Design for Manufacturing, Assembly, and Reliability

Module 3C Manufacturing Processes
Motivation

*Why is this module important?*

- Choosing an appropriate manufacturing process is perhaps the single most important decision you will make to scale up your production

- Manufacturing process selection drives:
  - Cost and time to produce
  - Make-or-buy decisions
  - Capital-investment decisions
  - Product look, quality, and reliability
  - Adaptability to design changes

*Selecting the right manufacturing process is paramount to your competitive advantage in the marketplace, so make an informed decision now!*
Module Outline

☐ Learning objectives
☐ What this module addresses
☐ Introduction to manufacturing processes
☐ Process attributes
☐ Manufacturing cost analysis
☐ Manufacturing process selection
☐ Additional resources
Learning Objectives

- LO1. Identify the manufacturing processes capable of producing necessary geometry
- LO2. Recommend appropriate manufacturing processes based on technical and business needs
- LO3. Estimate the capital and piece costs associated with alternative processes
What This Module Addresses

- The various types of manufacturing processes and their key attributes and cost factors
- How to select a manufacturing process based on the design requirements, material type, and process parameters
- How product geometry (such as shape and size) can limit the manufacturing-process selection decision
- Component and capital costs
- An introduction of how the manufacturing process influences product design
Selecting Manufacturing Processes

Where does this fit into the development cycle?

PRODUCT DESIGN OBJECTIVES
- Market Research
- Design Research
- Feasibility
- Development
- Qualification
- Field Readiness
- Launch

MANUFACTURING READINESS LEVELS

Levels: 1 2 3 4 5 6 7 8 9 10
- Manufacturing Research
- Mfg Development
- Mfg Capability
- Manufacturing Capacity
- Production
- Launch

PHASES
- Concept and Feasibility
- Definition
- Product and Process Design
- Implement and Validate
- Production and Stock
- Launch and Closure

BUILDS
- Pre-alpha
- Alpha
- Beta
- Pilot
- Ramp
- Scale

Engineering Validation
Design Validation
Process Validation

Manufacturing Processes
U.S. DEPARTMENT OF ENERGY • OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY
Manufacturing Processes

Introduction

- Manufacturing is about transforming (or converting) raw materials into finished components or products

Common manufacturing processes:

- Machining
- Press working
- Welding/fabrication
- Casting
- Powder materials
- Layered deposition
- Injection molding
- 3D Printing
- Extrusion – pipe, sheet stock, tubes
- Assembly
Manufacturing Processes

Classification

Primary shaping processes:
- These processes form the overall shape of the product, or the components that will be joined to form the final product

Secondary processes:
- The main objective of this is to provide the final shape surfaces to meet some of the product requirements such as surface finishing

Assembly/test processes:
- Assembly processes are used to join two or more components/sub-assemblies to obtain the final product while test processes are used to inspect dimensions and functionality

Adopted from “Introduction to Manufacturing Processes and Materials” By Robert Creese
www.build4scale.org
Manufacturing Process

Hierarchy

Raw Material

**PRIMARY SHAPING PROCESSES**
- Casting: Sand, die, investment casting
- Moulding: Injection moulding, blow moulding
- Forming: Forging, presswork, rolling
- Powder: Powder metal sintering
- Special: Composite lay-up
- Additive Manufacturing: 3D printing, fused decomposition modeling, Stereolithography

**SECONDARY PROCESSES**
- Bulk Heat Treatment: Hardening, tempering, annealing
- Material Removal Processes: Turning, drilling, milling, laser beam machining
- Surface Treatment: Plating, painting, anodizing, polishing

**ASSEMBLY/TEST PROCESSES**
- Joining Processes: Bolting, riveting, welding, brazing, soldering, adhesive bonding
- Assembly Systems: Component feeding, orientation, robotics, placement, insertion
- Test Processes: Measurement, inspection, functional testing

End Product

Adapted from K.G. Swift and J.D. Booker (2013)

www.build4scale.org
## Primary Processes

### Casting and molding

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
<th>Common Application</th>
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</tr>
</thead>
</table>
| Casting          | • Molten metal is poured into a mold cavity; upon solidification, metal conforms to the shape of the cavity.  
• Most casting processes use patterns that form the cavity of the mold made from wood, plastics, or metals. | Wind mill tower parts, generator blocks, metal blocks for machining, and other complex shapes with internal features. |                                                                              |
| Injection Molding| • Injecting or forcing of heated molten plastic into a cavity mold, which is in the form of the product to be made.  
• Part is ejected from the mold after it is cooled and solidifies.  
• It can produce varieties of part designs in a single molding operation. | Thermoplastic components, Turbine vanes, mechanical seals, O-rings, and plastic bottles. |                                                                              |
# Primary Processes

## Shaping and forging

<table>
<thead>
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</table>
| Roll Forming | • To form sheets of uniform cross-section.  
  • Material is fed through multiple pairs of forming rolls countered to produce the desired cross section.  
  • High mechanical strength, dimensional accuracy, closer tolerances, and good surface finish.                                                          | Frames of solar panel, parts of aircrafts, HVAC, rail tracks, automobile components, and other geometrically complex shapes. | ![Roll Forming](image1) |
| Forging     | • Controlled deformation of metal into a specific shape by compressive forces.  
  • Superior to casting because the parts formed have high strength, high resistance to wear, less porosity.  
  • Aluminum, copper, and magnesium are preferred for forging.                                                                                           | Wind mill turbine disks and gear blanks, bearing housings, seals, fan cases.                                       | ![Forging](image2) |
# Primary Processes

