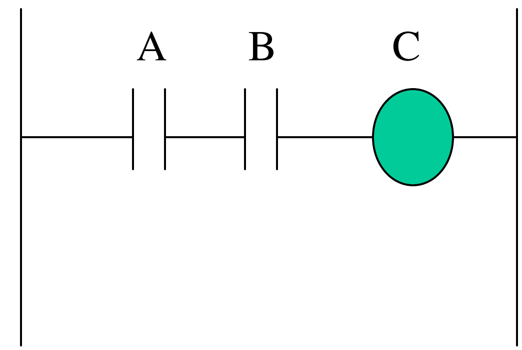
- Input modules
- Central processing unit (CPU)
- Memory
- Output modules
  - Input and output modules (I/O modules) are the interface between the physical inputs and outputs and the CPU.
  - Number of I/O determine the PLC size.
- The PLC is designed to control operations in real-time by scanning or reading the input module, executing the program, and setting or writing the outputs in the output memory to the appropriate states.

PLC Programming

- Basic ladder logic (programming) elements
  - rails
  - rungs
  - branches
  - inputs
    - examine on ┤ ├
    - examine off ┤/├
  - Outputs
    - outputs --( )--
    - timers --(T)--
    - counters --(CTR)--

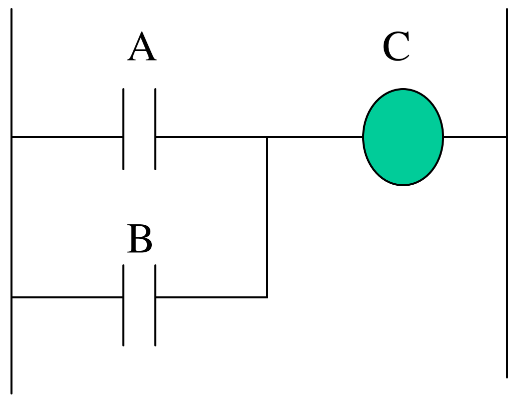
PLC Example One "AND"

- Contacts A and B are normally open.
- Both A <u>and</u> B must energize or close for output C to be energized. Output C represents a relay being energized.



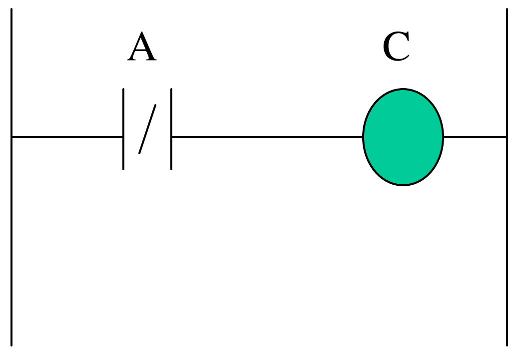
PLC Example Two "OR"

- In this example when either contact A or B are closed output C will be energized. A and B need not be closed a the same time.



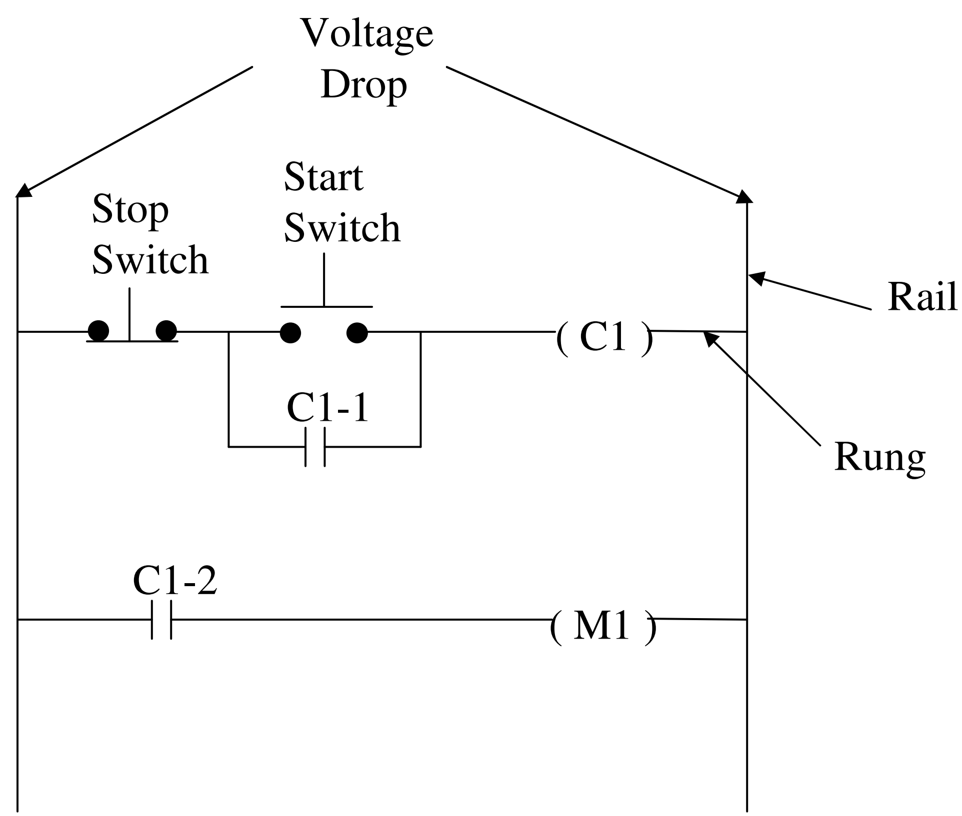
PLC Example Three "NOT"

- In this last example contact A is normally closed. Therefore, unless the switched is opened output C will remain energized.



Motor Starter

- C1-1 is a holding contact.
- When the start switch is depressed, C1 energizes making C1-1 and C1-2 true thus starting the motor.
- Depressing the stop switch is the only way to turn off C1 and thus turn off the motor (M1).



Distributive Numerical Control (DNC)

- DNC has the ability to download entire part programs to the CNC machine controllers connected to the network.
- DNC systems can support:
  - file management
  - input from bar code
  - communications with programmable logic controllers and enterprise computing systems.

Primary Elements of a CNC Control Unit

- Operator Interface
  - keyboard
  - network interface
- Machine Control Unit
  - CPU
  - RAM
  - ROM
- Machine Interface
  - encoder feedback
  - proximity switches
  - pressure switches

Control Theory

- Open Loop Control
  - No feedback to the controller indicating if the desired motion was completed correctly.
- Closed Loop Control
  - Feedback to the controller from encoders or resolvers indicating the desired motion was completed correctly.

Resolvers and Encoders

- Resolvers are analog devices that read machine movements and then convert the information to digital where encoders are strictly digital.
- Resolvers are less sensitive to vibration and temperature than encoders.

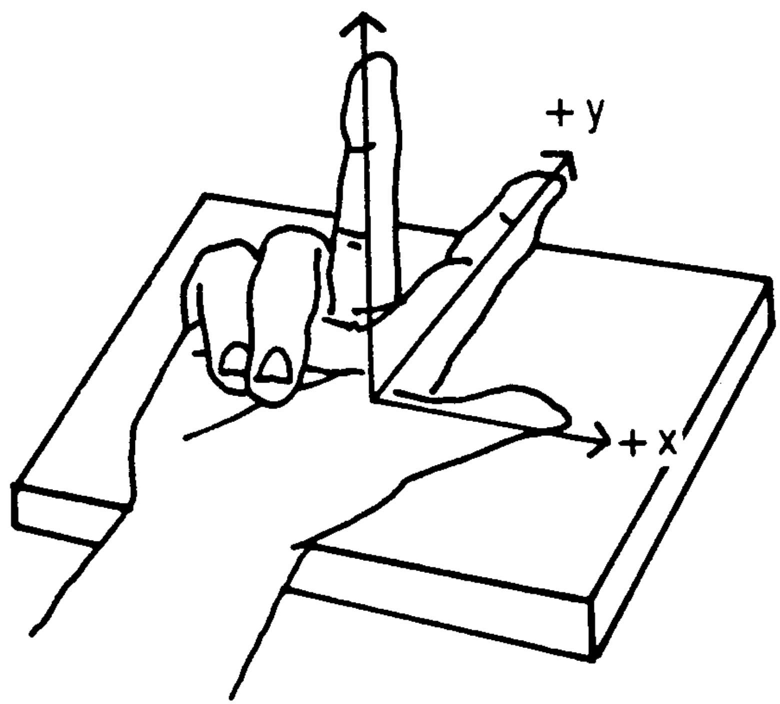
Programming Formats

- The syntax for the code is block number; G-code, and the X,Y,Z, A, B, C, I, J parameters with numerical values; and decimal points for the instruction.
- These are followed by spindle speed and feed rate if they are different than the previous block.
- M-functions control spindle operation, coolant operation and changes for machining centers or chuck operation.
- APT (automatically programmed tools)
  - programming language for parts where complex tool control is required

Machine Coordinate Axis

- The Z axis is always parallel to the spindle.
- The X axis is perpendicular to Z and is the major axis of the machine.
- The Y axis is perpendicular to X and Z and has a smaller range of movement than X.
- When a machine has rotation about X, Y and Z the letters a, b and c are used.
- In a two axis system (lathes) X and Z are used.

Right Hand Rule



Movement

- Point to Point
  - Early NC machines could only perform point to point operations which means that only one axis of the machine could move at one time.
- Linear Interpolation
  - can cut straight lines by moving more than one axis simultaneously
- Circular Interpolation
  - can cut curves and arcs by moving more than one axis simultaneously
- Full Contouring
  - inertia of the mechanical system is sufficient to continue at the same velocity between blocks of code

Common Forms of Automatic Identification

- Bar codes
- Radio frequency identification
- Magnetic strip
- Voice recognition
- Machine vision

Bar Codes

- One of the most robust and reliable forms of automatic identification.
- The density of the bar code , dimension of the narrowest bar (X dimension) varies from low to high density.
- The narrower the bar, the higher the density.
- Widths must be uniform throughout the code.
- A nine-segment start and a nine-segment stop bit on each end of the code.
- Each bar code must also have a plain (quiet) zone on each end of the code.

Bar Codes

- Most common linear bar codes are Universal Product Code (UPC), Code 39, Interleaved 3 of 5, and Code 128.
- The different bar codes offer different numeric or alphanumeric codes.
- UPC is strictly numeric, while Code 39 is alphanumeric.
- The bar code can be read from either end.

Radio Frequency Identification

- Uses a transponder attached to a pallet, part, or AGV (Automated Guided Vehicle).
- Used where processes or routings may cover a bar code.
- Newer units can receive and transmit.
- The data contained on the tag are hardened to withstand vibration, liquids common in manufacturing, and temperature extremes of –40°F to 400°F (-4°C to 205°C).

Magnetic Stripe

- Can not be read remotely.
- Not resistant to mechanical damage.

Voice Recognition

- Voice recognition systems are either dictation or command and control.
- Dictation is used to enter data via voice rather than keyboard or one of the other types of data entry.
- Computer voice recognition software is now capable of continuous speech versus speaking discrete words.
- Command and control software allows one to control a computer or a computer based system via voice commands.

Vision Systems

- Machine vision systems are used to create a computer generated model of a view of the world from images.
- A complete machine vision system is composed of
  - machine vision hardware and software
  - the lighting system
  - the optical system

Pixels

- The basic unit of machine vision is the pixel.
- Machine vision may be monochrome or gray scale, and gray scale systems may be either 2-D or 3-D.
- Monochrome systems are less expensive, faster with comparable hardware, and simpler than gray scale systems.

Lighting Techniques

- Front lightning
  - camera and the light source on the same side of the part
- Back lighting
  - the light source and camera on opposite sides of the part and generates a silhouette
- Structured lighting
  - similar to front lighting with the light beam controlled with lenses, apertures, coherent light sources or lasers
  - used to identify specific features of a part or specific parts

Optics

- The optics determine the area that the camera can see and for a given camera, the resolution of the display.
- The most common camera is the charge coupled device (CCD).

Machine Vision Stages

- Image formation
  - optics and lighting to detect the image
- Image preprocessing
  - capture the image and digitize the image
- Image analysis
  - analyze for geometric features or position
- Image interpretation
  - comparison of features to discriminate between parts or inspect parts for critical dimensions

Robotics

- Robots are reprogrammable, multifunctional manipulators designed to move material, parts, tools or specialized devices through variable programmed motions.

Robotic Power Supplies

- Electric
  - quiet, clean, fast movements
  - most accurate
- Hydraulic
  - slower, heavy payloads
  - not as accurate
- Pneumatic
  - quick
  - not as accurate

Robot Programming

- Most robot programming uses teach pendants
  - the robot is physically walked through the motions and the controller records the steps
- Offline programming is now available.
  - Programming is done on a computer and then down loaded to the robot controller.

Robot Control Systems

- Categorized according to:
  - the type of control (non-servo and servo)
  - the type of feedback (open loop or closed loop)
  - the resolution and accuracy
  - the communications capability
- Robot control systems like CNC control systems are incorporating network interfaces in their controllers.

NonServo Control System

- Programmable controllers are commonly used as control systems for non-servo robot systems.
- The non-servo controllers may have the same number of degrees of freedom (joints of motion) as a servo robot but will have only a limited number of programmable positions.
- Many use a pneumatic power system.
- These devices are often call pick-and-place machines.

Servo Control

- Servo control offers the programmer as many positions as the controller will accept in memory.
- The number of axes a controller can control simultaneously determines if the controller can cause a robot arm to do linear or circular interpolation or continuous path control.
- True continuous path allows the programmer to define irregular or regular paths, often by lead-through programming.

World Coordinate System

- X, Y, and Z zero coordinates at the center of the base of the robot.
- Ability to do linear interpolation is a fundamental requirement for a controller to move the robot arm in world, tool, or part coordinate systems.

Tool Coordinate System

- The tool coordinate system has its center on the tool flange.
- X and Y axes are parallel to the tool flange surface and Z is perpendicular to the flange.
- This coordinate system is used in programming a robot arm as it approaches parts or picks parts out of fixtures.
- The advantage of this system is that one can orient the tool flange parallel to an oblique surface and then easily move the tool flange parallel or perpendicular to that surface.

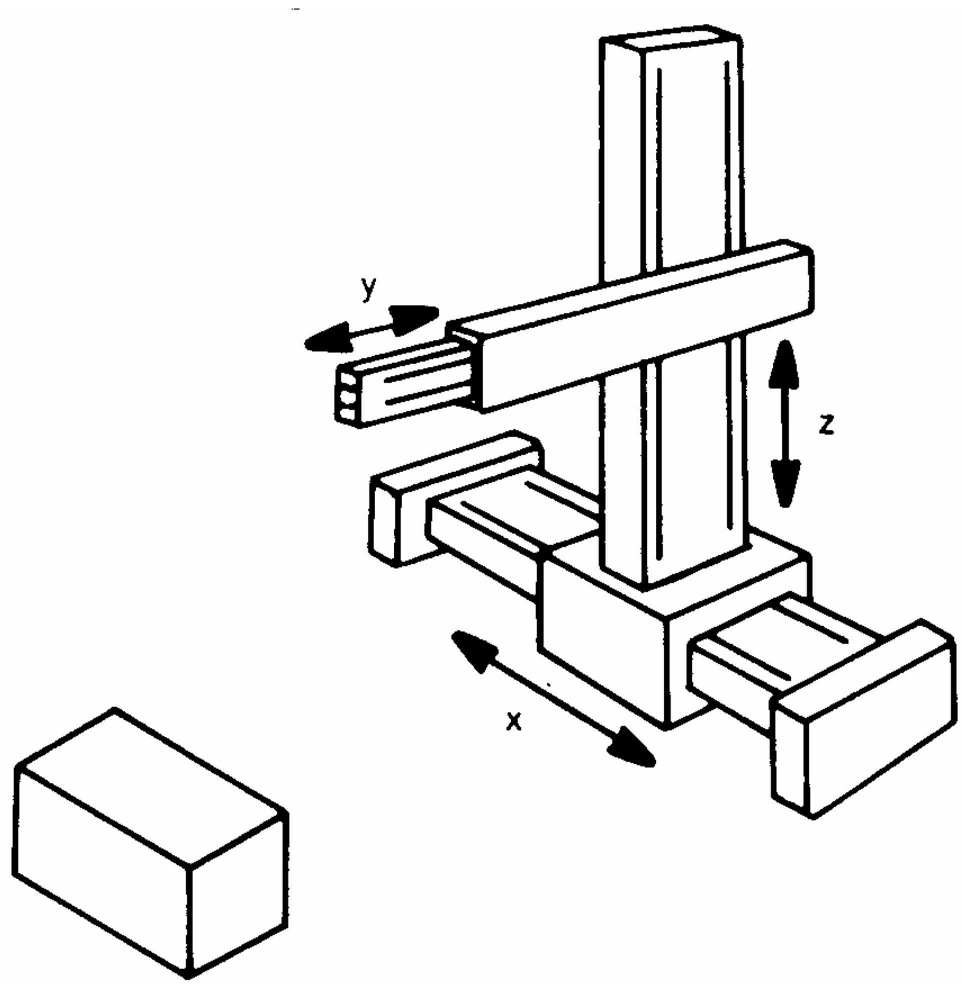
Part Coordinate System

- The part coordinate system has the coordinate center oriented according to the dimensions of the part.
- This system permits the robot tool, a MIG welding gun for example, to move according to the geometry of the part.