*Forging and shaping (cont.)*

<table>
<thead>
<tr>
<th>Process</th>
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</table>
| Sheet Metal Stamping  | • Stamping presses and stamping dies are tools used to produce sheet metal parts. The press machine provides the fore to close the stamping dies that shape and cut the sheet metal into finished parts  
  • Includes processes such as punching, blanking, embossing, bending, flanging and coining. | Sheet metal parts of simple and complex geometries can be produced in high volume.  
Example: Automobile body parts, wind turbine casings, rolled steel sheets and many others. | ![Sheet Metal Stamping Process](image)                                                                 |
# Primary Processes

*Additive manufacturing*

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>3D Printing (Rapid Prototyping)</td>
<td>• Produces part layer by layer from a material (both polymer and metal) based on the digital data (CAD). &lt;br&gt; • Increased design freedom compared to conventional processes such as casting and machining. &lt;br&gt; • No cutting tools, molds, or dies are required. &lt;br&gt; • Complex parts produced in a few hours.</td>
<td>Prototype for manufactured objects, medical field components (e.g., stents, artificial limbs, and joints).</td>
<td>![3D Printing Machine]</td>
</tr>
<tr>
<td>Wire + Arc-AM (WAAM)</td>
<td>• The process uses welding wire as feedstock. &lt;br&gt; • It produces very near net shape, without the need for complex tooling, moulds, dies. &lt;br&gt; • WAAM hardware currently uses standard, off the shelf welding equipment: welding power source, torches and wire feeding systems. &lt;br&gt; • Motion can be provided either by robotic systems or computer numerical controlled gantries.</td>
<td>• Suited for manufacturing of medium to large scale components. &lt;br&gt; • For aerospace industries components such as cruciform, stiffened panels, wing ribs, etc. &lt;br&gt; • It’s also used in industries such as nuclear, oil and gas for producing round shape end caps of pressure vessels.</td>
<td>![Wire + Arc-AM Machine]</td>
</tr>
</tbody>
</table>
## Primary Processes

*Additive manufacturing (cont.)*

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<tr>
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</table>
| Adhesive Manufacturing   | • Good alternative to welding, soldering, and brazing. Effective for joining dissimilar metal substrates with dissimilar melting points. Does not cause distortion, discoloration, or weld worms.  
  • Holes need not be drilled into the material to accommodate fasteners.  
  • Distributes stress load evenly over a broad area.                                                                                     | Typically used in applications such as thread locking; retaining rigid, cylindrical assemblies; and sealing between flanges. |
Secondary Processes

Heat treatment

<table>
<thead>
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</tr>
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</table>
| Heat Treatment| • An operation, or combination of operations, which involves the heating and cooling of a solid metal or alloy for the purpose of obtaining certain desirable conditions or properties.  
• It is usually desired to preserve, as nearly as possible, the form, dimensions, and surface of the piece being treated. | It improves the hardness of metal for their use in applications such as certain type of bolts, mower blades, axes, saw blades, drill bits, garden tools, etc. | ![Heat Treatment Example](image) |
# Secondary Processes

## Machining

<table>
<thead>
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| **Turning** | • Workpiece is rotated about its axis whereas cutting tool is fed into it.  
• This shears away unwanted material and creates the desired part.  
• Turning can be performed on both external as well as internal surfaces. | To manufacture rotating parts such as turbine shaft, axles, spindles, gear blanks, pump drives, and pinions, etc. | ![Turning Image] |
| **Threading** | • A single-point threading tool, typically with a 60-degree pointed nose, moves axially, along the side of the workpiece, cutting threads into the outer surface.  
• The threads can be cut to a specified length and pitch and may require multiple passes to be formed. | Application involving threads such as fasteners, connectors, worm drives, leadscrew of jack, micrometer, pipe joints and hoses. | ![Threading Image] |
| **Milling** | • It uses revolving cutters to remove material from a work piece advancing in a certain direction at an angle with the axis of the tool.  
• Milling can create complex shapes accurately. | Complex shapes such as blades of turbines, gearbox casings, flanges, aircraft body parts. | ![Milling Image] |
Secondary Processes
Machining (cont.)

<table>
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<tr>
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</tr>
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</table>
| Drilling | • To make straight cylindrical holes in solid rigid bodies and/or enlarge (coaxially) existing (pre-machined) holes.  
• Tool used in the process is called “Drill Bit”, which is a rotary multi-point cutting tool. | Bushing, flanges, collars, and applications where it required bulk production of drilled materials in various size and shape like metal sheets, plastic, wood, glass and concrete construction applications. | ![Drilling Process](image1) |
| Grinding | • It is an abrasive material removal and surface generation process.  
• Implement to shape and finish components made of metals and other materials.  
• It can achieve better surface finish compared to turning or milling. | Any component requiring surface finish such as transmission shafts, camshafts, bearings, crankshafts, etc. | ![Grinding Process](image2) |
| Reaming | • It is used to enlarge and true a hole.  
• Tool used for this process are called “Reamers”.  
• A reamer is a rotary cutting tool with one or more cutting elements used for enlarging to size and contour a previously formed hole. | Used to produce smooth and accurate holes, precision instruments, gauges, measurement tools, etc. | ![Reaming Process](image3) |
# Secondary Processes