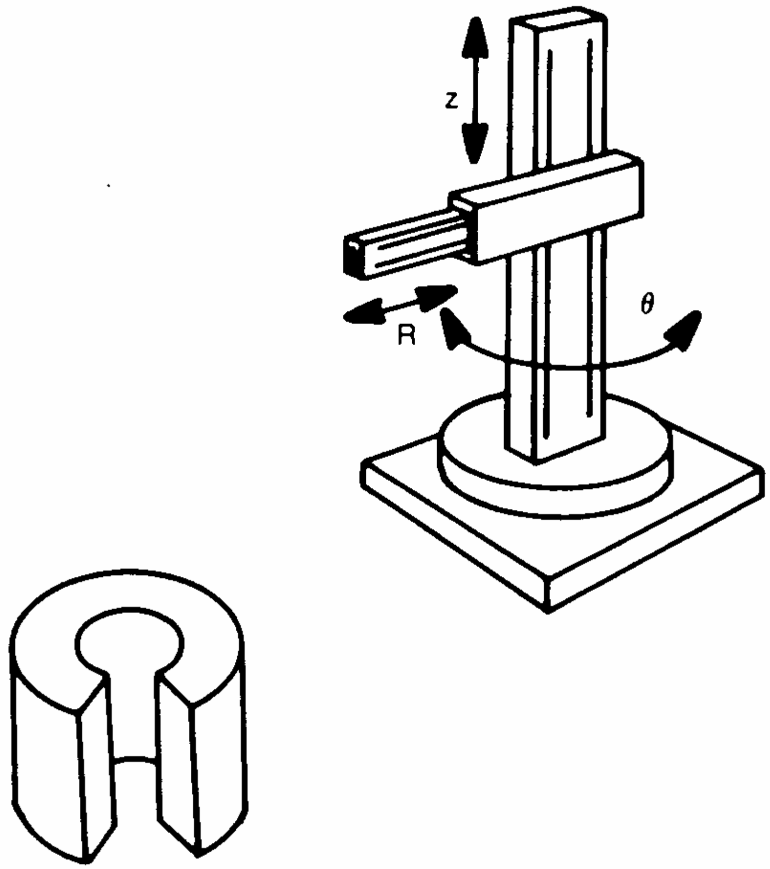
Work Envelopes

- Cartesian
  - cartesian and gantry robots
- Cylindrical
  - cylindrical and SCARA
- Spherical
  - polar and jointed-arm (articulated arm)

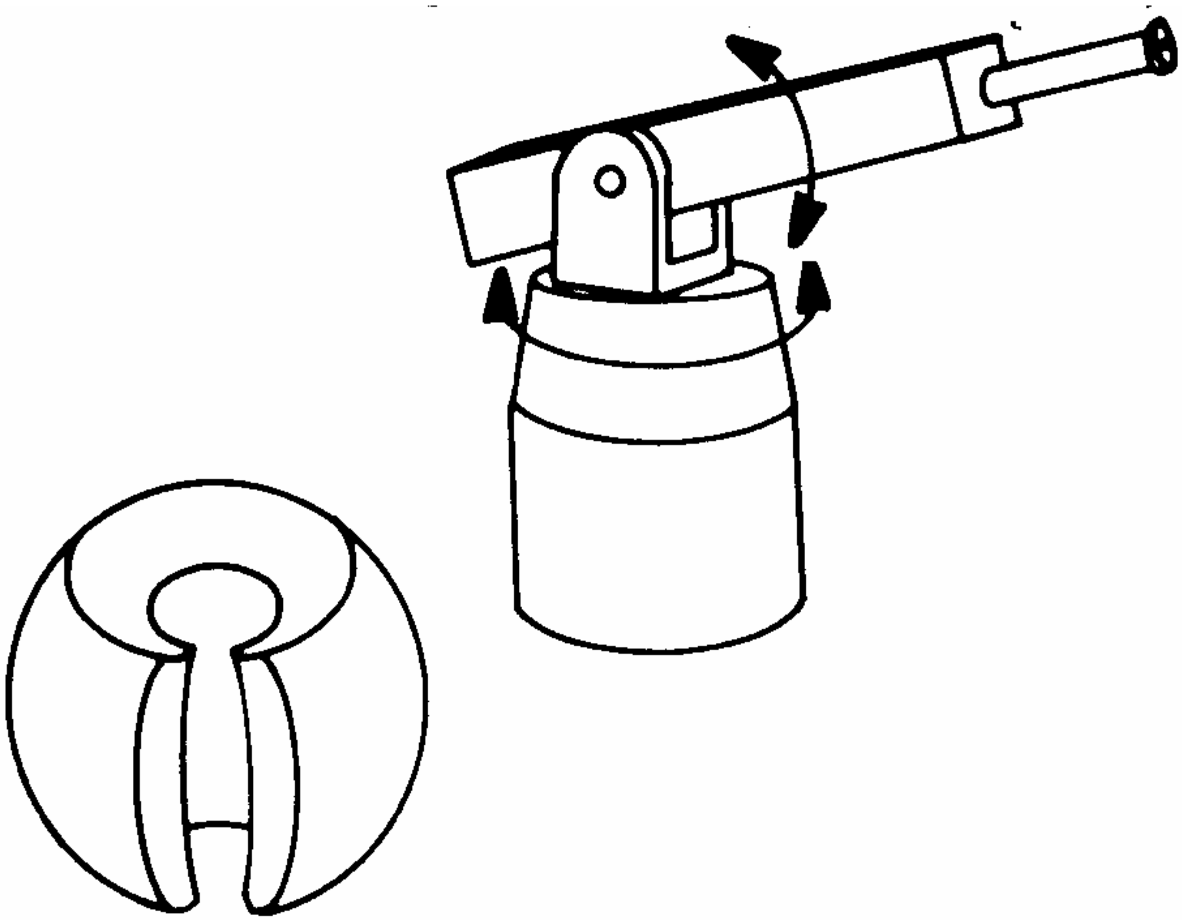
Cartesian Work Envelope



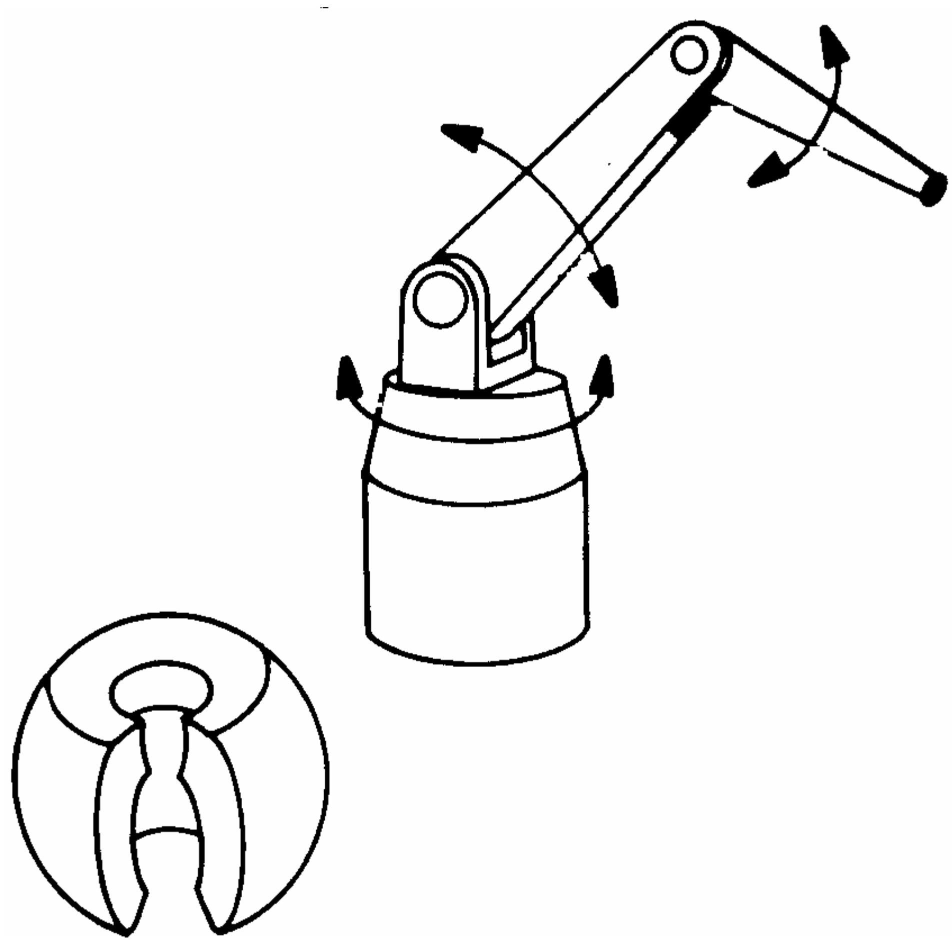
Cylindrical Work Envelope



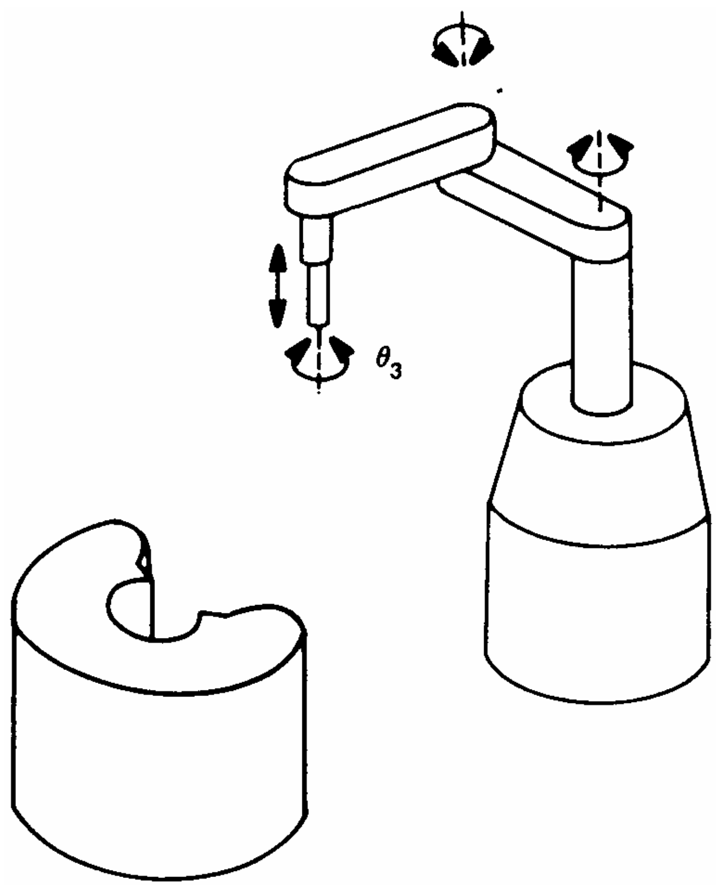
Spherical Work Envelope (Polar Arm)



Spherical Work Envelope (Articulate Arm)



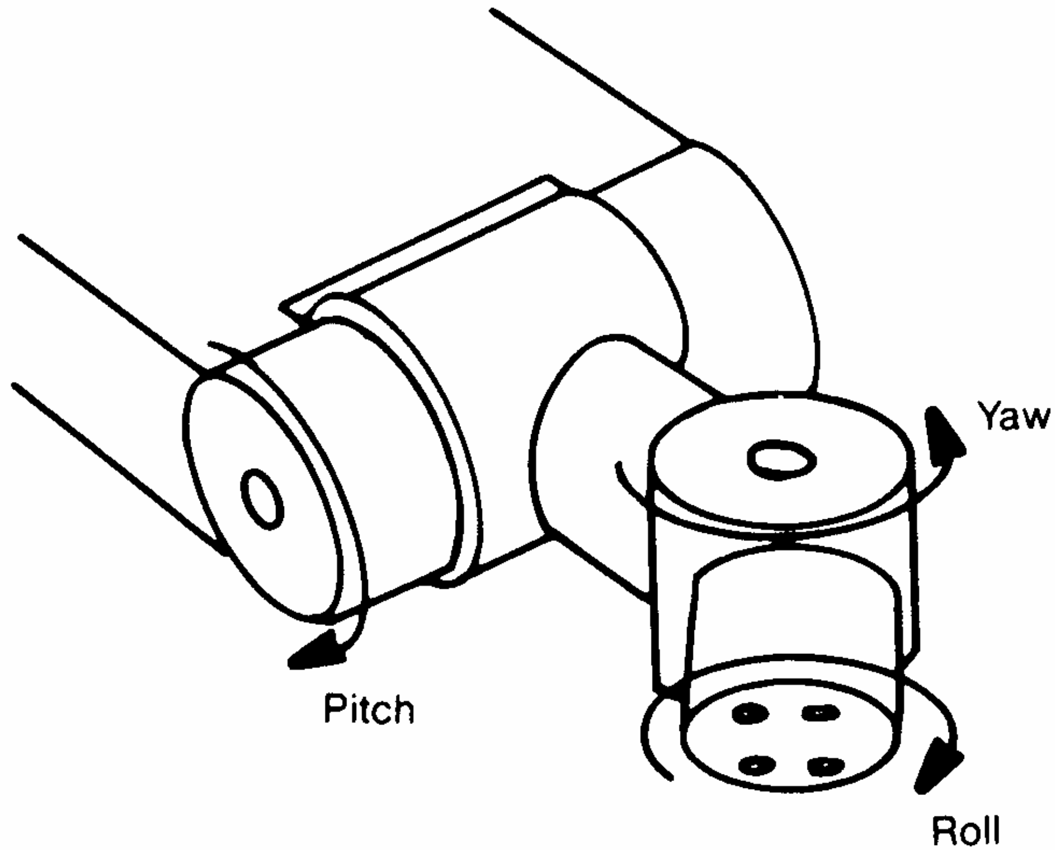
Cylindrical Work Envelope (SCARA)



Degrees of Freedom

- Robot
  - 3 degrees of freedom
  - the robot itself can move in the X, Y, and Z directions
- End Effector
  - 3 degrees of freedom
  - the end effector adds pitch, roll, and yaw movements

Wrist Degrees of Freedom



FMS and FMC

- Flexible manufacturing systems (FMS)
  - systems of computer controlled machines with and integrated material handling system
  - the purpose of FMS is to produce a family of parts in mid-volume quantities
- Flexible manufacturing cells (FMC)
  - have fewer machines and may not include the material handling function.
  - FMCs are simpler and less costly than FMS and have the option of being integrated at a later date into an FMS

Golden Rule

- Never automate confusion.
- If a process is out of control or not fully understood automating it will only make the situation worse.

Sensors and Transducers

- Discrete switches
  - generally on/off switched
  - can indicate if a tool is broken or a low fluid pressure
- Digital sensors
  - sensors such as encoders can provide positioning data
- Analog sensors (transducers)
  - can change a physical phenomenon to an electrical signal
  - a pressure transducer provide an variable electrical output corresponding to variable pressure levels

Sensor Selection Criteria

- Phenomenon being sensed
- Range of the phenomenon
- Resolution of the sensor
- Accuracy
- Response time for the sensor
- Environmental constraints for the sensor

Part 6
Quality

Quality Assurance and Control

- Quality Assurance (QA)
  - ensures that the quality function is appropriately executed
  - activities extend far beyond the quality department
  - is proactive in its approach to quality planning, system improvement such as defect prevention and reliability while maintaining the after-the-fact QC and audit functions
- Quality Control (QC)
  - primarily identifies and responds to nonconformities such as defects and is reactive in nature

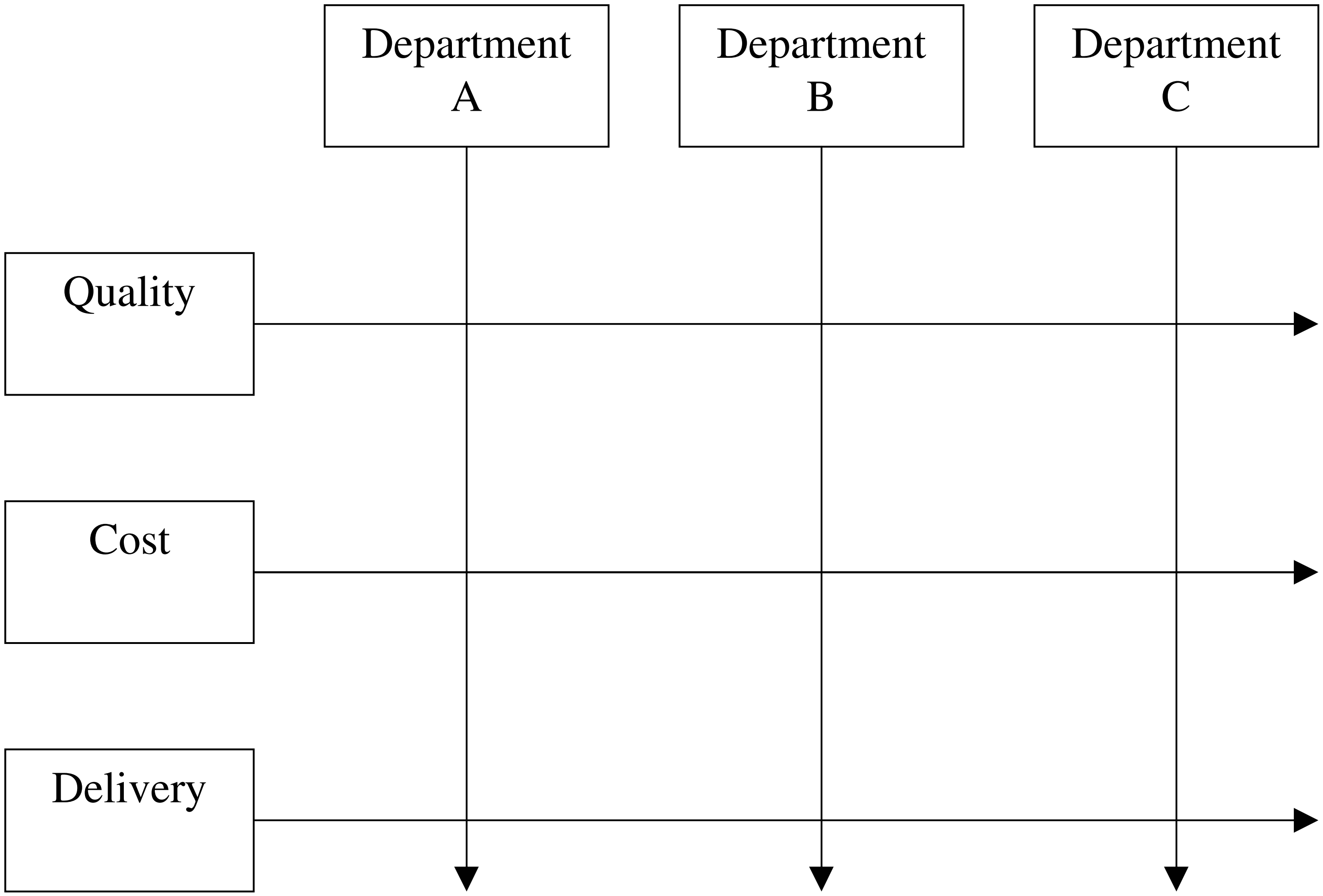
Total Quality Management (TQM)

- By the mid-1970's Japanese manufacturers were exporting products that were less expensive, contained fewer defects, and were closer to customer requirements than their American counterparts.
- The imported products were designed and produced in far less time than those domestically produced and many Japanese companies had institutionalized successful programs of continuous improvement.
- The Japanese adapted an American based system known as Total Quality Control (TQC) which is the predecessor of TQM.

Total Quality Control (TQC)

- The Japanese essentially focused on two things.
  - cross functional management
  - focus on the core
- Cross Functional Management
  - replaces the short-term focus with a long-term focus
  - replaces departmental goals with organizational goals
  - deal with issues that span several departments

Cross Functional Management Diagram



Focus on the Core

- The core business is the essence of what the company does:
  - Toyota might identify its core as the production of personal transportation vehicles.
- For full-time employees in the core, the company strives to provide a sense of family and belonging.
- Lifelong service to the employer is expected, and the employer demonstrates similar loyalty to the employee.

TQM

- TQM emerged in the early 1980's in response to increasing competition from Japanese products in the U.S. market.
- The phrase Total Quality Management represents a philosophy or worldview with implicit definitions of how a TQM enterprise will be organized and run.
- Central goals of TQM include:
  - increasingly higher levels of customer satisfaction achieved
  - continuously improving processes linked to business measurables such as cost and productivity

Quality Costs

- Prevention
  - process control
  - inspection
  - quality improvement programs
  - inspection
  - education and training
- Appraisal
  - inspection
  - customer surveys
  - audits
  - data collection
  - lab supports
  - field reports

Quality Costs

- Internal Failure
  - scrap
  - meetings not starting on time penalties
  - overnight letters due to poor planning or execution
  - administrative costs associated with recommunication
  - lost time due to safety issues
  - supplier training
- External Failure
  - lost sales
  - penalties
  - field change orders
  - complaint handling
  - legal actions
  - accounts receivable
  - allowances

Malcolm Baldrige Award

- Public Law 100-107 in 1987 created the Malcolm Baldrige National Quality Award (MBNQA) to encourage improved quality and competitiveness from American companies.
- The National Institute of Standards and Technology (NIST) manages the award.
- The Baldrige Award is granted annually to up to 6 winners in three categories: large manufacturing companies, large service companies, and small business.

Malcolm Baldrige Award

- MBNQA criteria include:
  – leadership
  – information and analysis
  – strategic quality planning
  – human resources development and management
  – management of process quality
  – quality and operational results
  – and customer focus and satisfaction
- A key difference between ISO 9000 and the MBNQA is the latter's emphasis on system outcomes, improvement and customer satisfaction.

Statistical Methods for Quality Improvement

- Data Characterization
- Variable Control Charts
  - X bar and R
  - X and moving R (individual x and moving range
- Process Capability
- Attribute Control Charts
  - p (fraction defective)
  - np (number defective)
  - c (count of defects)
  - u (defects per unit)
- Design of Experiments

Type of Data

- Variable data
  - measurable along a continuous scale
  - length, weight, force, etc.
- Attribute data
  - characteristics that are countable or categorized into discrete classes
  - number of scratches or number of defective items

Measure of Central Tendency

- Measure of central tendency is a numeric value that describes the central position or location of the data
  - mean
  - median
  - mode

Mean

$$\mu = \sum_{i=1}^{n} \frac{X_i}{N}$$

$\mu =$ true mean

N = total number of observations in the population

X_i = individual observations

$$\overline{X} = \sum_{i=1}^{n} \frac{X_i}{n}$$

$\overline{X}$ = sample mean

n = total number of observations in the sample

X_i = individual observations

Median

- The median is the middle observation in a group of data ordered by magnitude.
- The data are ordered in ascending or descending order and counted.
- The median is halfway through this ordered list.
- If there are an even number of observations, the median is the average of the two in the middle of the ordered list.

Mode

- The mode is the value that occurs most frequently.

Measure of Variation

- Range
  - Range (R) = Maximum x_i - Minimum x_i
- Variance
  - measure of the variability in data.
- Standard Deviation
  - more practical to use than variance since the units of standard deviation usually match the units in the problem such as inches or pounds
  - interpretations about the variability are more easily drawn with standard deviations

Population Variance

$$\sigma^2 = \frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N} = \frac{\sum_{i=1}^{N} x_i^{\ 2} - N\mu^2}{N}$$

Where,

μ = the population mean

N = population measurements

x_i = each individual data point

Sample Variance

$$s^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1} = \frac{\sum_{i=1}^{n} x_i^{\,2} - n(\bar{x})^2}{n-1}$$

Where,

$\bar{x}$ = the sample mean

x_i = each individual data point

n = sample size

Population Standard Deviation

$$\sigma = \sqrt{\sigma^2} = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)^2}{N}} = \sqrt{\frac{\sum_{i=1}^{N} x_i^{\ 2} - N\mu^2}{N}}$$

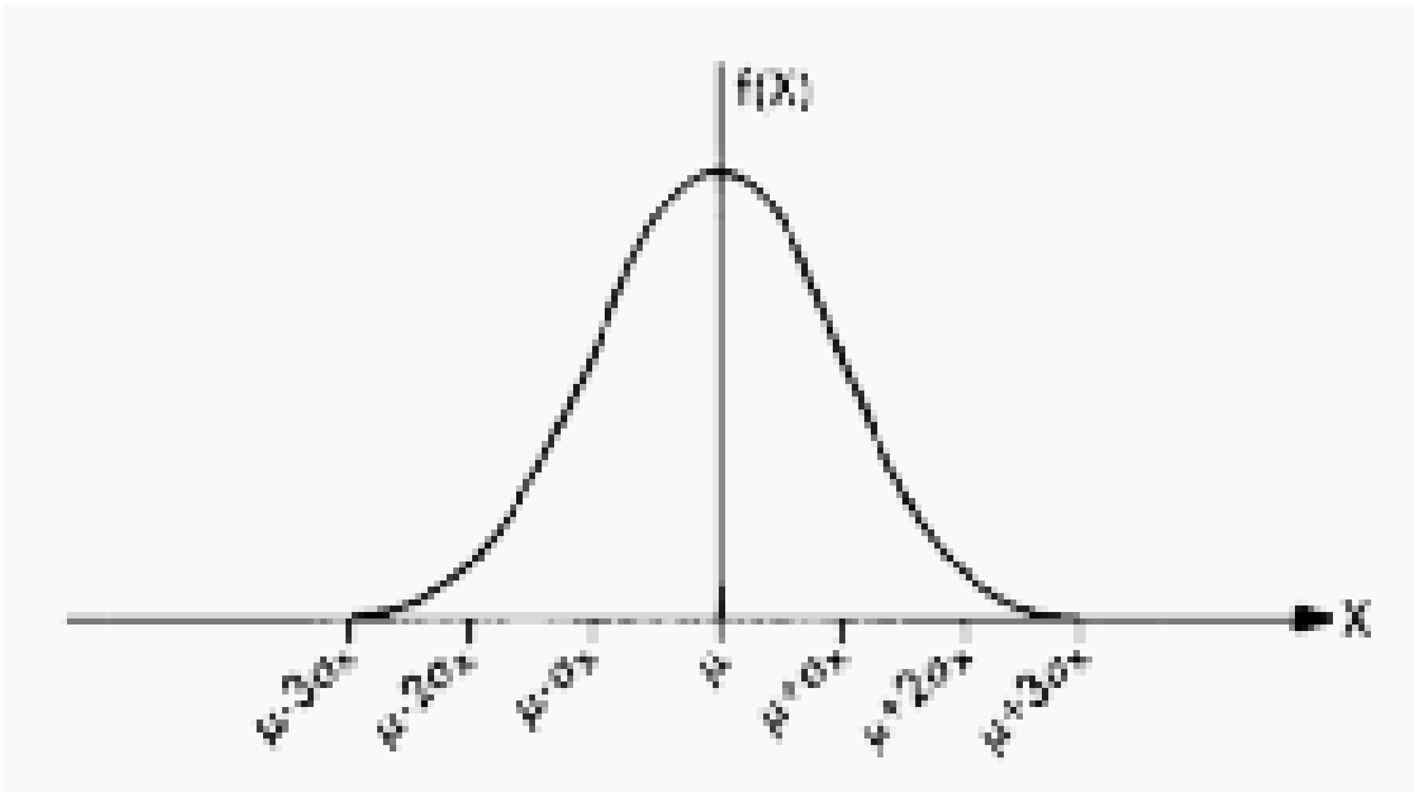
Sample Standard Deviation

$$s = \sqrt{s^2} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} x_i^{\,2} - n(\bar{x})^2}{n-1}}$$

Central Limit Theorem

- The Central Limit Theorem states that the distributions of sample means from an infinite population will approach a normal distribution as the sample size increases.
- The size of the sample that will give a nearly normal distribution depends on how non-normal the population is.

Normal Distribution



Normal Distribution

- 68.26% of the observations fall between $u \pm \sigma_x$
- 95.46% of the observations fall between $u \pm 2\sigma_x$
- 99.73% of the observations fall between $u \pm 3\sigma_x$

Standard Normal Distribution

- Because the mean and standard deviation of a normal distribution can take on many different values depending on the situation it is convenient to work with a standard normal distribution where z is a standardized normal random variable based on any normal distribution with mean *u* and standard deviation σ_x

$$z = \frac{(X - \mu)}{\sigma_x}$$

Standard Normal Distribution

- Using a table which provides areas under a normal curve the percentage of observations above or below a certain value can be calculated.

Example Problem

- If the diameter of shafts is normally distributed with a mean of 1.00 and a standard deviation of 0.01 what is the probability that a given shaft will have a diameter between 0.985 and 1.005?

$$z_1 = \frac{1.005 - 1.000}{0.01} = 0.5$$

$$z_2 = \frac{0.985 - 1.000}{0.01} = -1.5$$

- From a cumulative area under the normal curve table, the probability will be A1- A2 = 0.6915-0.0668 = 0.6247 or 62.47%.

X bar R Chart

$\bar{\bar{x}}$ = grand average and represents the population mean

$\bar{R}$ = average range and represents the typical variance

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \ldots \bar{x}_n}{n}$$

n = number of samples

$$\bar{R} = \frac{R_1 + R_2 + \ldots R_n}{n}$$

X bar and R Control Limits

$$UCL_{\bar{x}} = \bar{\bar{x}} + 3\sigma_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R}$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - 3\sigma_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R}$$

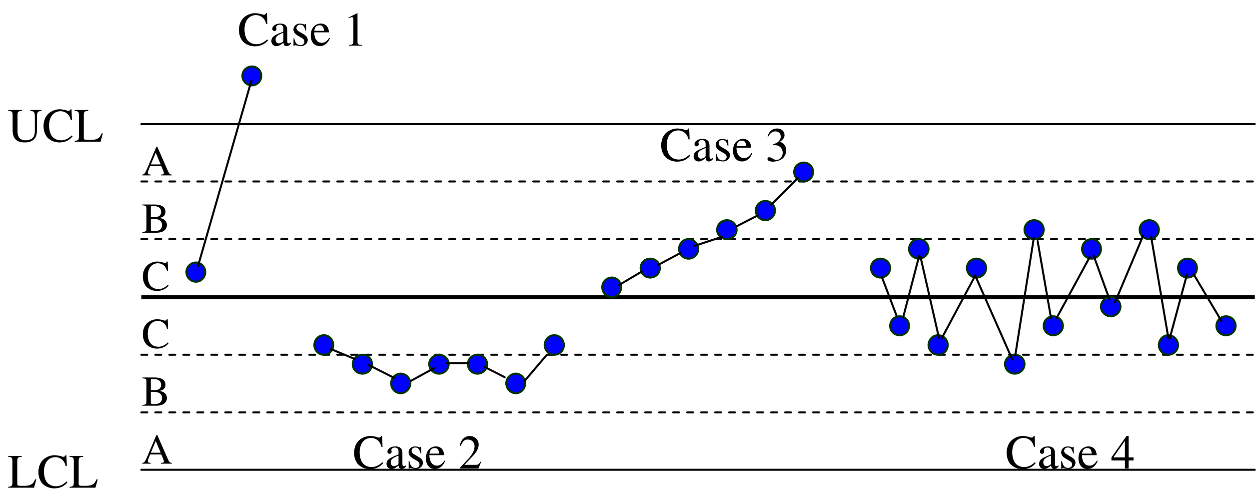
$$UCL_R = \bar{R} + 3\sigma_R = D_4\bar{R}$$

$$LCL_R = \bar{R} - 3\sigma_R = D_3\bar{R}$$

Control Chart Constants

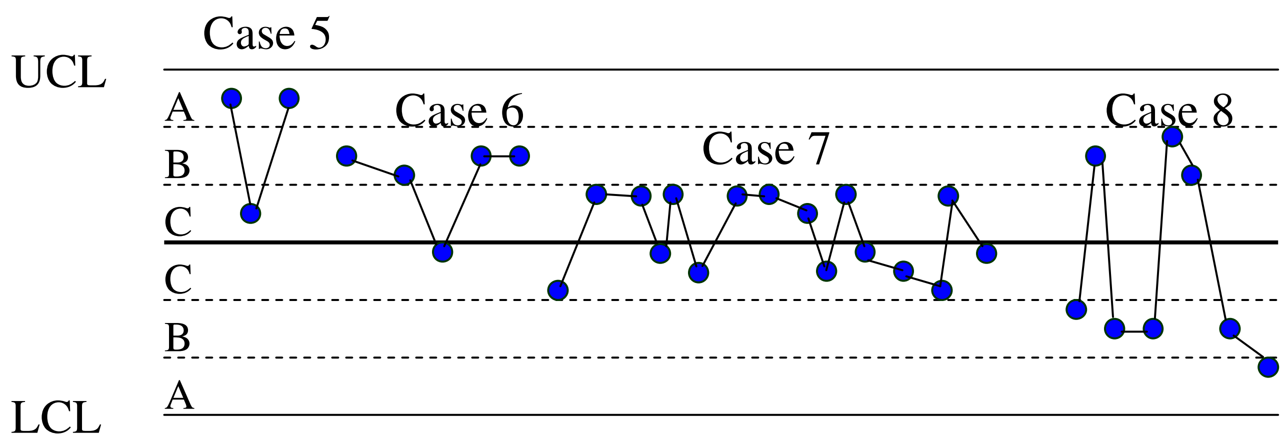
Sample Size	A_2	D_4	D_3	d_2
2	1.880	3.267	0	1.128
3	1.023	2.575	0	1.693
4	0.729	2.282	0	2.059
5	0.577	2.115	0	2.326
6	0.483	2.004	0	2.534
7	0.419	1.924	0.076	2.704
8	0.373	1.864	0.136	2.847
9	0.337	1.816	0.184	2.970
10	0.308	1.777	0.223	3.078

Pattern Analysis of X bar Charts



- Case 1 - one point beyond zone A
- Case 2 - seven points above or below the centerline
- Case 3 - six points in a row increasing or decreasing
- Case 4 - Fourteen points in a row alternating up and down

Pattern Analysis of X bar Charts



- Case 5 - two out or three points in zone A
- Case 6 - Four out of five points in zone B or beyond
- Case 7 - Fifteen points in a row in zone C
- Case 8 - Eight points in a row on both sides of the centerline with none in zone C

Process Capability

- Process capability (C_p) measures the capability of a process to meet specifications.
- A C_p of 1.33 is acceptable however higher values are preferred.

$$C_p = \frac{USL - LSL}{6\sigma}$$

$\mathrm{USL} =$ upper specified limit

$\mathrm{LSL} =$ lower specified limit

$\sigma =$ process standard deviation

$$\sigma \approx \hat{\sigma} = \frac{\overline{\mathrm{R}}}{\mathrm{d}_2}$$

Cpk

- Process capability (Cp) does not account for where the process distribution is relative to the center of the tolerance.
- A process may have a high capability but produce bad parts if it is centered towards one of the specifications.
- Cpk indicates where the process is located with respected to the upper and lower limits of the tolerance.

$$Cpk = \frac{NearestSpec - \overline{\overline{X}}}{3\hat{\sigma}}$$

Attribute Charts

- Sometimes quality characteristics are not measurable other than by pass/fail.
- Other times for economic reasons, variable measurements are not taken such as go/nogo

p chart (fraction defective)

- The p chart measures the output of a process as the number of nonconforming or defective units (Np) in a subgroup of size n.
- Each unit is recorded as being either conforming or nonconforming even if the unit has more than one defect.

Control Limits

$$\overline{P} \pm 3\sqrt{\frac{\overline{P}(1-\overline{P})}{n}}$$

$$\overline{P} = \frac{\sum Np}{\sum n}$$

$Np =$ number defective

n = number of items inspected

Conversion to Np Chart

$UCL_{Np} = UCL_P \times n$

$LCL_{Np} = LCL_p \times n$

c Chart -Nonconformities per Sample

- While the p chart monitors the fraction defective of the process, the c chart monitors the number of nonconformities (defects) per sample(unit).
- Examples of defects on a part are missing rivets on an aircraft wing.

Control Limits

$$C = \pm 3\sqrt{\overline{C}}$$

$$\overline{C} = \sum_{i=1}^{k} \frac{c_i}{k}$$

c_i = number of defects in the i-th sample

k = number of samples

u Chart - Defects per Unit

- Used when the sample size is not consistent.

Average number of defects per unit

$$u = \frac{c}{n}$$

u = number of defects per unit in a subgroup

c = number of defects per subgroup

n = number of units per subgroup

u Chart Control Limits

Centerline of u chart

$$\bar{u} = \frac{\sum_{i=1}^{k} c_i}{\sum_{i=1}^{k} n_i}$$

$$\text{Control Limits} = \bar{u} \pm 3\sqrt{\frac{\bar{u}}{n}}$$

Gage Capability

- Gage capability is the ability of a gage to accurately reflect process characteristics.

$$\sigma_{observed} = \sqrt{\sigma^2 process + \sigma^2 gage\ error}$$

$$\sigma_{gage\ error} = \sqrt{\sigma^2 repeatability + \sigma^2 reproducibility}$$

Gage Capability

- Repeatability
  - the variation in measurements observed with one gage, used several times by one operator, while measuring identical characteristics on the same parts
  - typically due to the measuring instrument not the operators
- Reproducibility
  - the variation in the average of the measurements made by different operators using the same gage while measuring identical characteristics on the same parts
  - typically due to the operator or measurement procedure

Sample Size

- Small enough to achieve the objective that all members of the sample are subject to one fixed system of variation causes
- Large enough to ensure the presence of a normal distribution (4 or more)
- Large enough to enhance the sensitivity to the detection of special causes

Consecutive Sampling

- Used if there are abrupt shifts in the process and those shifts are sustained.
- Minimizes the chance for other than common cause variation within the subgroup to occur.
- Maximizes the chance for special cause variation between subgroups to be detected.
- Examples
  - 5 consecutive measurements at 9:00 a.m.
  - 5 consecutive measurements at 9:45 a.m.
  - 5 consecutive measurements at 10:30 a.m.

Distributed Sampling

- Used if the process experiences frequent abrupt but short-lived shifts in the mean.
- Units in a sample are taken at approximately equally spaced time periods within each sampling interval.

Sampling Pitfalls

- Stratification
  - sample consists of 5 parts taken from 5 seemingly identical machines
  - X bar chart will have very wide limits and the chart will look “too good”
- Mixing
  - samples are taken from a product stream fed by two or more identical machines
  - precludes the detection of special causes attributed to the problems of one machine

Lot-by-Lot Acceptance Sampling Plans

- Not all companies use acceptance sampling.
- Some customers require 0 defects per lot and require the supplier to do 100% inspection onsite if a defective part is found by the customer.
- Single Sampling
  - One sample is taken from a lot and the decision to reject or accept is based on that sample.