## Machining (cont.)

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<tr>
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| Tapping     | • A process for producing internal threads using a tool (tap) that has teeth on its periphery to cut threads in a predrilled hole.  
• A combined rotary and axial relative motion between tap and workpiece forms threads. | Widely used in machine tool industry to hold or fasten parts together (screws, bolts and nuts), and to transmit motion (the lead screw moves the carriage on an engine lathe). | ![Tapping](image1.png) |
| Boring      | • Process of producing circular internal profiles on a hole made by drilling or another process.  
• It uses single-point cutting tool called a boring bar which can be rotated, or the workpart can be rotated. | Any component requiring a tighter surface finish such as that for transmission shaft, cam shafts, cam shafts bearing, end crank shafts. | ![Boring](image2.png) |
| Counter Sinking | • It produces a larger step in a hole to allow a bolt head to be seated below the part surface, except that the step is angular to allow flat-head screws to be seated below the surface.  
• A countersink is an conical cutting tool with angular relief, having one or more flutes with specific size angle cutting edges. | Used to recess a flat head screw or to chamfer hole edges, especially in aviation industries. | ![Counter Sinking](image3.png) |
# Secondary Processes

## Machining (cont.)

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| Broaching   | • A machining operation that uses a toothed tool called a “broach” to remove material.  
• Broaching can be performed either horizontally or vertically by either pushing or pulling the broaches over or inside the workpiece. | Typical use of this process includes cutting keyways on the objects such as driveshafts, gears, pulleys, etc. | ![Broaching Example](image1.png) |
| Honing      | • An abrasive machining process where honing tools (honing sticks) are pressed against the rotating workpiece to obtain required material removal. | Improves the dimensional accuracy of internal surfaces of cylindrical parts such as bore of automobile gear box. | ![Honing Example](image2.png) |
| Burnishing  | • It is a process of polishing and work hardening used for a metallic surface.  
• It smoothens and hardens the surface, creating a finish which lasts longer. | Used mainly in clockmaking and watchmaking industries. Parts such as bearing surfaces, pivots, and, pivot holes are few examples. | ![Burnishing Example](image3.png) |
| Super-finishing | • As name suggests, it’s a fine material removal process.  
• It involves very low surface roughness values of the order of 0.012-0.025µm.  
• It involves relatively larger grained stone removing desired stock. | Particularly used forgiving high surface finishes to ball bearings parts such as races, etc. | ![Super-finishing Example](image4.png) |
## Secondary Processes

### Machining (cont.)

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</table>
| Shaping | • Tool is reciprocating horizontally and the work piece is fed in to the cutting tool.  
• Tool used for shaping is called shaper.  
• Feed and depth of cut are provided by moving the work piece. | Used for machining flat surfaces on small sized jobs.  
Work piece is held on a fixed bed to be usually rectangular in shape. | ![Shaping Machine](image) |
| Plaining | • Work piece is reciprocating and the tool is fed in.  
• Produces flat surfaces in different planes.  
• Much larger and more rugged with longer length and heavy cuts compared to shaping machines. | Used if the size of the job requiring longer and faster stroke, e.g. large stamp dies and plastic injection molds.  
Other uses contains any task where large block of metals have to be squared. | ![Plaining Machine](image) |
| Slotting | • Tool is reciprocating vertically and the work piece is fed in to the cutting tool.  
• Can be considered as vertical shaping machines.  
• Length and position of stroke can be adjusted. | Used to machine internal surfaces (flat, formed grooves and cylindrical).  
Work piece is held on a fixed bed to be usually circular in shape. | ![Slotting Machine](image) |
## Secondary Processes

### Machining (cont.)

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| Electrical Discharge Machining (EDM) | • Removes metal by means of electric spark erosion.  
• Electric spark is used as a cutting tool to cut (erode) the work piece.  
• Pulsating (on/off) electric charge of high-frequency current is supplied through the electrode to the work piece.  
• Removing very tiny pieces of metal from the work piece at a controlled rate. | The most common use of EDM is in die making. It can produce very small and accurate parts as well as large items like automotive stamping dies and aircraft body components. | ![EDM Image]
# Secondary Processes

## Types of grinding

<table>
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</thead>
</table>
| Surface Grinding         | • It is used for grinding plain flat surfaces.  
• Either periphery of the grinding wheel (horizontally) or the flat face of the wheel (vertically) is used to perform this operation.                               | Used for grinding of special contoured surfaces and has high metal removal rates.                           |                                                          |
| Cylindrical Grinding     | There are two sub types:  
• External or center-type: similar to turning operation, work-piece is rotated between centers and the grinding wheel is fed against it.  
• Internal: similar to boring operation, work-piece is held in chuck (rotated at a very high speed) against the rotating grinder. | External: crankshafts, axles, spindles, rolls for rolling mills.  
Internal: to grind rotational parts such as the hardened inside surfaces of bearing races and bushing surfaces. |                                                          |
| Centerless Grinding      | • Workpiece is not held between centers.  
• Workpiece is supported by a rest blade and fed through between the two wheels.  
• Sometimes, two support rolls are used instead of rest blade to maintain the position of the work. | Used for grinding external and internal cylindrical surfaces.  
This is specifically used to ground bar stock and chromed bar stock.                                 |                                                          |
## Assembly Processes

### Joining

<table>
<thead>
<tr>
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</tr>
</thead>
</table>
| **Welding**     | • It is a materials joining process wherein two or more parts are coalesced at their contacting surfaces by a suitable application of heat and/or pressure.  
• Most of the welding processes are accomplished by heat alone, with no pressure applied; others by a combination of heat and pressure; and still others by pressure alone, with no external heat supplied. | Common application includes (but not limited to) construction, such as buildings and bridges, pressure vessels, boilers, piping, and storage tanks, shipbuilding, aircraft, aerospace, and automotive and railroad. | ![Welding Process](https://via.placeholder.com/150) |
| **Brazing**     | • A joining process wherein a filler metal is melted and distributed by capillary action between the faying surfaces of the metal parts being joined.  
• No melting of the base metals occurs in brazing; only the filler melts. | It can be used to join any metals including dissimilar metals.  
It can be used in application where welding cannot be performed, e.g. thin wall plates | ![Brazing Process](https://via.placeholder.com/150) |
| **Pressure Welding** | • External pressure is applied to produce welded joints either at temperatures below the melting point, which is solid state welding, or at a temperature above the melting point, which is fusion state welding. | Used for metals that are highly ductile or whose ductility increases with increasing temperatures.  
Applications include joining sheets, wires, and electric components. | ![Pressure Welding Process](https://via.placeholder.com/150) |
# Assembly Processes

## Joining (cont.)

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</tr>
</thead>
<tbody>
<tr>
<td>Spin Welding</td>
<td>• It uses heat generated by rotational friction at the joint line to weld thermoplastic parts with rotationally symmetric joints.</td>
<td>Most efficient method of joining circular parts that require high quality permanent joints.</td>
<td><img src="image" alt="Spin Welding" /></td>
</tr>
<tr>
<td></td>
<td>• The spin welding machine applies pressure axially while rotating one part against its stationary mate, and the resulting friction generates heat that melts the parts together.</td>
<td>Note: Only applicable for thermoplastic parts.</td>
<td></td>
</tr>
<tr>
<td>Electric Resistance Welding</td>
<td>• It includes the spot, seam, and projection welding processes.</td>
<td>This is a widely used welding method to join any carbon steel parts.</td>
<td><img src="image" alt="Electric Resistance Welding" /></td>
</tr>
<tr>
<td></td>
<td>• Spot welding occurs when the work is squeezed between two copper electrodes which have an electric current flowing between them.</td>
<td>These welding methods are widely used in automobile final assembly plants to weld the car bodies.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• In seam welding, the electrodes are in the form of opposing wheels which effect a continuous fused joint or seam.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• In projection welding, fusion occurs at predetermined locations characterized by embossments, projections, or joint intersections.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Process Attributes

Basics

Manufacturing processes have many attributes:

- Tolerance
- Surface roughness
- Mass range
- Size range
- Economic batch size
- Capital costs
- Production rate
Process Attributes

Basics (cont.)

- Only specific materials can be shaped or formed by specific processes
- Specific designs can be achieved with specific processes and materials
- Process-attribute tables provide detailed information on the above-mentioned attributes, thereby helping decision makers in choosing the right manufacturing processes for their design and material requirements
# Process Attributes

## Machining

### Attributes of Machining Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Material</th>
<th>Size Range</th>
<th>Tolerance (mm)</th>
<th>Surface Finish (µm)</th>
<th>Costs</th>
<th>EOQ</th>
<th>Production rate per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turning</td>
<td>All except some ceramics</td>
<td>&lt;φ3000 mm</td>
<td>±0.05</td>
<td>0.025-25</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Milling</td>
<td>All except some ceramics</td>
<td>&lt;1000 mm²</td>
<td>±0.1</td>
<td>0.2-25</td>
<td>Medium-high</td>
<td>Medium</td>
<td>Medium-high</td>
</tr>
<tr>
<td>Drilling</td>
<td>All except some ceramics</td>
<td>&lt;φ250 mm</td>
<td>±0.05</td>
<td>0.8-12.5</td>
<td>Low-medium</td>
<td>Low</td>
<td>Low-medium</td>
</tr>
<tr>
<td>Grinding</td>
<td>All metals</td>
<td>&lt;φ0.5 mm - 2 m 6 m long</td>
<td>±0.005</td>
<td>0.025-6.3</td>
<td>Low-high</td>
<td>Medium</td>
<td>Medium-high</td>
</tr>
<tr>
<td>Threading</td>
<td>All metals</td>
<td>0.1 m – 0.8 m</td>
<td>±0.05</td>
<td>0.2-25</td>
<td>Low-high</td>
<td>Low-high</td>
<td>Medium</td>
</tr>
</tbody>
</table>
# Process Attributes

## Machining (cont.)

<table>
<thead>
<tr>
<th>Process</th>
<th>Material</th>
<th>Size Range</th>
<th>Tolerance (mm)</th>
<th>Surface Finish (µm)</th>
<th>Costs</th>
<th>EOQ</th>
<th>Production rate per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broaching</td>
<td>All metals</td>
<td>25 mm – 3m long</td>
<td>±0.005</td>
<td>0.4-6.3</td>
<td>Low-high</td>
<td>Low-Medium</td>
<td>1+</td>
</tr>
<tr>
<td>Honing</td>
<td>All including some ceramics and plastics</td>
<td>Ø6-750 mm 12 m long</td>
<td>±0.005</td>
<td>0.025-1.6</td>
<td>Medium</td>
<td>Low-high</td>
<td>Medium</td>
</tr>
<tr>
<td>Lapping</td>
<td>All hard materials</td>
<td>500 mm</td>
<td>±0.005</td>
<td>0.012-0.8</td>
<td>Low-high</td>
<td>Low-high</td>
<td>Medium</td>
</tr>
<tr>
<td>Shaping</td>
<td>All metals</td>
<td>2 m long</td>
<td>±0.05</td>
<td>0.4-25.0</td>
<td>Medium-high</td>
<td>Low</td>
<td>Medium-high</td>
</tr>
<tr>
<td>Planning</td>
<td>All metals</td>
<td>25 m long</td>
<td>±0.05</td>
<td>0.4-25.0</td>
<td>Medium-high</td>
<td>Low</td>
<td>Medium-high</td>
</tr>
</tbody>
</table>

**Attributes of Machining Processes**

- **Process:** The type of machining process.
- **Material:** The types of materials that can be processed.
- **Size Range:** The dimensions of the material that can be processed.
- **Tolerance (mm):** The tolerance that can be achieved.
- **Surface Finish (µm):** The surface finish that can be achieved.
- **Costs:** The costs involved include labor, equipment, and tooling.
- **EOQ:** Economic Order Quantity.
- **Production rate per hour:** The production rate of the process.
## Process Attributes