Lot-by-Lot Acceptance Sampling Plans

- Double Sampling
  - If the initial sample taken is very good the lot is accepted.
  - If the initial sample taken is very poor, the lot is rejected.
  - If the initial sample taken is marginal, a second sample is taken.
- Multiple Sampling
  - continuation of double sampling
- Sequential Sampling
  - items are sampled and inspected sequentially until there is enough cumulative evidence to accept or reject

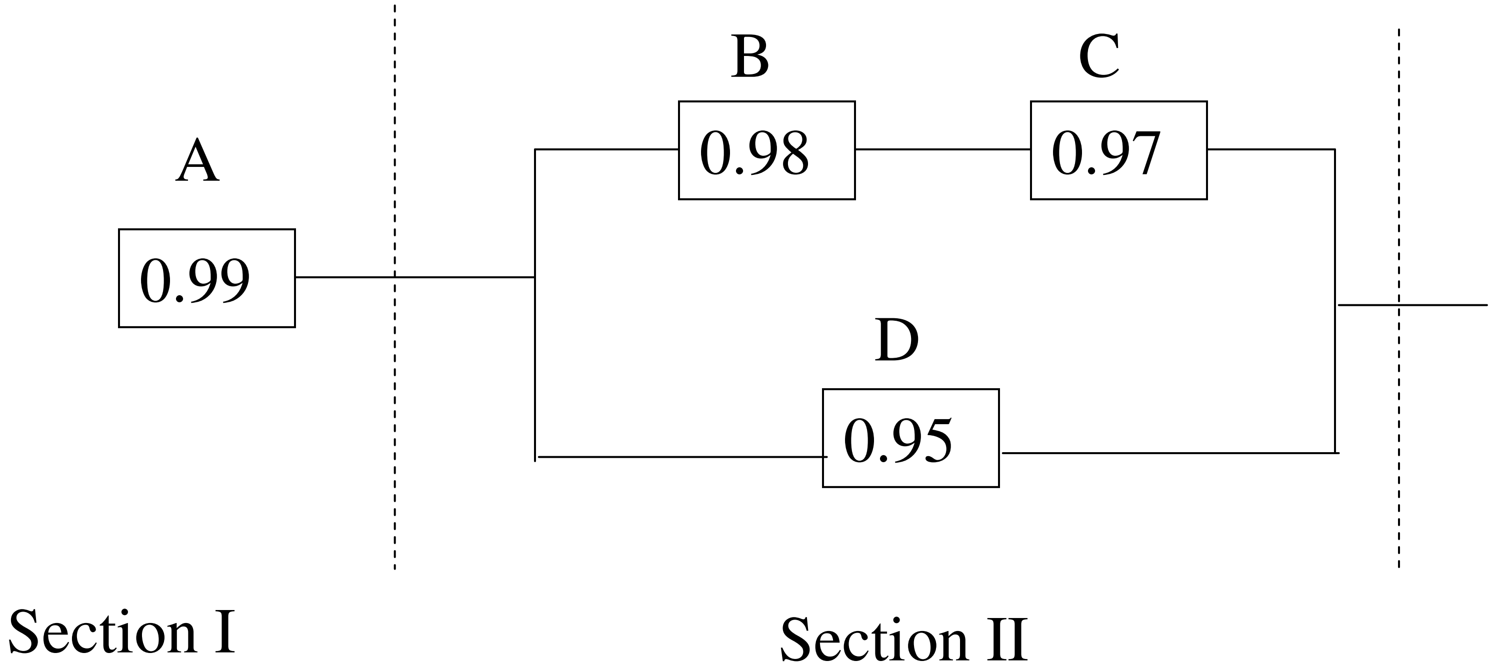
Probability and Reliability

- The probability of *A* or *B* occurring is:
  - $P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B)$
- Mutually exclusive events
  - if two events cannot occur simultaneously
  - For example, in a coin tossing experiment if a head occurs then a tail cannot.
  - $P(A \text{ and } B) = 0$
  - $P(A \text{ or } B) = P(A) + P(B)$

Probability and Reliability

- Independent events
  - if two events can occur in a single experimental trial however one event does not affect the probability of the occurrence of the other
  - For example when tossing a pair of dice, rolling a four on the first die and a four on the second die are independent events.
  - *P(A and B) = P(A) P(B)*

Reliability



- P(system works) = P(I and II)

P(system works)

P(system works) = P(I and II)

P(I) = 0.99

P(II) = P(B and C) or P(D)

P(II) =(0.98)(0.97) + 0.95 - (0.98)(0.97)(0.95) = 0.99753

P(system works) = P(I and II) = 0.99(0.99753) = 0.9875

P(system works) = <u>98.75%</u>

Design of Experiments (DOE)

- The purpose of DOE is to determine which variables have the greatest impact on a quality characteristic.
- Traditionally, process variables were changed one at a time and then their respective effect was compared to a control.
- In other words, change each variable one at a time to see which has the greatest impact on the process.

Faults of Traditional Experiments

- Effects of changing variables repeatedly are not studied.
- Interaction of variables is not studied.
- Many experiments or trials need to be conducted.
  - Statistical trials are also known as monte carlo simulations
- Random errors are compounded or not considered.

Full Factorial Experiments

- Common experiments are called 2-level full factorial which indicates that each variable is tested at 2 levels and all the interaction effects of the variables is determined.
- Experiments can also be run at 3-levels where each variable is tested at high, medium and low levels.
- 2-level full factorial experiments require 2^k trials or runs where k is the number of variables.
- For example,
  - 2 variables require 2^2 trials or runs
  - 4 variables require 2^4 trials or runs

Full Factorial Experiments

- Obviously more variables significantly increases the number of trials and cost.
- It’s a good idea to carefully select the variables prior to designing the experiment.
- Fractional factorial experiments can also be conducted.
  – for example, 4 variables requires 16 trials or runs
  – in a half-factorial design, 8 trials would be run, however, the interaction effect among the variables would not be determined

Replication and Randomization

- Replication means running an experimental design more than once to improve the accuracy of the experiment and help make the results of the experiment more precise.
- Randomization means that the order of the experimental runs is performed randomly.
  - randomization is important in reducing the possibility of systematic error influencing the results

Example Experiment

- Typically in a process there is a quality characteristic that needs to be optimized, for example surface finish.
- From previous experience, variables that effect surface finish are
  – feed rate (R)
  – cutting fluid (F)
- The goal is to determine how to set the variables to achieve the best finish.
- For example the slowest feed rate and fluid A may yield the best finish.
- Or it may be found that it doesn’t matter which cutting fluid is used.

Experiment Design To Maximize Surface Finish

Number of trials = $2^2 = 4$

R= Feed Rate

- (-) 0.200 ipm
- (+) 0.400 ipm

F= Fluid

- (-) Fluid A
- (+) Fluid B

RF is the interaction effect

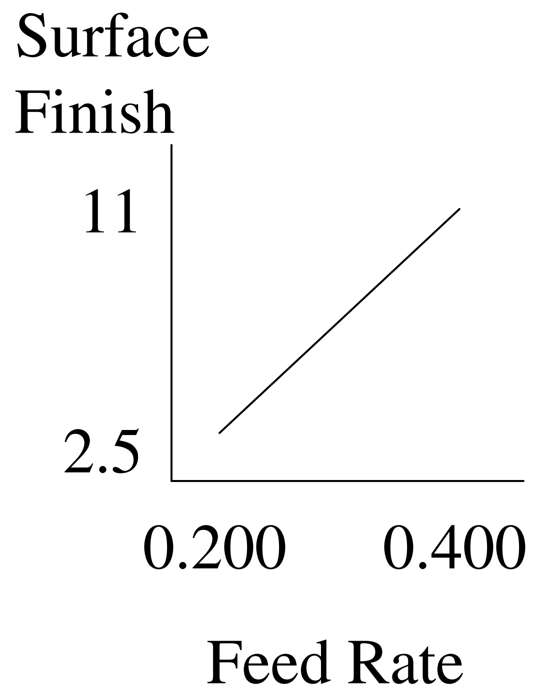
Trial	R	F	RF
1	-	-	+
2	+	-	-
3	-	+	-
4	+	+	+

Experiment Results

Trial	R	F	RF	Surface Finish (*u*m)
1	-	-	+	4
2	+	-	-	12
3	-	+	-	1
4	+	+	+	10

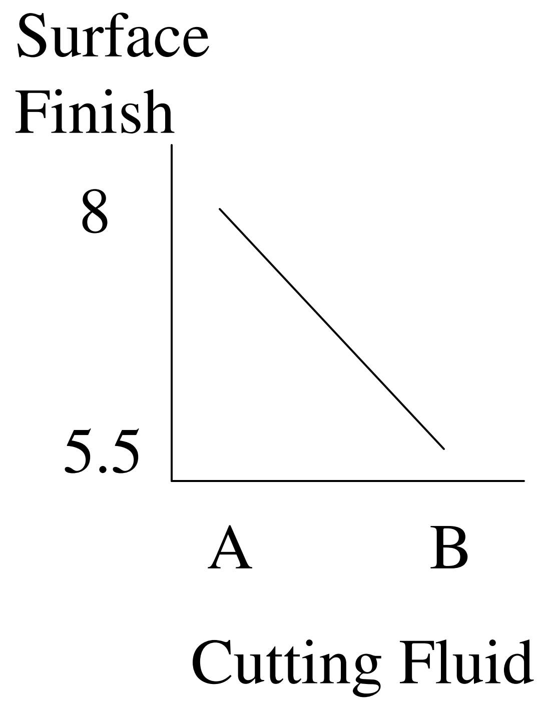
Comparison of Means

- Feed Rate = 0.200
  - (4+1)/2 = 2.5
- Feed Rate = 0.400
  - (12+10)/2 = 11

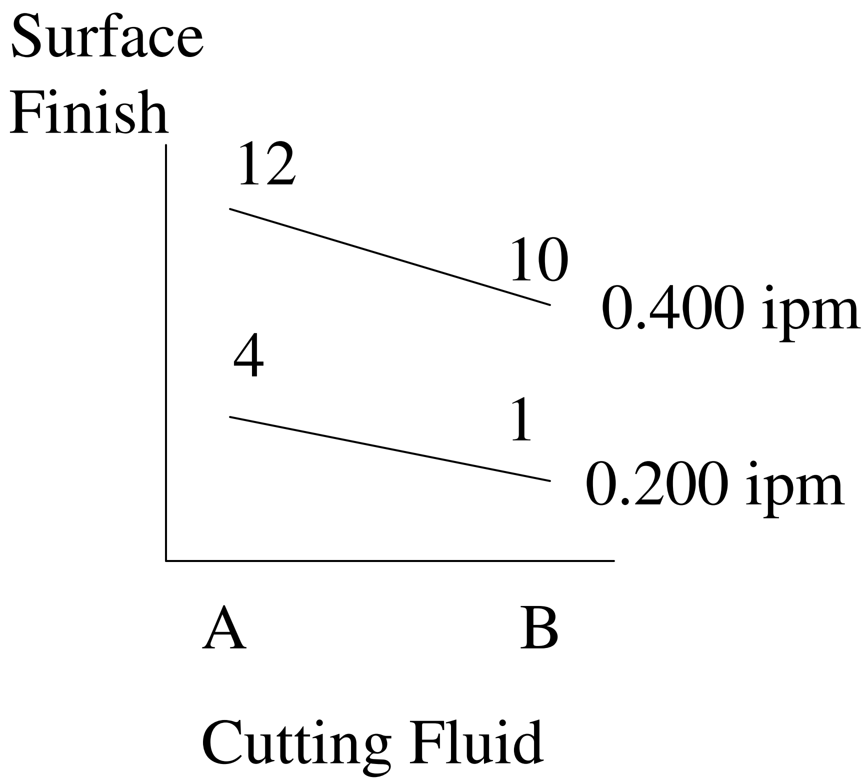


Comparison of Means

- Fluid A
  - (4+12)/2 = 8
- Fluid B
  - (1+10)/2 = 5.5



Interaction Effects



Three Pillars of Experimental Design

- Comparison of means
  – Is there a statistically significant change in the mean response of the quality characteristic in question?
- Comparison of variances via the F-test
  – Is there a statistically significant change in the variance of the quality characteristic in question?
  – Is the change in variance due to noise?
  – Analyze the change in variance due to one factor.
    - For example, does changing the cutting tool geometry reduce the variation of shaft diameters in a turning operation?

Three Pillars of Experimental Design

- Classical analysis of variance (ANOVA)
  - calculates the contribution each factor made to change the variance of the quality characteristic
  - For example, an ANOVA could determine that changing the cutting tool geometry had no effect on reducing the shaft diameter variation however 40% of the reduction was due to changing the cutting speed and 20 % was due to changing the operator.

Regression Analysis

- In some situations, instead of conducting a designed experiment, data are passively gathered over time on one or more quality and/ or productivity measures and on several factors that are felt to impact those measures.
- The data are then analyzed by techniques such as regression analysis in an effort to determine the relationship between the factors and which factors are important.

Taguchi Methods

- Taguchi defines quality as the loss imparted to the customer from the time the product is shipped.
- As a quantitative measure, he defines quality as loss due to variation/ deviation of the product's function from the desired target value as mandated by design.

Taguchi 3-Stage Design Process

- System design
  - apply current technology to arrive at an alternative design
- Parameter design
  - analysis of important factors or parameters of the system design to determine the optimum nominal values for those parameters.
- Tolerance design
  - the use of simulation through mathematical modeling to optimize a design
  - the use of design of experiments methods as a framework for performance evaluation through simulation.
  - “robust design ”
    - levels of the parameters of the product or process are sought that minimize the functional variation in performance caused by external (environmental) variation sources called noise factors.

Loss Function

- The closer the part characteristic is to the design intent (the nominal value), the smaller will be the variation in its performance (smaller functional variation), and so the quality of the part should be considered better.
- It is important to note that given two products that both function at about the same level of performance, the product that performs more consistently (less variation about the nominal) is considered a better product (higher quality).

Factor Classification

- Signal factors
  - selected based on engineering knowledge to attain the desired level of performance
  - examples would be the steering angle in a steering mechanism and the speed control on a fan
- Control factors
  - constitute the product or process parameters that can be set at various levels
  - specified by the designer according to some criterion such as maximizing the performance stability of the design

Factor Classification

- Noise factors
  - Noise factors in the product/ process environment are generally uncontrollable or very expensive to control, although they do influence performance.
  - According to Taguchi, noise factors can only be described in terms of statistical characteristics.
  - Noise factors are further broken down into outer noise, inner noise, and variational noise classifications.

Signal to Noise Ratio

- The signal-to-noise ratio is the ratio of the average response to the root-mean-square of the variation.

$$\frac{S}{N} = \frac{\overline{Y}}{S_Y}$$

where S/N = signal to noise ratio

$\overline{Y}$ = average response

S_Y = root-mean-square variation

Signal to Noise Ratio

- It can also be thought of as the ratio of the variance of the signal to the variance of the noise.

$$\frac{S}{N} = 10\log\frac{\sigma_g}{\sigma_c}$$

where S/N = signal to noise ratio

σ_g = the variance of the signal

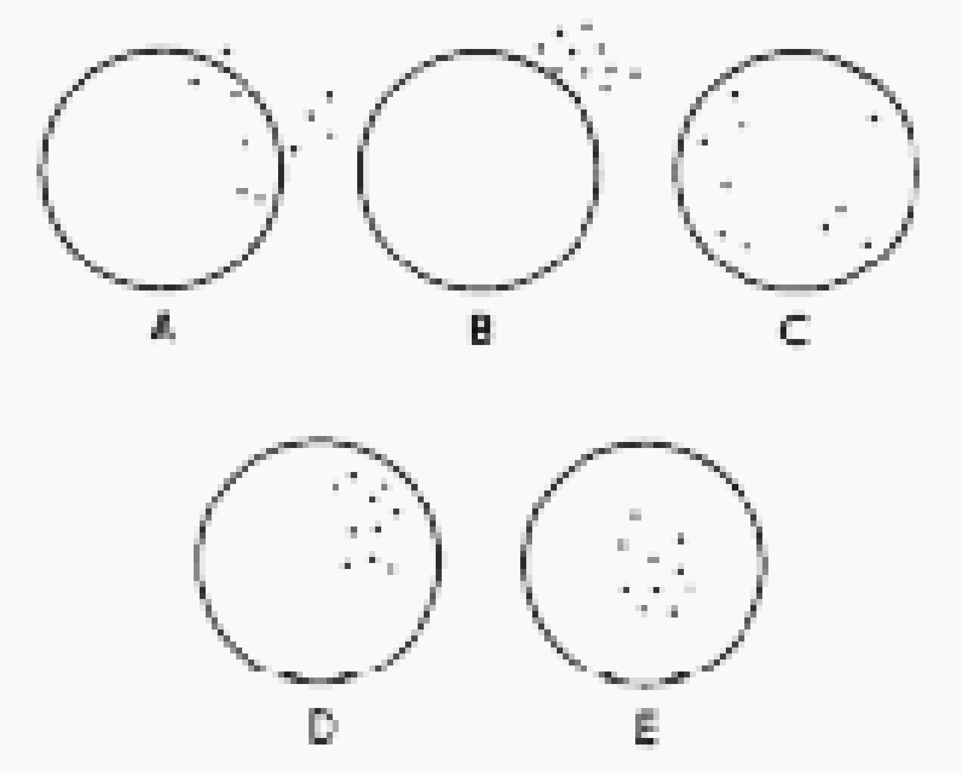
σ_g = the variance of the noise

Signal to Noise Ratio

- Increasing the signal-to-noise ratio means increasing the signal or decreasing the noise or a combination thereof.
- In a fatigue failure problem for example, increasing the signal may mean increasing the wall thickness while decreasing the noise may mean studying design configuration changes that would reduce stress variation for the same general external loading conditions (reduce the noise).

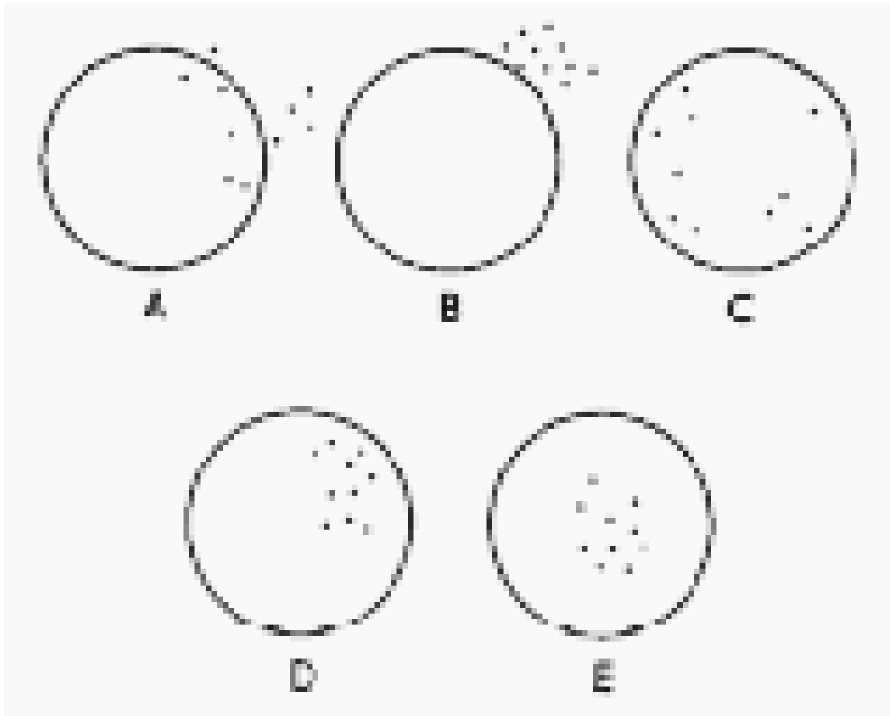
Dimensional Metrology

- **Accuracy** is the closeness to the true answer.
- **Precision** refers to the dispersion of measurements or fineness of the readings.
  - Marksman B is very precise but not very accurate.
  - Marksman E is both precise and accurate.



Dimensional Metrology

- **Reliability** is the probability of achieving a desired outcome.
  - Marksman D and E are precise however marksman E is more reliable than D.
  - If the wind shifts or another variable changes marksman E has a higher probability of having more shots in the target than marksman D.



Dimensional Metrology

- **Repeatability** of a group of measurements taken with the same instrument on the same part is the extent to which they are in agreement.
  - repeatability is a test of precision not accuracy
- **Sensitivity** is the minimum input required to produce a noticeable output.
- **Resolution** is the ratio of one scale division to the width of the dial hand of a dial indicator. The finer the resolution of the gage the smaller the range.

Dimensional Metrology

- **Discrimination** refers to the fineness of an instrument's scale divisions.
  - smallest division of an instrument's scale that can be read reliably

Length Standards - Gage Blocks

Grade	**Tolerance (in)**	**Application**
0.5 (grand master)	+/- 0.000001	Extremely high precision gaging work.
1 (laboratory-grade)	+/- 0.000002	Used for checking and calibrating other grades of gage blocks.
2 (precision-grade)	+0.000004 - 0.000002	Used as inspection and tool room standards.
3 (working-grade)	+0.000008 - 0.000004	Used as shop standards.

Testing

- Destructive Testing
  - tensile test
  - hardness test
  - chemical etching
- Nondestructive Testing
  - ultrasonic inspecting
  - magnaflux
  - liquid penetrant

Ultrasonic Inspection

- Superior penetrating power, permitting detection of flaws deep in the part.
- Ability to detect extremely small flaws.
- Only one surface needs be accessible.
- Parts that are rough, irregular in shape, very small or thin, or not homogeneous are difficult to inspect.
- Discontinuities that are present in a shallow layer immediately beneath the surface may not be detectable.
- Couplant is needed to provide effective transfer of the ultrasonic beam between the transducer and part being tested.

Magnetic Particle Inspection

- The magnetic particle method is a sensitive means of locating surface and near-surface cracks in ferromagnetic materials.
- The size and shape of the parts inspected by this method are almost unlimited.
- Elaborate precleaning is not necessary, and cracks filled with nonmagnetic foreign materials can also be detected.
- Magnetic particle inspection does not work with nonmagnetic materials.
- Demagnetization after inspection is often necessary.

Liquid Penetrant Inspection

- Can be used to inspect all types of surface cracks, porosity, laminations, and bond joints.
- Portable penetrant kits can be used in the field.
- High-sensitivity fluorescent penetrants are capable of identifying extremely small flaws.
- Can only finds flaws that are open to the surface of the part.
- The part must be clean and dry.
- Rough or porous surfaces produce heavy background indications making it difficult to locate small defects.
- Wire brushing, shot peening, and sanding also create problems for liquid penetrant inspection techniques.

Part 7
Manufacturing Management

What is Planning?

- Planning As A Central Control System
  - management should have a comprehensive planning and information system covering the total enterprise
- Planning As a Framework for Innovation
  - the plan should serve as a stimulus for local initiative
- Planning As a Social Learning Process
  - management should use the process as a means of learning about the environment and the system which they are managing

Top-Down Planning

- Effectiveness results from top-down planning with bottom-up implementation.
  - the overall strategy should be formulated at the top of the organization and handed down to lower levels of the organization for implementation
- Bottom-up formulation with top-down implementation
  - many companies possess in their lower levels a vast reservoir of creative energy that can be successfully harnessed

Planning Levels

- Industry-Level Strategy
  - strategic concerns revolve around broad issues such as the strategic alliances within the industry; incentives for investment; import and export trade barriers, duties, and quotas
- Corporate-Level Strategy
  - concern revolves around the definition of businesses in which the corporation wishes to participate, and the acquisition and allocation of resources to these business units

Planning Levels

- Business-Level Strategy
  - generally referred to as strategic business unit (SBU) or strategic planning unit (SPU), three critical issues are specified:
    - the scope or boundaries of each business and the operational links with corporate strategy
    - the basis on which the business unit will achieve and maintain a competitive advantage within its industry
    - the form (if any) of the strategic alliances between the business unit and other participants in the industry

Planning Levels

- Functional-Level Strategy
  - specifies how functional-level strategies like marketing/sales, manufacturing, research and development, and accounting/control, will support the desired competitive business-level strategy

Planning Horizons

- Strategic Planning (5 years and beyond)
  - Which businesses should the firm be in?
  - How should they be financed?
  - How should scarce resources be allocated across business sectors?
- Tactical Planning (1-5 years)
  - What are the optimal patterns of capital investment and divestment for implementing some longer range plan?
  - What decisions about facility location, expansion, or shutdown will maximize profitability?

Planning Horizons

- Operations Planning (1-12 months)
  - What is the optimal operating plan (raw material acquisition, product sources, inventory levels, etc.) to meet specified system objectives, consistent with some longer term plan, with existing facilities.
- Scheduling and Dispatching (Right now)
  - What specific operations or sequences of operations should be performed with which existing facilities, to meet specified output requirements in the next operational period (for example, hour, day, week)?

Evolution of Management Practice

- Charles Babbage - 1792-1871
  - better know for inventing the difference engine
  - studied the use of machines and the organization of humans for that purpose
- Henry R.Towne - 1844-1924
  - first industrialist to publicly recognize that it was important to train people to manage enterprises more effectively
- Fredrick w. Taylor 1856-1915
  - “Father of scientific management”
  - known for his focus on identification of the various elements of each task

Evolution of Management Practice

- Frank Gilbreth 1868-1924, Lillian Gilbreth 1878-1972
  - advocate of time and motion studies but also pioneered motion pictures as a tool for analyzing movement.
  - micromotion - motion picture taken as constant and known speeds
  - memomotion - slow film speeds for long tasks
- Henry Fayol - 1841-1925
  - European industrialist concerned about improving the management of industry

Management of the Organization

- Centralization
  - localized authority, authority resides in one person
- Decentralization
  - delegate authority, the more important decisions are made at lower ranks

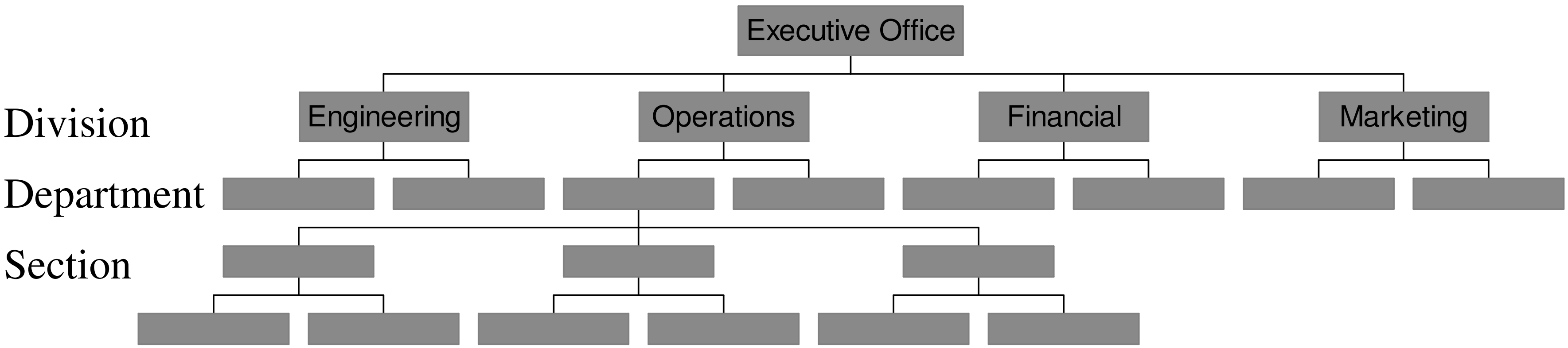
Organizational Structures

- Organizations must be dynamic in nature.
- They must be capable of restructuring should environmental conditions dictate.
- Major factors behind the organizational revolution.
  - the technology revolution
  - competition and profit squeeze
  - high cost of marketing
  - unpredictability of consumer demands

Definitions

- Authority
  - power granted to individuals so they can make final decisions for others to follow
- Responsibility
  - obligation incurred by individuals in their roles in the formal organization in order to effectively perform assignments
- Accountability
  - state of being totally answerable for the satisfactory completion of a specific assignment

Traditional Management Structure (Line and Staff)



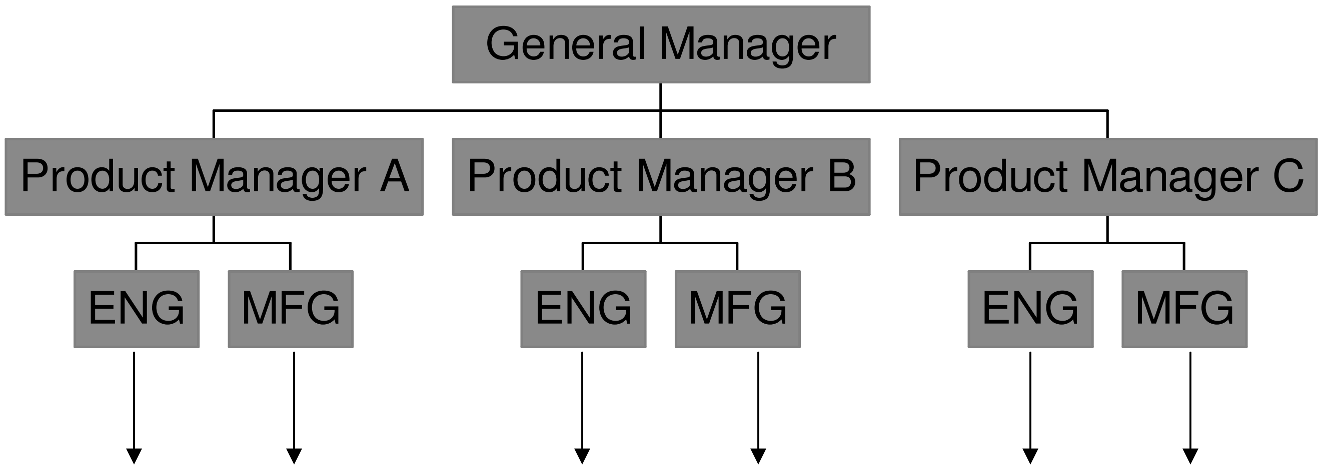
Line and Staff

- Line and staff
  - line relationships are established by the flow of authority
  - staff relationships are advisory
- Span of management
  - same as span of control
  - the number of subordinates that report to one supervisor

Traditional Management Structure

- Advantages
  - easier budgeting and control
  - communication channels are well established
- Disadvantages
  - decisions favor the strongest functional group
  - coordination becomes complex

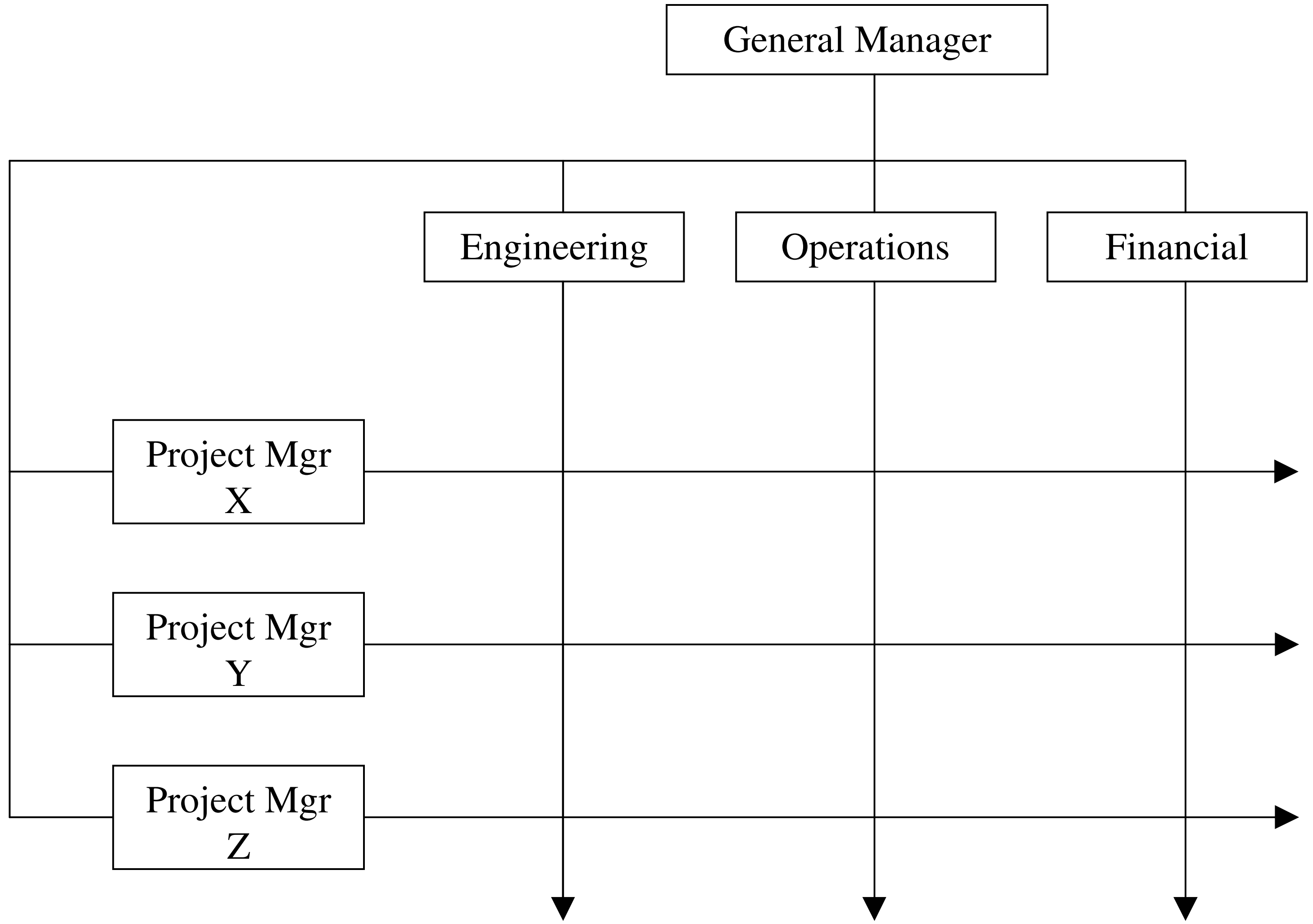
Pure Product Structure



Pure Product Structure

- Advantages
  - provides complete line authority over the project
  - project participants work directly for the project manager
  - strong communication channels
- Disadvantages
  - cost of duplicate efforts
  - retain personnel on projects long after they are needed
  - lack of opportunities for technical interchange between departments

Pure Matrix Structure



Pure Matrix Structure

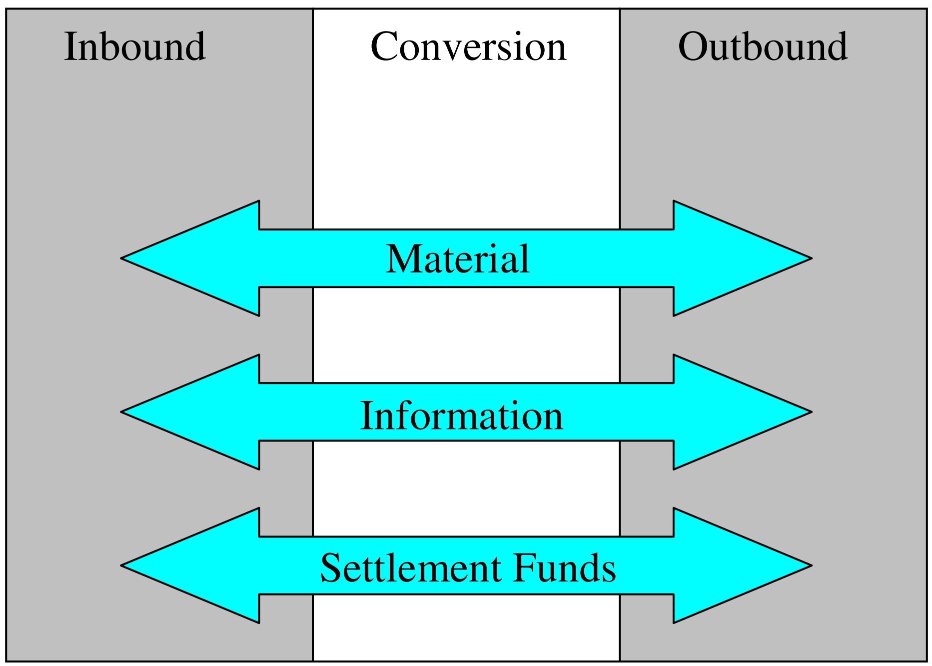
- Advantages
  - project manager maintains maximum project control
  - policies and procedures can be set up differently for each project
  - rapid response to changes
  - project teams develop when needed
- Disadvantages
  - multidimensional information flow
  - dual reporting

Organizational Form Selection Factors

- Interdependencies among subunits
- Level of technology
- Presence of economies of scale
- Organizational size
- Diversity of product lines
- Rate of change of product lines

Supply Chain Management

- Supply chain management is the task of coordinating and tuning the chain of business entities to accept and fulfill customer's orders.



Supply Chain Categories

- Manufacturing Oriented Supply Chain
  - emphasis on factory capacity and production scheduling
  - automotive
- Purchasing Oriented Supply Chain
  - emphasis on efficient procurement from steady, reliable sources
  - consumer electronics and appliances
- Distribution Oriented Supply Chain
  - emphasis on replenishment and transportation
  - oil and gas

Integration

- Vertical Integration
  - A vertically integrated pipe producer, for example, may own its own steel mill and mining operations in addition to its pipe mill.
- Horizontal Integration
  - For example, manufacturing, people, technology, and business processes can be integrated via computer/communication systems, reducing the levels of hierarchy in the system.

Theory of Constraints

- Emphasizes the need to identify and manage constraints or bottlenecks.
- Attacks bottlenecks and constraints because they significantly limit the level of value a firm can generate.
- Balances work flows in a way that accommodates unavoidable variance.

Management Schools

- Classical/Traditional
  - Management is the process of getting things done, with little regard for the people involved.
- Empirical
  - Managerial capabilities can be developed by studying the experiences of other managers, whether or not the situations are similar.
- Behavioral
  - Management emphasizes personal relationship between individuals and their work.
- Decision Theory
  - Management is a rational approach to decision making using a system of mathematical models and processes.

Management Responsibilities

- Planning
- Organizing
- Staffing
- Controlling
  - measuring
  - evaluating
  - correcting
- Directing
  - staffing
  - training
  - supervising
  - delegating
  - motivating
  - counseling
  - coordinating

Theory X

- Theory X assumes that:
  - average worker dislikes work and avoids work whenever possible
  - to induce adequate effort, the supervisor must threaten punishment and exercise careful supervision
  - average worker avoids increased responsibility and seeks to be directed
- Theory X managers normally exercise authoritarian-type control and allow little participation during decision making.