### Shaping and forging

<table>
<thead>
<tr>
<th>Process</th>
<th>Material</th>
<th>Weight (kg)/size</th>
<th>Tolerance (mm)</th>
<th>Surface Finish (µm)</th>
<th>Costs</th>
<th>EOQ</th>
<th>Production rate per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Shape Rolling</td>
<td>Most Metals</td>
<td>10-1000</td>
<td>±0.5</td>
<td>0.8-25</td>
<td>Low-medium</td>
<td>Medium-high</td>
<td>Medium-high</td>
</tr>
<tr>
<td>2. Shape drawing</td>
<td>Steel or Al and/or Cu alloys</td>
<td>10-1000</td>
<td>±0.1</td>
<td>0.2-0.8</td>
<td>Low-medium</td>
<td>Medium-high</td>
<td>Medium</td>
</tr>
<tr>
<td>3. Cold forging and extrusion</td>
<td>Most metals</td>
<td>0.001-50</td>
<td>±0.1</td>
<td>0.4-3.2</td>
<td>Low-medium</td>
<td>Medium-high</td>
<td>High</td>
</tr>
<tr>
<td>4. Hot extrusion</td>
<td>Most metals</td>
<td>1-5000</td>
<td>±0.1</td>
<td>1.0-25.0</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>5. Hot forging (open die)</td>
<td>Most metals</td>
<td>0.1-200000</td>
<td>±0.5</td>
<td>1.0-25.0</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>
### Attributes of Shaping/Forming Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Material</th>
<th>Weight (kg)/size</th>
<th>Tolerance (mm)</th>
<th>Surface Finish (µm)</th>
<th>Costs</th>
<th>EOQ</th>
<th>Production rate per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot forging (impression)</td>
<td>Most metals</td>
<td>0.01-100</td>
<td>±0.5</td>
<td>1.0-25.0</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Bending</td>
<td>Steel or Al and/or Cu alloys</td>
<td>Any</td>
<td>±0.2</td>
<td>0.2-0.8</td>
<td>Low-medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Deep Drawing</td>
<td>Steel or Al and/or Cu alloys</td>
<td>Any</td>
<td>±0.1</td>
<td>0.2-0.8</td>
<td>Low-medium</td>
<td>Medium-high</td>
<td>High</td>
</tr>
<tr>
<td>Vacuum forming</td>
<td>Thermoplastics</td>
<td>20 m²</td>
<td>±0.25</td>
<td>Good</td>
<td>Low-medium</td>
<td>Low-Medium</td>
<td>Low-Medium</td>
</tr>
<tr>
<td>Blow molding</td>
<td>Thermoplastics</td>
<td>3 m²</td>
<td>±0.5</td>
<td>Good</td>
<td>Low</td>
<td>Medium-high</td>
<td>Medium-high</td>
</tr>
<tr>
<td>Contact molding</td>
<td>Glass reinforced fibers, thermosetting liquid resins</td>
<td>0.01 – 500 m²</td>
<td>±0.03-20</td>
<td>Good</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>
## Process Attributes

### Casting

<table>
<thead>
<tr>
<th>Process</th>
<th>Material</th>
<th>Weight (kg)</th>
<th>Tolerance (mm)</th>
<th>Surface Finish (µm)</th>
<th>Costs</th>
<th>EOQ</th>
<th>Production rate per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand casting</td>
<td>Any, but steel difficult</td>
<td>0.05-No limit</td>
<td>±0.5</td>
<td>3.2-25</td>
<td>Low-medium</td>
<td></td>
<td>&lt;100</td>
</tr>
<tr>
<td>Shell casting</td>
<td>Most metals except (Pb, Zn, Mg, titanium alloys, refractory and zirconium alloys)</td>
<td>0.05-100</td>
<td>±0.2</td>
<td>0.8-6.3</td>
<td>Low-medium</td>
<td>Medium-high</td>
<td>Low-medium</td>
</tr>
<tr>
<td>Plaster casting</td>
<td>Non-ferrous metals (Al, Mg, Zn, Cu)</td>
<td>0.025-25</td>
<td>±0.05</td>
<td>0.8-3.2</td>
<td>High</td>
<td>Medium</td>
<td>Low-medium</td>
</tr>
<tr>
<td>Investment casting</td>
<td>Any metal</td>
<td>0.005-100</td>
<td>±0.05</td>
<td>0.4-3.2</td>
<td>High</td>
<td>Low-medium</td>
<td>Medium-high</td>
</tr>
<tr>
<td>Die casting</td>
<td>Non-ferrous metals (Al, Mg, Zn, Cu)</td>
<td>0.05-300</td>
<td>±0.05</td>
<td>0.4-3.2</td>
<td>Low-medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Centrifugal casting</td>
<td>Any metal and some ceramics</td>
<td>1-5000</td>
<td>±0.2</td>
<td>1.6-12.5</td>
<td>Low-medium</td>
<td>Medium-high</td>
<td>Medium</td>
</tr>
</tbody>
</table>
### Process Attributes

**Casting (cont.)**

<table>
<thead>
<tr>
<th>Process</th>
<th>Material</th>
<th>Weight (kg)</th>
<th>Tolerance (mm)</th>
<th>Surface Finish (µm)</th>
<th>Costs</th>
<th>EOQ</th>
<th>Production rate per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection molding</td>
<td>Most thermoplastics, some thermosets, composites and elastomers</td>
<td>6-25</td>
<td>±0.05-8.0</td>
<td>0.2-0.8</td>
<td>Low</td>
<td>Medium-high</td>
<td>High</td>
</tr>
<tr>
<td>Reaction injection molding</td>
<td>Most thermoplastics, some thermosets, composites and elastomers</td>
<td>6-25</td>
<td>±0.05-8.0</td>
<td>0.2-0.8</td>
<td>Low</td>
<td>Medium-high</td>
<td>High</td>
</tr>
<tr>
<td>Compression molding</td>
<td>Most thermoplastics, some thermosets, composites and elastomers</td>
<td>0.05-15</td>
<td>±0.05-9.0</td>
<td>0.2-0.8</td>
<td>Low</td>
<td>Medium-high</td>
<td>High</td>
</tr>
</tbody>
</table>
## Process Attributes

### Additive manufacturing

<table>
<thead>
<tr>
<th>Process</th>
<th>Material</th>
<th>Part Dimensions</th>
<th>Part Complexity</th>
<th>Dimensional Accuracy</th>
<th>Deposition Rate</th>
<th>Build-Up On</th>
<th>Surface Roughness (µm)</th>
<th>Layer Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMD (Laser Metal Deposition)</td>
<td>Large materials diversity</td>
<td>Limited by the handling system</td>
<td>Limited</td>
<td>≥0.1 mm</td>
<td>3 – 10 mm³/s</td>
<td>3D surface and on existing parts</td>
<td>60-100</td>
<td>≥ 0.03 – 1mm</td>
</tr>
<tr>
<td>SLM (Selective Laser Melting)</td>
<td>Limited and lower materials diversity</td>
<td>Limited by the process chamber (φ 250mm, height: 160 mm)</td>
<td>Nearly unlimited</td>
<td>≥0.1 mm</td>
<td>1 – 3 mm³/s</td>
<td>Flat surface and flat performs</td>
<td>30-50</td>
<td>≥ 0.03 – 0.1mm</td>
</tr>
</tbody>
</table>

Manufacturing Cost Estimation

Basics

Cost estimations are critical for:

- Determining whether to make an investment to produce a product or part, or to buy it from a vendor (outsourcing decision)
- Deciding if a company should provide a quote on a product for sale to another company
- Also called a make-versus-buy analysis
Manufacturing Cost Estimation

Purpose

- Establish the bid price, specifications, quality, and engineering requirements of a product for a quotation or contract
- Verify quotations submitted by suppliers – typically three quotes if possible
- Ascertain whether a proposed product can be manufactured and marketed profitably
- Provide data for make-versus-buy decisions
Manufacturing Cost Estimation

Purpose (cont.)

- Help determine the most economical method, process, and material for manufacturing a product
- Provide a temporary standard for production efficiency and guide operating costs at the beginning of a project
- Support evaluation of design proposals
- Compare different concepts of product designs and manufacturing processes
Manufacturing Cost Drivers

*Sample list*

**Variable costs:**
- Materials: raw materials, any other process consumables
- Energy: to run the machines
- Labor: direct labor that goes into your process

**Fixed costs:**
- Main machine and additional equipment: the main machine(s) for your process
- Tooling: the dedicated tooling or fixtures that are required for your process
- Building: the cost of the space that houses your operations
- Maintenance: the cost of keeping equipment running
Overhead Cost Drivers

Sample list (cont.)

Fixed Costs: (cont.)

- Fixed overhead: non-process-specific operating costs (e.g., management, administration)

Production management:
- Plant supervisor
- Plant administrator
- Plant engineer
- Quality control
- Production control

Other units and administrators:
- Laboratory
- Health and work-safety departments
- Maintenance
- Plant security
Total Cost Calculations

Basics

- Total cost (TC) = Total fixed cost (FC) + Total variable cost (VC)
- Average costs:

\[ AFC = \frac{\text{Fixed cost}}{\text{Quantity}} = \frac{FC}{Q} \]
\[ ATC = \frac{\text{Total cost}}{\text{Quantity}} = \frac{TC}{Q} \]
\[ AVC = \frac{\text{Variable cost}}{\text{Quantity}} = \frac{VC}{Q} \]

- Average cost is the per-unit cost of a component (this is a good metric to compare between different process options)

See Module 3A for a more detailed cost analysis
Cost Analysis

*Example – Plastic bottles*

- Plastic bottles are products in wide use on a daily basis—Let’s analyze the costs involved in their manufacturing process.
- The production process involves the following steps:

  1. Injection Molding
  2. Stretch Blow Molding
  3. Blow Molding
  4. Injection Molding
Initial Data Collection

*Example – Plastic bottles (cont.)*

All calculations from here on are based on the following assumptions:

- Monthly rent of production facility = $8,000
- Monthly production capacity = 400,000 bottles
- Average lifetime of machines = 10 years
- Average lifetime of tools = 2 years
- Production period = 1 month
- Production quantity = 400,000 units

*Note:* Average lifetimes source: Nevada Dept. of Taxation, Personal Property Manual 2011–2012. Actual machine lifetimes are less than stated above due to continuous technological advancements
Depreciation Cost Calculations

Example – Plastic bottles (cont.)

Injection Mold Machine:
- Total Cost (TC) = $13,000
- Salvation Cost = $1,000
- Depreciable Cost = TC – Salvation cost = $12,000
- Expected Lifetime = 10 years
- Monthly Depreciation Percent = 100% of its value/number of months in life (in this case 10 years X 12 months or 120 months.

Calculation: \[ \frac{100\%}{120 \text{ months}} = 0.8334\% \text{ depreciation per month} \]

- Monthly Depreciation Value = Depreciation Costs x Depreciation Percent

Calculation: \[ $12,000 \times 0.0834\% = $100 \]
Depreciation Cost Calculations

Example – Plastic bottles (cont.)