Theory Y

- Theory Y assumes:
  - average worker wants to be active and finds the physical and mental effort on the job satisfying
  - greatest results come from willing participation which will tend to produce self-direction toward goals without coercion and control.
  - average worker seeks opportunity for personal improvement and self-respect
- Theory Y managers normally advocate participation and a management-employee relationship.

Theory Z Managerial Style

- Bottom-up process
  - initiative, change, and problem solving are accomplished best by those who are closest to the problems
- Senior management as a facilitator
  - facilitate inquiries
- Middle manager as an initiator and coordinator
  - understand the nature of the problems, formulate tentative solutions, coordinated with other managers and present solutions to senior management

Theory Z Managerial Style

- Decision by Consensus
  - reach a common decision based on discussion among all the functional areas
  - each employee may not sign off on the decision but they must consent that their point of view was heard
- Concern for the Employee
  - concern for the whole employee not just his/her work performance

Types of Teams

- Informal Sense of Team
  - “We are all in this together.”
- Traditional Work Units With a Supervisor
  - Departments, crews, staff
- Problem-solving Task Forces, Committees
  - Quality circles, problem solving teams
- Leadership Teams
  - Advisory teams, steering committees
- Self-directed Work Teams
  - self-regulating work groups, area supervision

Components of Effective Teams

- Clear sense of direction
- Talented members
- Clear and enticing responsibilities
- Reasonable and efficient operating procedures
- Constructive interpersonal relations
- Active reinforcement relations
- Constructive external relations

Team Facilitator (Coach)

- Focuses on the processes of the team.
- Remains neutral and helps the team operate smoothly.
  - prepares for meetings
  - creates a tentative agenda
  - plans for completing the meeting work
  - informs team members of the meeting time

Nominal Group Technique

- Arrive at a group consensus regarding things that are difficult to quantify
- Each person in the group is given an equal voice in
- making the decisions
- Participants will likely agree with the outcome
- They will feel committed to the direction that is determined through using the technique

Delphi Technique

- A group of participants with different skills but with experience applicable to the problem in question are assembled.
- The participants make anonymous, subjective judgements or suggestions for solving the problem.
- The results are compiled by the team coordinator and distributed to the team for another round of suggestions.
- After at least 75% of the team agrees on a solution the process stops.

Focus Groups

- Typically, the focus group is conducted in a room that seats up to 10 participants and the moderator.
- Participants are recruited randomly (a rare occurrence), or from clubs, organizations and church groups, etc.
- A session begins with an introduction by the focus group moderator, who explains the purpose of the discussion, and sets important discussion rules.
- The moderator controls the flow of discussion by probing, summarizing, and paraphrasing, and by direct questioning if necessary.
- The group discussion progresses and a consensus usually develops.

Management Pitfalls

- Lack of self-control
  - knowing ones’s capabilities and weaknesses
- Activity traps
  - when the means become the end
- Managing vs. doing
  - in some cases good managers must become doers
- People vs. task skills
  - utilize people with good relationships or people who can get the job done

Management Pitfalls

- Ineffective Communications
- Time Management
  - putting in many hours does not necessarily mean good management
- Management Bottlenecks
  - most management bottlenecks are created by poor communications

Conflict Environment

- Most common conflicts involve:
  - manpower resources
  - capital expenditures
  - technical opinions and trade-offs
  - priorities
  - scheduling
  - personality clashes
  - administrative procedures

Managing Conflict Modes

- Withdrawal
  - retreating from an actual or potential disagreement
- Smoothing
  - de-emphasizing or avoiding areas of difference and emphasizing areas of agreement
- Compromising
  - bargaining for solutions that bring some satisfaction to all parties involved
- Forcing
  - exerting one's viewpoint at the potential expense of another (win/lose situation)
- Confrontation
  - facing the conflict directly which involves a problem-solving approach whereby affected parties work through disagreements

Employee Motivation Weaknesses

- Disincentives
  - lack of connection between employee effort and pay
- Managers who don't motivate
  - failure of managers to motivate people to perform effectively
- Mismatch between people's values and existing reward system
  - gap between what employees value and the rewards they receive
- Confusion between job satisfaction and productivity
  - a satisfied worker is not always an effective worker

Motivation

- Content Theories - motivation is to identify the “thing,” the immediate trigger for the way a person behaves.
  - Maslow
  - McClelland
  - Herzberg
- Process Theories - the process that individuals go through in coming to a decision about whether they wish to behave in a certain way
  - Equity
  - Expectancy
  - Behaviorist
  - Goal Setting

Maslow - Hierarchy of Needs

- Self-Actualization needs (highest level)
  - desiring to utilize one's potential and constant self-development
- Esteem needs
  - self-esteem, reputation, esteem of others, recognition, and self-confidence
- Social needs
  - love, belonging, togetherness, approval, and group membership
- Safety needs
  - economic security and protection from harm, disease, and violence
- Physiological needs (lowest level)
  - food, water, etc.

Hierarchy of Needs

- Once a need becomes satisfied, men/women are no longer motivated unless there is a lower-level need that motivates them further.
- Fulfilled needs are not motivators.

McClelland Approach

- He suggested a model that relates needs of leaders and followers in terms of power, achievement, and affiliation.
- Each individual may have a need to give or receive each of these factors to some degree.
- By recognizing the extent of these needs in each individual, organizations can provide for need satisfaction and consequently increased productivity.

Herzberg Approach

- He suggests a two-factor approach,
  - motivators or satisfiers
  - hygiene factors or dissatisfiers
- The organization has a normal duty to prevent dissatisfaction by providing acceptable levels of a quality work environment and reasonable supervision.
- Without these, individuals become dissatisfied and less productive.

Equity Theory

- Equity theory looks at how individuals weigh the relationship between their input, such as effort, experience, education, and the like, and the output received, such as various rewards and returns from the organization.
- In addition to the ratio of output received to input given, the individual compares his or her own ratio to that of others.

$$\frac{\text{Outcome(individual)}}{\text{Input(individual)}} = \frac{\text{Outcome(other)}}{\text{Input(other)}}$$

Expectancy Theory

- For a given level of effort, the individual learns the likelihood (probability) of resulting success.
- This successful performance may or may not result in a reward. The outcome will have a certain value to the individual.
- If all of the variables and linkages are high enough and likely enough, then the individual will be motivated to try again (effort).

Behaviorist Approach

- The behaviorist approach is not concerned with the thinking processes of an individual, but only with his or her actions.
- If the behavior is good, the leader rewards; if it is not, the leader is likely to not react (punishment for poor behavior is not usually imposed).

Goal Setting (Management by Objectives)

- Establish a set of objectives for each person in an organization against which his or her performance will be measured in coming coming months.
- It is important to develop an action plan capable of delivering the objectives.
- Objectives are contingent on management supplying certain resources.
- Objectives should be written in a manner that makes them possible to evaluate.

Job Enlargement and Enrichment

- Job Enlargement
  - Jobs are more motivating if a person has responsibility for doing a larger portion of the work.
  - A greater variety of work over a longer cycle is believed to relieve some of the job boredom.
- Job Enrichment
  - Building autonomy into the job where the person's decision-making authority is increased.
  - Autonomy is the extent to which a person has authority to make decisions about the work.
  - As autonomy increases, so does motivation.

Leadership Theories

- Leadership is the ability to influence others toward the achievement of goals.
- The source of this influence may be the formal role held by the leader, such as the role of manager.
- Not all leaders are managers, nor are all managers leaders.
  - Trait Theory
  - Leader Behavior Theory
  - Situational Theory
  - Normative Theory
  - Path-goal Theory

Trait Theory

- A few qualities that correlate very slightly with the effective leader are intelligence, dominance, self-confidence, a high energy level, and knowledge relevant to the task.
- Correlation's between these characteristics is small.

Leader Behavior Theory

- Study the behavior that effective leaders exhibit and, from this information, make decisions about the development of leadership skills for those in the designated roles.
- The job-centered leader practices close supervision so that subordinates may know specifically what is expected of them.
  - The human element is not viewed in a negative light by the job-oriented leader, but rather is seen as a luxury.

Leader Behavior Theory

- The employee-centered set of behaviors includes delegating decision making, thereby creating a supportive environment that will permit subordinates to achieve and grow.
  - These people-oriented approaches lead to more cohesive groups, greater job satisfaction, lower absenteeism, and somewhat higher group productivity.
  - Productivity is not ignored by the leader, but rather is treated as an aspect that will take care of itself after the people concerns are addressed.

Situational Theories

- The concept behind so-called situation theories is that the leader's choice of effective behavior should depend in part on the circumstances under which the leader will act.

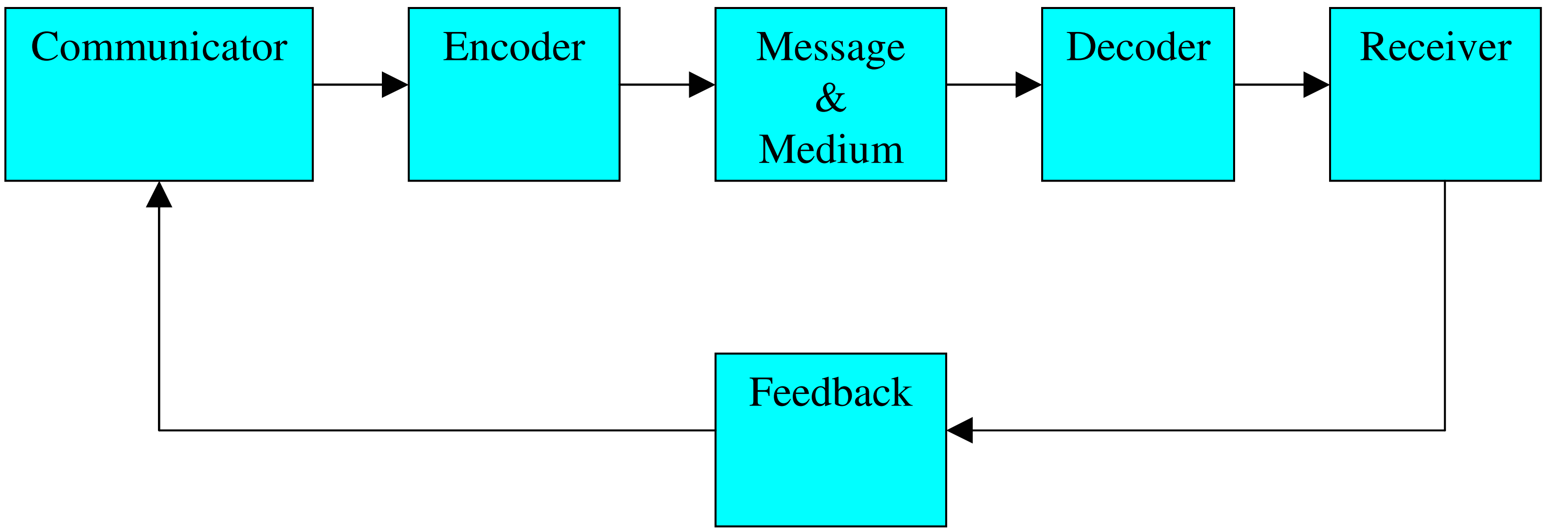
Normative Theory

- A situation theory that gives the leader a set of rules (norms) to guide his or her behavior.
- This is then a decision-making theory that uses two criteria for measuring the effectiveness of a decision.
  - Decision quality refers to the effect a decision may have on job performance.
  - Acceptance refers to the need for followers to be committed to or accepting of a decision.

Path-Goal Theory

- The effectiveness of a leader is measured by a positive impact on the motivation of the followers, their ability to perform well, and their satisfaction.
- The model focuses on how the leader influences the perceptions held by subordinates of their own work goals, personal goals, and the means by which they can and should reach those goals.

Communication Model



Communication

- Communication effectiveness can be evaluated by the degree to which the receiver obtains the message as intended by the sender.
- Communication barriers
  - nonverbal cues
  - selective listening
  - jargon
  - perceived credibility of the source
  - filtering based on personal agendas

Communication

- Graphics is an important complement to oral or written communication.
- A person remembers:
  - 10% of what is read
  - 20% of what is heard
  - 30% of what is seen
  - 50% of what is seen and heard

Project Management

- Project Control Tools
  - PERT (Program Evaluation and Review Technique)
  - CPM (Critical Path Method)
  - Gantt charts
  - Force field analysis

Program Evaluation and Review Technique (PERT)

- PERT assists project managers in their scheduling efforts when it is difficult to predict the time to complete various jobs or activities.
- PERT determines the probability of meeting specified deadlines by development of alternative plans.
- PERT has the ability to evaluate the effect of changes in the program such as a contemplated shift of resources from less critical activities to bottleneck activities.

Program Evaluation and Review Technique (PERT)

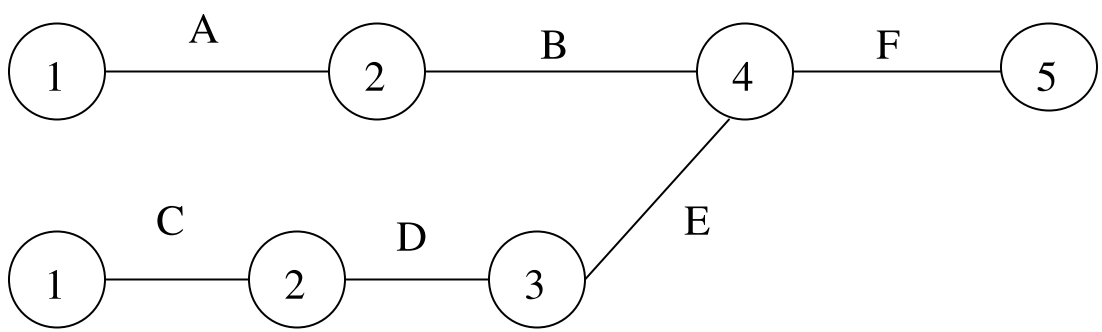
- The heart of PERT is the construction of a network that comprises all tasks and milestones of the project.
- These tasks and milestones are then linked together in a flow network represented by circles called events.
- Successive events are connected by arrows indicating the direction and content of the activity.
- These activities, or tasks, may be related in series or in parallel relationships, as required of the project plan.

Critical Path Method (CPM)

- Primarily developed for scheduling and controlling industrial projects where job or activity times were considered known.
- CPM identifies the sequence of activities or operations which takes the longest. The longest sequence or “critical path” determines the total length of the project.

Critical Path Example

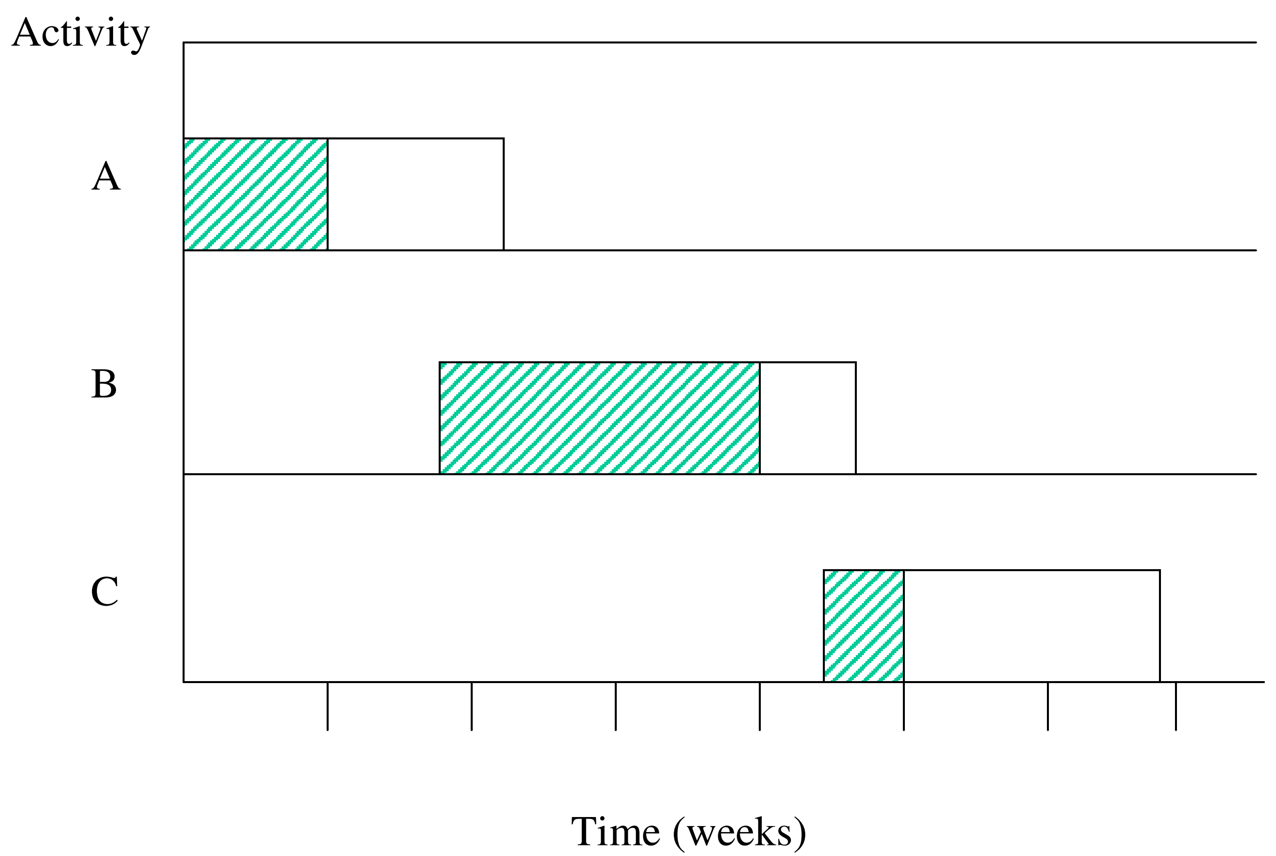
- In the following routing if process 1 through 5 take the same time then the critical path would be C, D, E, F.



Gantt Charts

- A Gantt chart is a graphical tool that enables operations managers to know exactly what activities should be performed at a given time and to monitor daily progress of an activity and take corrective action when necessary.