Injection Molds:
- Total Cost (TC) = $8,000
- Salvation cost = $200
- Depreciable Costs = TC – Salvation cost = $7,800
- Expected Lifetime = 2 years
- Monthly Depreciation Percent = 100% of its value/number of months in life (in this case 2 years X 12 months or 24 months.

Calculation: 100%/24 months = 04.167% depreciation per month

- Monthly Depreciation Value = Depreciation Costs x Depreciation Percent

Calculation: $7,800 x 4.167% = $325
Depreciation Cost Calculations

*Example* – *Plastic bottles (cont.)*

**Blow Molding Machine:**
- Total Cost (TC) = $34,000
- Salvation cost = $4,000
- Depreciable Costs = TC – Salvation cost = $30,000
- Expected Lifetime = 10 years
- Monthly Depreciation Percent = 100% of its value/number of months in life (in this case 2 years X 12 months or 24 months.

*Calculation:* 100%/24 months = 4.167% depreciation per month

- Monthly Depreciation Value = Depreciation Costs x Depreciation Percent

*Calculation:* $30,000 x 0.834% = $250
Depreciation Cost Calculations

Example – Plastic bottles (cont.)

Blow Molding Molds:

- Total Cost (TC) = $4,000
- Salvation cost = $280
- Depreciable Costs = TC – Salvation cost = $3,720
- Expected Lifetime = 2 years

- Monthly Depreciation Percent = 100% of its value/number of months in life (in this case 2 years X 12 months or 24 months.

Calculation: 100%/24 months = 4.167% depreciation per month

- Monthly Depreciation Value = Depreciation Costs x Depreciation Percent

Calculation: $3,720 x 4.167% = $155
## Cost Analysis

**Example – Plastic bottles (cont.)**

<table>
<thead>
<tr>
<th>Fixed Cost Type</th>
<th>Total Cost (A)</th>
<th>% Applicable for This Job (B)</th>
<th>Net Fixed Cost for This Job (A*B/100)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection molding Machine</td>
<td>$100</td>
<td>60%</td>
<td>$60</td>
</tr>
<tr>
<td>Stretch Blow Molding Machine</td>
<td>$250</td>
<td>100%</td>
<td>$250</td>
</tr>
<tr>
<td><strong>Equipment Subtotal</strong></td>
<td></td>
<td></td>
<td>$310</td>
</tr>
<tr>
<td><strong>Tooling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection Molds</td>
<td>$325</td>
<td>100%</td>
<td>$325</td>
</tr>
<tr>
<td>Blow Molding Dies</td>
<td>$155</td>
<td>100%</td>
<td>$155</td>
</tr>
<tr>
<td><strong>Tooling Subtotal</strong></td>
<td>$480</td>
<td></td>
<td>$480</td>
</tr>
<tr>
<td><strong>Building</strong></td>
<td>$8,000</td>
<td>20%</td>
<td>$1,600</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>$3,000</td>
<td>20%</td>
<td>$600</td>
</tr>
<tr>
<td>Management and Administrative Overheads</td>
<td>$4,000</td>
<td>20%</td>
<td>$800</td>
</tr>
<tr>
<td><strong>Total Fixed Cost for This job</strong></td>
<td></td>
<td></td>
<td>$3,790</td>
</tr>
</tbody>
</table>

*Note*: The building may be used to house other manufacturing processes and office uses, therefore, can’t be charged 100% just for this job. Same concept may be applicable to other cost categories as well.
## Cost Analysis

*Example – Plastic bottles (cont.)*

<table>
<thead>
<tr>
<th>Variable Cost Type</th>
<th>Per Unit Cost (A)</th>
<th>Quantity Produced (B)</th>
<th>Net Variable Cost for This Job (A*B)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Materials</td>
<td>$0.03</td>
<td>40,000</td>
<td>$1,200</td>
</tr>
<tr>
<td>Consumables</td>
<td>$0.06</td>
<td>40,000</td>
<td>$2,400</td>
</tr>
<tr>
<td><strong>Materials Subtotal</strong></td>
<td></td>
<td></td>
<td>$3,600</td>
</tr>
<tr>
<td>Labor</td>
<td>$0.10</td>
<td>40,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>Energy</td>
<td>$0.05</td>
<td>40,000</td>
<td>$2,000</td>
</tr>
<tr>
<td><strong>Total Variable Cost</strong></td>
<td>$0.24</td>
<td></td>
<td>$9,600</td>
</tr>
</tbody>
</table>
Marginal Costs

Example – Plastic bottles (cont.)

- Marginal cost (MC) is the increase in TC that arises from an extra unit of production
- MC helps answer the following question: How much does it cost to produce an additional unit of output?

\[
\text{Marginal Cost (MC)} = \frac{\text{Change in Total Cost (TC)}}{\text{Change in production quantity}}
\]
Marginal Costs

*Example – Plastic bottles (cont.)*

MC calculations are based on the following assumptions (any changes in these assumptions would require new calculations):

- Production capacity of machines for current utilization rate (60% of injection molding machine and 100% of blow molding machine) is 40,000 units/month

- FC remains the same until the 40,000 units/month because it is within the current capacity
  — If production quantity is more than the current capacity, new machines need to be purchased, which would require accounting for that additional investment in your FC

- The newly bought machines and their tooling would be used 100% for this product only

- The per unit rate for VC remains the same regardless of product quantity
Marginal Costs