Gantt Chart



Force Field Analysis

- At any point in time during the life cycle of a project there exist forces that push the project toward success and restraining forces that induce failure.
- In a steady state environment, the driving forces and restraining forces balance.
- Can be used to:
  – monitor the project team and measure potential deficiencies
  – audit the project on an ongoing basis
  – measure the sensitivity of proposed changes
  – involve project personnel (team-building)

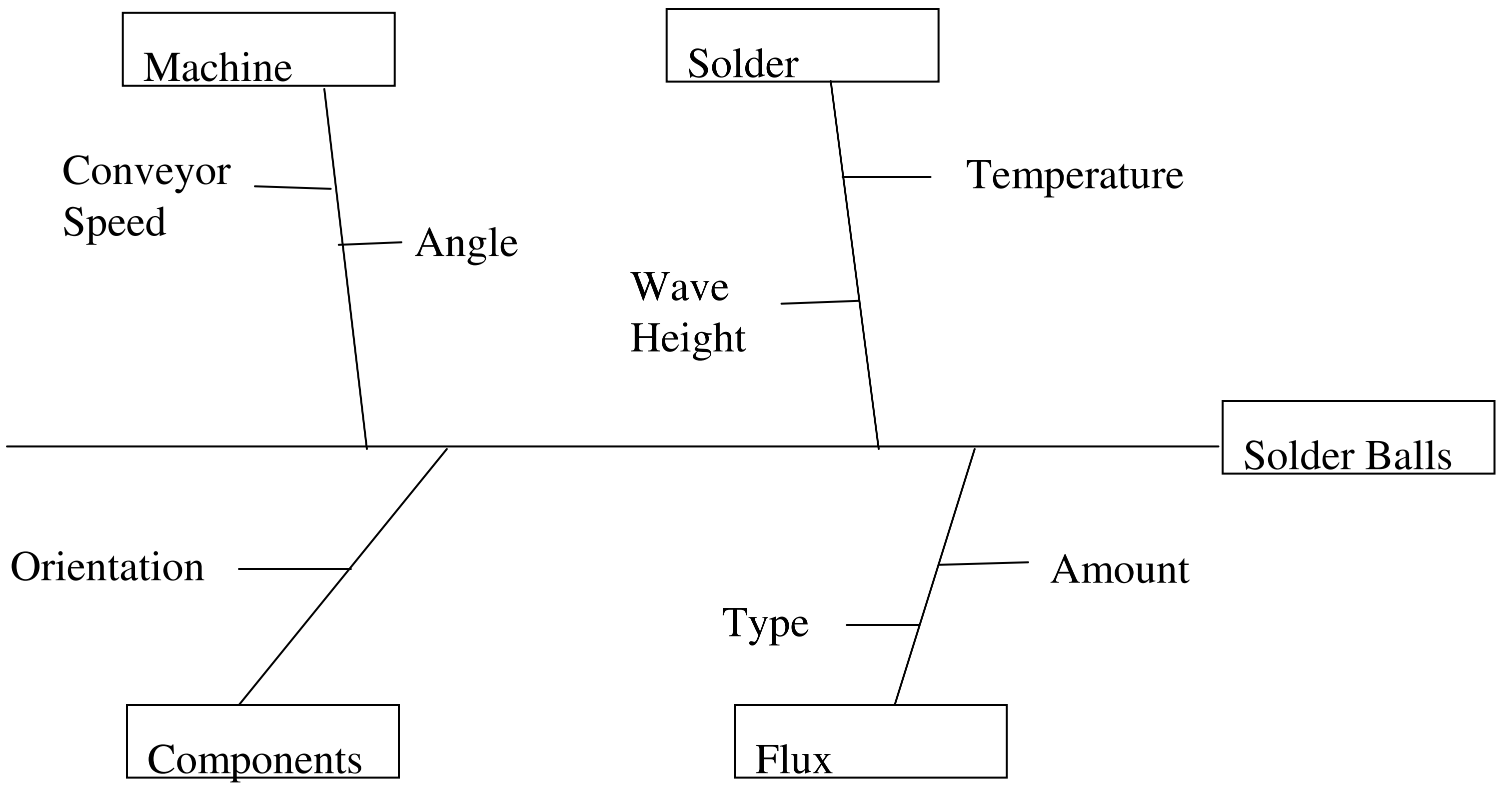
Manufacturing Management

- Problem Solving Tools
  - Ishikawa diagram or fishbone diagram
  - Pareto charts
  - brainstorming
  - control charts

Ishikawa Diagram

- An Ishikawa Diagram also know as a cause-and-effect diagram or a fishbone diagram is a graphical method for quality problem identification.
- Quality characteristics (effect)
- Causes
  - man
  - machine
  - material
  - method

Ishikawa Diagram



Pareto Analysis

- A few process characteristics (vital few) cause most of the quality problems, whereas most process characteristics (trivial many) account for a small portion of the quality problems.

Intellectual Property

- Patents
- Licenses
- Copyrights
- Trade Secrets
- Trademarks

Patents

- Patents stimulate creativity and inventiveness by making inventions visible to the public to induce further inventiveness.
- Patent rights generally consist of the exclusive right, for a limited time, to manufacture, use, and sell the patented invention and to exclude others from so doing.
- The patentability of an invention depends on three essential criteria:
  - newness or novelty
  - usefulness or utility
  - nonobviousness

Patents

- In the United States, a patent is granted for a term of 17 years from the date of issue and will be granted only to the inventor or inventors.
- The infringement of a patent consists of the unauthorized exercise of any rights granted to the inventor, such as unauthorized manufacture, use, or sale.

Licenses

- Often companies, for various reasons, can not directly capitalize on their patents.
- Two options exist:
  - manufacture the invention and license other organizations to market it
  - license other organizations to manufacture, use, and market the invention

Copyrights

- U.S. code defines a copyright as "original works of authorship fixed in any tangible medium of expression, now known or later developed, from which they can be perceived, reproduced, or otherwise communicated, either directly or with the aid of a machine or device. "
- Protection extends to written, pictorial, audio, and theatrical works, but not to ideas, processes, principles, and the like.

Trademarks

- A trademark “includes any word, name, symbol, or device, or any combination thereof adopted and used by a manufacturer or merchant to identify his goods and distinguish them from those manufactured or sold by others. ”
- As with patents and copyrights, trademarks enjoy legal protection.
- A trademark offers a monopoly of sorts, because it provides the owner with the exclusive right to use the mark.

Trade Secrets

- A trade secret is simply a means used in the business world for restricting information on formulas, designs, systems, or compiled information, thus giving the organization an opportunity to obtain an advantage over competitors who do not know or use the secret.
- In many cases, an organization would rather avoid the time, expense, and risk involved in the more common patent procedures; they choose therefore to enshroud the project with secrecy and capitalize on it immediately.

Legal Liability Theories

- Negligence
  - reasonable and prudent care has not been taken in manufacturing the product
- Breach of express warranty
  - when representations are made, often in advertisements or sales agreements, that the product does not meet
- Breach of implied warranty
- Strict liability
  - when a defect exists in a product that makes the product unreasonably dangerous to use and thus causes harm

Labor Relations

- Congress enacted the National Labor Relations Act (Wagner Act) in 1935.
- It was amended in 1947 by the Taft-Hartley Act, also known as the Labor Management Relations Act (LMRA).
- In 1957 the law was further amended in part by the Landrum-Griffin Act, also known as the Labor-Management Reporting and Disclosure Act.
- The rights specifically provided in the Labor Management Relations Act, as amended, do not apply to certain categories of workers such as independent contractors, supervisors, and public employees.

Types of Unions

- Closed non-union shop
  - no one belonging to a union may work in this shop
- Open shop
  - employees are not required to join a union
  - "right to work" laws forbid an employer form forcing someone to join a union to keep his/her job
- Exclusive bargaining shop
  - union is the bargaining agent for all employees, even nonunion members
- Agency shop
  - does not require union membership but does require nonmembers to pay equivalent dues

Basic Rights of Employees

- The right to self-organization.
- To form, join, or assist labor organizations.
- To bargain collectively through representatives of their own choosing.
- To engage in other concerted activities for the purpose of collective bargaining or other mutual aid or protection.
- To refrain from any or all such activities except to the extent that such right may be affected by an agreement requiring membership in a labor organization as a condition of employment.

Basic Rights of Employees

- Employees cannot be prevented from:
  - forming or attempting to form a union
  - assisting a union in organizing
  - striking to secure better working conditions
  - refraining from organizing should they so choose
- It is important to recognize that the rights specified are rights granted to individuals who choose to act collectively.

Collective Bargaining

- Requires an employer and the employee's representative to meet at reasonable times to confer in good faith with respect to wages, hours, and other terms or conditions of employment.
- Neither management nor labor may refuse to bargain collectively with the other.
- The obligation to bargain collectively does not require either party to concede or agree to a proposal by the other.

Collective Bargaining

- First, a party seeking modification or termination must provide the other party written notification 60 days prior to the expiration of the agreement of a proposal for termination or modification.
- Second, the party must offer to meet and confer with the other party to negotiate a new collective bargaining contract.
- Third, after notice to the other party, the Federal Mediation and Conciliation Service must be notified of the existence of a dispute.
- Finally, neither party can resort to a strike or lockout until 60 days after notice to the other party.

Right to Strike

- An employee's right to strike may not be impeded or diminished.
- An employee's right to strike assumes the strike is lawful, which will depend on the purpose of the strike, its timing, and on the conduct of the strikers.
- A strike that has a lawful purpose, such as higher wages or better working conditions, may become unlawful because of the conduct of the strikers, such as blocking the entrance or exit of a plant, threatening violence against nonstriking employees, or attacking management representatives.

Right to Strike

- Employees who participate in an unlawful strike or unlawful strike activities may be discharged and are not entitled to reinstatement when the strike ends.
- Employees striking for economic concessions such as higher wages or improved working conditions are economic strikers.
  - Although they cannot be discharged, they can be replaced during the strike.
  - They are not entitled to reinstatement if the employer has hired permanent replacements, however, they may be entitled to recall when an opening occurs.

Right to Strike

- Employees who strike to protest a company's unfair labor practice cannot be discharged or permanently replaced.
  - When the strike ends, the strikers are entitled to immediate reinstatement even if replacements hired during the strike have to be discharged.

OSHA

- The Occupational Safety and Health Act (OSHAct) was enacted to assure safe and healthy working conditions for every working man and woman in the nation.
- The Act applies to every employer in the U.S. or in U.S. possessions who has any number of employees and who engages in a business affecting commerce.

OSHA

- Employers covered by the Act have the obligation of complying with the safety and health standards connected with the Act.
- The OSHA act has a “general-duty clause” that obligates employers to provide employees with a workplace free from recognized hazards that are likely to cause death or serious physical harm to the employees.
- This legislation makes on the job safety and health a management responsibility.

OSHA

- The law places on every employee the duty to comply with safety standards, however, final responsibility for compliance remains with the employer.
- Regardless of the size of a manufacturing organization, the integration of the safety ethic throughout the business is essential if the safety function is to be effective.
- If safety is a separate function, its effectiveness is doomed

OSHA Authority

- Institute and revoke safety and health standards.
- Conduct inspections and investigations.
- Issue citations and penalties.
- Place requirements for record keeping of safety and health data.
- Petition the courts to act against employers with dangerously hazardous work environments.
- Provide employer and employee training.
- Implement voluntary protection programs including injury prevention consultation.
- Grant funds to states for the operation of safety and health programs.

Employer Rights

- Seek off-site consultation, as needed, through contact with the nearest OSHA office.
- Receive free on-site consultation service to help identify hazardous conditions and determine corrective measures.
- Request and receive proper identification of the OSHA compliance officer before an inspection takes place.
- Realize that OSHA's right to inspect is not unlimited.
- Request and receive advice from the OSHA compliance officer for the reason for the inspection.
- Receive an opening and closing session with the OSHA compliance officer, if an inspection takes place.

Employer Rights

- Receive protection of proprietary trade secrets observed by an OSHA compliance officer.
- Realize that they are not necessarily in violation of the law when a citation is issued. The owner can first request a conference with the Area Director. A Notice of Contest can be filed within 15 working days from receipt of a citation and proposed penalty to challenge the citation.
- If unable to comply with a standard within the required time, application to OSHA can be made to request extension of abatement period for a short time. This is called a petition for modification of abatement (PMA).

Employer Rights

- Assist in developing safety and health standards through participation with OSHA Standards Advisory Committees, through standards writing organizations, and through public comment and public hearings.
- Use Small Business Administration loans to help bring establishment into compliance, if applicable.

Material Safety Data Sheets (MSDS)

- "Right-to-Know" laws mandate that employers make Material Safety Data Sheets (MSDS) available to employees, in a readily accessible manner, for those hazardous chemicals in their workplace.
- Employees cannot be discharged or discriminated against for exercising their rights, including the request for information on hazardous chemicals.
- Employees must be notified and given direction for locating Material Safety Data Sheets and the receipts of new or revised MSDS(s).

Material Safety Data Sheets (MSDS)

- All hazardous materials must be labeled in accordance with federal MSDS.
- The U.S. Environmental Protection Agency has oversight of hazardous materials with regard to use and human exposure, labeling, containment, and disposal.

Workers Rights Under OSHA

- An employer cannot punish or discriminate against a worker (by firing, demotion, harassment, or reassignment) for job safety or health activities, such as complaining to the union or OSHA or participating in union or OSHA inspections or conferences,
- Employees can privately confer and answer questions from an OSHA compliance officer in connection with a work-place inspection.
- During an OSHA inspection, an authorized workers' representative may be given an opportunity to accompany the compliance officer to aid the inspection,
- An authorized worker has the right to participate in the opening and closing inspection conferences with pay.

Workers Rights Under OSHA

- If an employer fails to correct a hazard causing a dangerous situation, the worker can contact OSHA to make an inspection. OSHA will not tell the employer who requested an inspection if this is the worker’s preference.
- An employee can notify OSHA or a compliance officer in writing of a potential violation before or during a work-place inspection.
- A worker can give OSHA information which could affect proposed penalties by OSHA against that employer.
- If OSHA denies the inspection request of a worker, then the worker must be informed of the reasons in writing by OS HA. The worker may request an OSHA hearing should he object to the OSHA decision.

Workers Rights Under OSHA

- If an OSHA compliance officer fails to cite an employer concerning an alleged violation submitted to him in writing by a worker, then OSHA must furnish the worker with a written statement of the reason for the disposition.
- Workers have the right to review an OSHA citation against their employer. The employer must post a copy of the citation at the location where the violation took place.
- Employees can appear to view, or be a witness in, a con-tested enforcement matter before the Occupational Safety and Health Review Commission.

Workers Rights Under OSHA

- If OSHA fails to take action to rectify a dangerous hazard, and an employee is injured, then that employee has the right to bring action against OSHA to seek appropriate relief.
- If a worker disagrees with the amount of time OSHA gives his employer to correct a hazard, then the worker can ask for review by the Occupational Safety and Health Review Commission within 15 days of when the citation was issued.
- Employees can request OSHA to adopt a new standard or to modify or revoke a current standard.
- Employees may take action for or against any proposed federal standards and may appeal any final OSHA decisions,
- An employer must inform his employees when he applies for a variance of an OSHA standard.

Workers Rights Under OSHA

- Employees must be given the opportunity to view or take part in a variance hearing and have a right to appeal OSHA'S final decision,
- Workers have the right to all information available in the workplace pertaining to employee protections and obligations under the Act and standards and regulations.
- Employees involved in hazardous operations have a right to information from the employer regarding toxicity, conditions of exposure, and precautions for safe use of all hazardous materials in the establishment.

Workers Rights Under OSHA

- The employer must inform the worker should the worker be overexposed to any harmful materials, and the worker must be told of the corrective action taking place.
- If an OSHA compliance officer determines that an alleged imminent danger exists, he must tell the affected workers of the danger and further inform them that court action will be taken if the employer fails to eliminate the danger.
- If an employee makes a request for access to records covering his exposure to toxic materials or harmful physical agents which require monitoring, then the employer must meet his request.

Workers Rights Under OSHA

- Workers must be given the opportunity to observe the monitoring or measuring of hazardous materials or harmful physical agents, if OSHA standards require monitoring.
- If a worker requests to review the Log and Summary of Occupational Injuries (OSHA No. 200), then the employer must post or provide it for his/her perusal.

Workplace Inspections

- OSHA inspections are almost always conducted without prior notice.
- An employer representative and employee representative can accompany the compliance officer during an inspection.

- Imminent danger investigation.
- Catastrophic or fatal accident investigation.
- Employee complaint investigation.
- High hazard industry inspections.
- Reinspection

Violations

- Imminent danger.
  - The OSHA act defines imminent danger as “any condition or practice in any phase of employment which is such that a danger exists which could reasonably be expected to cause death or serious physical harm immediately.”
- Serious violation.
  - A serious violation is one where there is a strong probability of death or serious harm from a hazard and that the employer knew or should have known about it.

Violations

- Nonserious violation.
  - A nonserious violation is one where a condition exists that is likely to cause an injury but not a death or serious physical harm, or that the employer did not know of the hazard.
- DeMinimis violation.
  - A violation of a standard without having a direct relationship to safety or health.

Hazard Analysis

- The first step toward controlling a hazard is to recognize the hazard.
- Management must work with the site safety professional to determine locations with a high accident potential as well as to identify severe hazards with a low occurrence likelihood.
- When specific hazards are being evaluated, both the probability of accident occurrence and the severity of injury or property damage are factored in.
- Each hazard should be ranked according to its probability to cause an accident and the severity of that accident.

Hazard Control Methods

- Eliminate the source of the hazards.
- Substitute a less hazardous equivalent.
- Reduce the hazards at the source.
- Remove the employee from the hazards (i.e., automating the process).
- Isolate the hazards (i.e., by enclosure).
- Dilute the hazards (i.e., ventilation).
- Reduce employee's exposure to hazard by administrative control such as employee rotation.
- Use personal protective equipment. Train employees in the proper methods used for hazard avoidance.
- Practice good housekeeping.

Cost of Industrial Accidents

- If a minor injury occurs, it may require only prompt first aid.
- If the injury is serious, the individual may be at home or in a hospital for days, weeks, or months.
- The injured person also receives compensation benefits according to the rates established in the particular state.
- The employer is responsible for the cost of first aid, medical treatments, and compensation benefits.

Job Safety Analysis

- Job safety analysis (JSA) is a valuable tool that can help reduce accidents and at the same time improve the efficiency of operations.
- A JSA is an observation-based study or analysis of
  - selecting and defining jobs to study
  - breaking the job down into steps or tasks
  - identifying the hazards
  - seeking solutions and developing controls for hazards

Lockout/Tagout

- A lockout program involves establishing written procedures for isolating machines and equipment from energy sources, and affixing locks to the energy-isolating devices.
- The major components of an effective lockout program
  – shutting down equipment
  – placing locks on the energy-isolating device(s)
  – releasing stored energy
  – verifying isolation of equipment
- Lockout will not be complete until the locks are removed in accordance with an established procedure.

Ergonomics

- Ergonomics is the process of fitting the job to the person.
- Occupational ergonomics seeks to create a match between the worker and the demands of the job.
- Engineers typically make equipment adjustable to fit from the 5th to the 95th percentile of size.
- The Americans with Disabilities Act (ADA) also addresses making accommodations for persons with disabilities, who may not have all of the capabilities ordinarily required by a job.

Anthropometric Data

Feature	Percentile Values							
	5th Percentile				95th Percentile			
	Men		Women		Men		Women	
	(in)	(mm)	(in)	(mm)	(in)	(mm)	(in)	(mm)
Stature-Clothed	66.4	1685	61.8	1568	74.4	1890	70.3	1787
Functional Forward Reach	28.3	726	25.2	640	34.0	864	31.1	790
Overhead Reach, Standing	78.9	2004	73.0	1853	90.8	2305	84.7	2151
Overhead Reach, Sitting	50.3	1279	46.2	1174	57.9	1469	54.9	1394
Functional Leg Length	43.5	1106	39.2	996	50.3	1277	46.7	11186
Kneeling Height	48.0	1219	445.1	1145	53.9	1369	51.3	1303
Kneeling Leg Length	25.2	639	23.3	592	29.7	755	27.8	705

Manual Handling Task Redesign

- Minimize significant body motions.
  - reduce bending motions
  - reduce twisting motions
  - reduce reaching out motions
- Reduce object weights and forces.
  - reduce lifting and lowering forces
  - increase the weight of the object so that it must be handled mechanically
  - reduce the handling distance

Manual Handling Task Redesign

- Reduce carrying forces.
  - eliminate the need to carry by converting to pushing or pulling
  - reduce the weight of the object
  - reduce the distance

Exposure to Repetitive Wrist and Hand Injuries

- Bench assembly of electrical and electronic equipment such as computers, typewriters, communication equipment, and radio and television transmitting and receiving equipment.
- Repetitive manual pushing of machine controls.
- Buffing or grinding hand-held objects.
- Etching or engraving of glassware such as bowls, vases, and goblets.
- Cutting, sewing, or folding goods.
- Wrapping and packaging various small goods.

Contributing Factors To Cumulative Trauma Injuries

- High frequency of repetition of the task
- High forcefulness of exertion
- Awkward postures
- Mechanical pressure
- Vibration
- Exposure to cold

Techniques For Reducing Cumulative Trauma Injuries

- Work practices
  – rotating workers, reducing task frequency, etc.
- Training procedures
  – show workers correct methods for performing their jobs
  – train management to understand the problems and their controls
- Medical controls
  – discuss medical issues with health professionals
  – early diagnosis of a cumulative trauma disorder could yield a quick recovery

Max Noise Levels

Duration Per Day (hours)	Sound Level (dBA)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

Methods Engineering/Analysis

- Analyzing workers job performance by video taping them
- Micromotion
  - uses motion pictures taken at constant and known speeds
- Memomotion
  - uses a slower film speed for analyzing jobs with long cycle times
- Output at moderate effort and minimal structuring (low task) can be improved by methods analysis and standardization to attain medium task.
- Effort can be increased by proper incentives to attain high task output

Methods Engineering

- Low task
  - The basic state of moderate effort and minimal structuring of the work.
  - Output at moderate effort can be improved by methods analysis and standardization to attain medium task.
  - Then effort can be increased by proper incentives to attain high task output.

Work Measurement

- Normal Time
  - the average time to perform an operation multiplied by the performance rating of the operator

$$\text{Normal Time} = \frac{\text{Average time x Performance Rating \%}}{100}$$

- Standard Time
  - due to delays and interruptions the normal time is increased by an allowance

$$\text{Standard Time} = \frac{\text{Normal Time x (100\% + Allowance\%)}}{100}$$

Allowances

- Allowance is based on PF&D inefficiencies.
  - personal = 4% - 5%
  - fatigue = 0 - 25%
  - delay = 2% - 8%

$$\text{Allowance} = \frac{100\%}{100\% - \text{PFD}\%}$$

Part 8
Engineering Economics

Engineering Economics

- Time Value of Money
- Depreciation
- Accelerated Cost recovery System (ACRS)
- Payback
- Minimum Annual Rate of Return (MARR)

Time Value of Money

- The value of money over a long period of time changes.
- $1000 dollars invested today is worth more than $1000 dollars 5 years from now.
- Economic decision making requires careful consideration of the value of money over time.

Cash Flow Patterns

- P- pattern
  - a single amount P (principal or present amount) at the beginning of n periods
- F- pattern
  - a single amount F (future amount) occurs at the end of n periods
- A- pattern
  - equal amounts of A (annual or periodic amount) occur at the ends of n periods

Proportionality Factors

- F = P (F/P,i,n)

- The present sum of P produces a future amount F in n periods with a periodic interest rate of i.
- (F/P, i ,n) is a proportionality factor and is calculated using the equations on the next slide or using tables found in most economics texts.

Proportionality Factors

Given ➡ **To Find** ⬇	**P**	**F**	**A**
P	1	$\frac{1}{(1+i)^n}$	$\frac{(1+i)^n - 1}{i(1+i)^n}$
F	$(1+i)^n$	1	$\frac{(1+i)^n - 1}{i}$
A	$\frac{i(1+i)^n}{(1+i)^n - 1}$	$\frac{i}{(1+i)^n - 1}$	1

Example 1

Truck purchase price = \$78,000

Down payment = \$5,000

12 monthly payments

Annual rate = 12%

$P = \$78{,}000 - \$5{,}000 = \$73{,}000$

$n = 12$

$i = 12/12\% = 0.01$

$$A = (\$73{,}000)(A/P, 0.01, 12) = \$73{,}000\left[\frac{0.01(1.01)^{12}}{(1.01)^{12} - 1}\right]$$

$\underline{A = \$6{,}482}$

Comparisons Based on Annual Cost

- EUAC
  - equivalent uniform annual cost
  - allows the comparison of two nonuniform cash flows to identify the minimum cost alternative based on their respective uniform annual costs

EUAC Assumptions

- There is a uniform time value or interest rate on all money involved in the problem whether it is borrowed or not.
- The annual cost of an asset is reduced by the money made from the sale or salvage of an asset at the end of its useful life.
- If two alternatives have different useful service life, it is assumed the asset with the shorter life, will be replaced with an identical item.

Example 2

Purchase Price = $10,000

Life = 12 years

Maintenance = $150 per year

Salvage value = $3,000

Interest = 10%

EUAC = 10,000(A/P, 0.10,12) + 150 - 3,000(A/F, 0.1,12)

EUAC = 10,000(0.1468) + 150 - 3,000(0.0468) = <u>$1479</u>

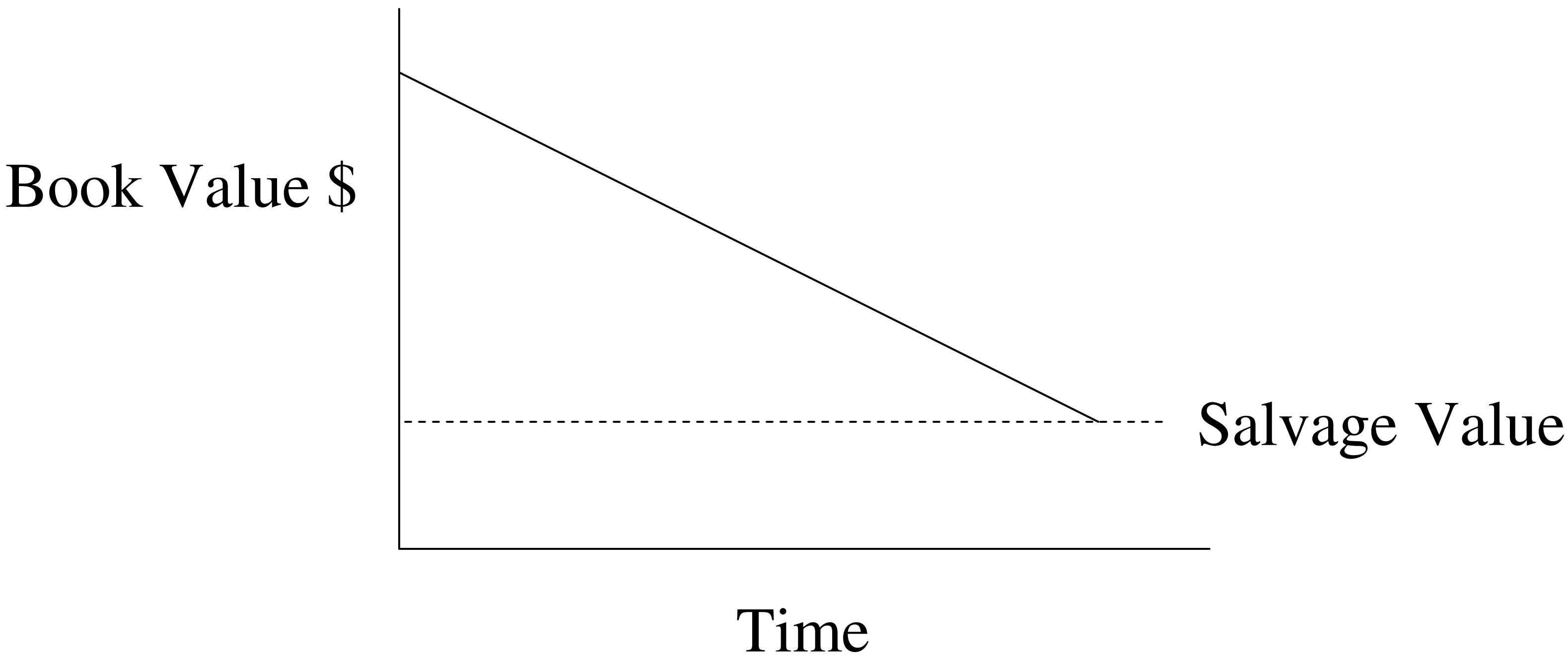
Depreciation Terms

- First Cost
  - initial total cost including purchase price, delivery, and installation (unadjusted basis)
- Life
  - anticipated useful life in years of the asset prior to disposal and/or replacement (recovery period); not necessarily the same as actual usage
- Salvage Value
  - trade-in value or net realizable value at the end of its useful life

Depreciation Methods

- Straight-Line Depreciation
- Sum-of-the-Years Digits Depreciation
- Declining Balance (and double declining balance) Depreciation
- Accelerated Cost Recovery System (after 1980; modified 1981 and 1986)

Straight Line Depreciation



Straight Line Depreciation

$$D = \frac{P - SV}{n}$$

$$BV = P - t \cdot D$$

where,

D = annual depreciation charge

t = year

P = first cost

SV = salvage Value

n = expected depreciable life or recovery period

BV = book value after t years

Straight Line Depreciation

- If you have a first cost of \$40,000 with a \$10,000 salvage value after five years calculate the straight line depreciation.

$$D = \frac{P - SV}{n} = \frac{40,000 - 10,000}{5} = \underline{\$6,000}$$

- What is the book value after the third year?

$$BV = P - t \cdot D = 40,000 - (3 \cdot 6,000) = \underline{\$22,000}$$

Sum-of-the-Years Digits Depreciation

- The depreciation charge is found by multiplying the first cost less its salvage value by the ratio of the number of years remaining in its life to the sum of the year digits during its life.

$$\text{Rate of Depreciation in Year t} = \frac{n - t + 1}{s}$$

where

s = sum of the years digits

n = total number of years over which the product is depreciated

Sum-of-the-Years Digits Depreciation

- Suppose a machine has an initial value of $40,000 and a salvage value of $10,000. What is the annual depreciation and the annual end-of-year book value?

Year	Depreciation	End-of-Year Book Value
0	0	$40,000
1	5/15(30,000) = 10,000	$30,000
2	4/15(30,000) = 8,000	$22,000
3	3/15(30,000) = 6,000	$16,000
4	2/15(30,000) = 4,000	$12,000
5	1/15(30,000) = 2,000	$10,000

Sum-of-the-Years Digits Depreciation

- The end-of-year book value for any year can be found with the equation below.

$$BV = P - \frac{t\left(n - \frac{t}{2} + 0.5\right)(P - SV)}{s}$$

where,

BV = book value

P = first cost

t = year of depreciation period

n = number of years for depreciation

SV = salvage value

s = sum of the years digits

Declining Balance Depreciation

- A constant rate of depreciation is applied over the useful life, N or the asset.
- Under the current tax code the rates are
  - 150% of SL depreciation
  - 175% of SL depreciation
  - 200% of SL depreciation (also called double declining depreciation)

Declining Balance Depreciation

$$D = \left(\frac{rate}{N} \right) BV$$

where,

D = depreciation in any year

rate = 1.50, 1.75, or 2.00

N = number of years over which the property is depreciated

BV = book value

Declining Balance Depreciation

- Suppose a machine has an initial value of $40,000 and a salvage value of $10,000 after five years of useful life. What is the annual depreciation and the annual end-of-year book value using double declining depreciation?
- The depreciation is therefore,

$$\frac{2}{5}BV$$

- The next slide shows the values.

Declining Balance Depreciation

End of Year #	Depreciation	Book Value
0	0	40,000
1	2/5(40,000)= 16,000	24,000
2	2/5(24,000)=9,600	14,400
3	*4,400	10,000
4	-----	10,000
5	-----	10,000

*Book value is never allowed to go below the salvage value.

Accelerated Cost Recovery System (ACRS)

- Made possible by the Tax Reform Acts of 1981 and 1986.
- The depreciable lives are shorter than the actual lives
- Salvage value is assumed to be zero.
- Computation are simplified.

ACRS Property Classes

Personal Property (all except real estate)	**Class**
Autos and light trucks; Machinery and equipment used for research; Special tools with a life < 3 years	3 year
Most machinery and equipment; Office furniture and equipment; Heavy duty trucks; Ships and aircraft	5 year
Public utility property with a life ≤ 25 yr.; railroad tank cars; manufactured homes.	10 year

ACRS Property Classes

Personal Property (all except real estate)	**Class**
Public utility property with life > 25 yr.	15 year
Real Estate	
All buildings	15 year

ACRS Depreciation for Personal Property

Year	**3 year**	**5 year**	**10 year**	**15 year**
1	33%	20%	10%	7%
2	45	32	18	12
3	22	24	16	12
4		16	14	11
5		8	12	10
6			10	9
7			8	8
8			6	7
9			4	6
10			2	5
11				4
12				3
13				3
14				2
15				1

ACRS Example

- A microcomputer cost $8,000. Compute its ACRS depreciation schedule.
- Microcomputer = office equipment = 5 year depreciation schedule.

Year	**Depreciation Cost**		**Book Value at End of Year**
1	20%(8000) =	1600	6400
2	32%(8000) =	2560	3840
3	24%(8000) =	1920	1920
4	16%(8000) =	1280	640
5	8%(8000) =	640	0

Payback Period

- Simple payback is finding the number of periods or years required to recover the cost of capital
- Minimum Attractive Rate of Return (MARR)
  - the number of periods or years required to recover the cost of capital and some profit is calculated

Payback Example

- A semi-automatic machine can be purchased for \$18,000. Annual revenues are expected to be \$3,000/yr and have a salvage value of \$3,000 any time during its life. The anticipated product life is 10 years and there is no desire to re-tool the machine. Find the payback period if MARR = 15%.
- Without MARR:

$$18,000 = n(3,000) + 3,000$$

$$n = \frac{18,000 - 3,000}{3,000} = \underline{5\, years}$$

Payback Example

- With MARR:

$$18,000 = 3,000\left[\frac{(1+0.15)^n - 1}{0.15(1+0.15)^n}\right] + 3,000\left[\frac{1}{(1+0.15)^n}\right]$$

$$6 = \frac{(1.15)^n - 1 + 0.15}{0.15(1.15)^n}$$

$$6(0.15)(1.15)^n = (1.15)^n - 0.85$$

$$0.85 = (1.15)^n - 0.9(1.15)^n$$

$$0.85 = 0.1(1.15)^n$$

$$\ln(0.85) = \ln(0.1) + n\ln(1.15)$$

$$\underline{n = 15.31}$$

Breakeven Analysis

- A brake drum plant has historically produced at about 80% of capacity in its production of 14,000 units per month. Decreased demand and a work slowdown has put production at 8,000 units per month for the foreseeable future. Use the information below to determine:
  - Where the 8000-unit level will place production relative to the linear breakeven point and the profit at this reduced level.
  - The variable cost per drum necessary to break even at the 8000-unit level, if revenue per unit and fixed costs remain constant.

Breakeven Analysis

- F = Fixed Cost = $75,000 per month
- V = Variable Cost = $2.50 per unit
- R = Total Revenue = $8.00 per unit
- Q = Quantity
- TC = Total Cost

Total Revenue = Total cost

$R(Q) = TC(Q)$

$8(Q) = 75{,}000 + 2.50(Q)$

$5.5Q = 75{,}000$

$\underline{Q = 13,\ 636}$ (Breakeven point)

Breakeven Analysis

At 8000 units,

Revenue = 8000 ($8) = $64,000

Total costs = 75,000 + 8000(2.50) = $95,000

Profit(loss) = 64,000 - 95,000 = ($31,000) (loss)

The variable cost, V, required to break even:

8(8000) = 75,000 + V(8000)

V = $-1.38 (can’t be done, need to lower the fixed cost or increase the revenue)

Breakeven Analysis

The unit price to break even at 8000 units:

$$R(8000) = 75{,}000 + 8000(2.50)$$

$$R = \$12$$

Types of Costs

- Fixed Costs
  - independent of the production quantity that is being built.
  - setup costs for machine tools
- Variable Costs
  - incurred on a per-unit basis of the quantity that is being produced.
  - per-piece direct labor and direct material and costs for assembled or machined parts

Types of Costs

- Semifixed Costs
  – independent of quantity and vary with specific groups of units that are produced
  – cost to change cutting tools and the completion of scheduled maintenance operations after a specified number of production units
- Direct Labor
  – cost of all "hands-on" effort associated with the manufacture of a specific product
  – machining, assembly, etc.
  – usually adds value to the product being produced

Types of Costs

- Direct Material
  - cost of all components included in the end product being produced
  - direct material is a variable manufacturing cost
- Indirect Labor
  - cost of all labor effort that cannot be directly associated with the manufacture of a product
  - salary costs of workers in the accounting, purchasing, and personnel departments

Types of Costs

- Indirect Manufacturing Cost
  - used synonymously with overhead costs
  - rent, heat, electricity, water, and expendable factory supplies, together with the annual costs of building and equipment depreciation
- General and Administrative Costs
  - incurred at the plant or interplant level that are not easily associated with a specific workcenter or department.
  - top executives' salaries, plant mainframe computer procurement/ operation costs, and technical library facilities.

Cost Models

- For medium-size and large workpieces, the cost of the original workpiece mainly determines the cost of the finished part.
- The cost per unit volume or per unit weight of small components increases rapidly as size is reduced.
- Nonproductive times do not reduce in proportion to part size.
- Power available and material removal rate required is lower for smaller parts.
- Surface area per unit volume to be finish machined is higher for smaller components.

Material Losses

- Mistakes
  - scrap
- Process loss
  - excess material from blanking
- Shrinkage
  - spoilage
  - theft
  - corrosion

Waste Loss, L_W

Process	**Waste %**
Machining	10-60
Closed die forging	20-25
Sheet-metal forming	10-25
Extrusion	15
Casting	10
Powder metallurgy	5

Cost Center Budgets

- Responsibility cost center budgets lose effectiveness as the internal supplier-customer chain is followed.
- For example, when a purchasing agent saves a dollar buying a substandard product, other departments will make up for it in rework, overtime, or quality, or in another nonvalue-added activity.

Activity Based Costing

- ABC is the tool that identifies and computes costs for activities, processes, and the outputs of activities, such as products or services.
- Significant amounts of different overhead activities, from testing to material handling, are disproportionately consumed by certain parts, products, and product families.
- ABC provides a much closer match between costs and outputs.

Activities and Resources

- Activities are what people and equipment do to satisfy customer needs.
- Activities are what consume business resources.
- Resources represent people, computers, technology, equipment, machines, supplies, tooling, and other factors.
- Resources allow productive activity and the serving of customers, whether internal or external.