*Example – Plastic bottles (cont.)*

- The calculated TC for 40,000 bottles/month was $13,390 (row 1)
- When this quantity is increased from 40,000 to 45,000 units, it requires purchasing new machines; therefore, MC increases
- However, when change is from 45,000 to 80,000 units, the additional FC is offset with the additional production volume (The MC then reduces even further to $0.11/unit)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>FC</th>
<th>VVC</th>
<th>TC</th>
<th>Average TC</th>
<th>MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>40,000</td>
<td>$3,790</td>
<td>$9,600</td>
<td>$13,390</td>
<td>$0.33</td>
<td>$0.24</td>
</tr>
<tr>
<td>45,000</td>
<td>$4,620*</td>
<td>$10,800</td>
<td>$15,420</td>
<td>$0.35</td>
<td>$0.41</td>
</tr>
<tr>
<td>80,000</td>
<td>$4,620*</td>
<td>$19,200</td>
<td>$23,820</td>
<td>$0.30</td>
<td>$0.11</td>
</tr>
</tbody>
</table>

*Note:* The FC calculation table for more than 40,000 production units is provided at the end of this module
Break-Even Analysis

Basics

- The break-even point is the minimum quantity required to make a profit from manufacturing
- It is the point at which the burden of fixed costs (FC) is made equal to the profit made from selling a product

Formulation:
- Total Revenue = selling price x total quantity sold
- TC = total FC + total VC

At the break-even point:
- Total Revenue = TC
- SP x Q = FC + VC x Q
- Q = FC/(SP-VC)
Break-Even Analysis

Basics

- The break-even point is the minimum quantity required to make a profit from manufacturing.
- It is the point at which the burden of fixed costs (FC) is made equal to the profit made from selling a product.

Formulation:

- Total Revenue = selling price x total quantity sold
- Total Cost (TC) = total Fixed Cost (FC) + total Variable Cost (VC)

At the Break-Even (BE) point:

- Total Revenue = TC
- BE is when Sale Price (SP) x Quantity (Q) = FC + VC x Q
- Break Even Quantity = FC/(SP-VC)
## Break-Even Analysis

### Example

- **If SP = $0.50,**
  - **Total Revenue** = SP x Q = $0.50 x Q
- **Break-Even Point**
  - = 0.5 x Q
  - = 3,790 + 0.24 x Q
  - Q = 3,790/(0.5 – 0.24)
  - Q ≈ 14577
- **TC = FC + VC x Q**
  - = 3,790 + 0.24 x Q

### Table

<table>
<thead>
<tr>
<th>Quantity</th>
<th>FC ($)</th>
<th>VC ($)</th>
<th>TC ($)</th>
<th>Total Revenue ($)</th>
<th>Profit ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$3,790</td>
<td>$0</td>
<td>$3,790</td>
<td>$0</td>
<td>-$3,790</td>
</tr>
<tr>
<td>1,000</td>
<td>$3,790</td>
<td>$240</td>
<td>$4,030</td>
<td>$500</td>
<td>-$3,520</td>
</tr>
<tr>
<td>10,000</td>
<td>$3,790</td>
<td>$2,400</td>
<td>$6,190</td>
<td>$5,000</td>
<td>-$1,190</td>
</tr>
<tr>
<td>20,000</td>
<td>$3,790</td>
<td>$4,800</td>
<td>$8,590</td>
<td>$10,000</td>
<td>$1,410</td>
</tr>
<tr>
<td>30,000</td>
<td>$3,790</td>
<td>$7,200</td>
<td>$10,990</td>
<td>$15,000</td>
<td>$4,010</td>
</tr>
</tbody>
</table>
Manufacturing Process Selection

Selecting the best manufacturing process for a given component depends on several factors such as the following:

- Material selection
- Final shape and appearance
- Desired tolerance and surface finish
- Design requirements
- Tooling cost
- Product market price (if it is a commodity product)
- Safety and environmental concerns
Manufacturing Process Selection

Flow chart

1. **Product design specifications**
   - (Engineering drawings, parts lists, any specific customer requirements)

2. **Manufacturing requirements**
   - (Surface finish, tolerance, special treatments, tooling)

3. Analyze processing factors from material selected, manufacturing requirements and geometry to identify potential manufacturing process class (e.g., machining, casting, forming, etc.)

4. **Geometry**
   - (Shape, size, weight, features, threads)

5. **Material specifications**
   - (Material type, grade, properties)

6. **List of suitable processes**

- **Yes**
  - **More than one suitable process?**
    - **Financial analysis**
      - (Piece cost, capital cost, break-even analysis)
    - **Select the final process**

- **No**
  - **Select the available process**
Manufacturing Process Selection

Key steps

- Understand customer (or design) requirements
  - Conduct materials analysis
  - Conduct component geometry analysis (shape, size, features like threading, holes, etc.)
  - Process parameters or manufacturing information analysis (tolerance, surface finish, volume needed, etc.)

- Analyze critical processing factors
  - Determine critical processing factors based on component geometry, materials selection, and manufacturing information

- Review process attributes
  - Compare the candidate processes with respect to processing factors by using process attributes tables

- Identify a suitable process
  - Financial analysis: compare average cost per unit for various process options
## Manufacturing Options

### Part geometry

<table>
<thead>
<tr>
<th>Shape/ Features</th>
<th>Production Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat surfaces</td>
<td>Rolling, planning, broaching, milling, shaping, grinding</td>
</tr>
<tr>
<td>Parts with cavities</td>
<td>End milling. Electrical-discharge machining, electrochemical machining, ultrasonic machining, cast-in cavity</td>
</tr>
<tr>
<td>Parts with sharp features</td>
<td>Permanent-mold casting, machining, grinding, fabricating</td>
</tr>
<tr>
<td>Thin hollow shapes</td>
<td>Slush casting, electroforming, fabricating</td>
</tr>
<tr>
<td>Shaping of tubular parts</td>
<td>Rubber forming, expanding with hydraulic pressure, explosive forming, spinning</td>
</tr>
<tr>
<td>Curvature on thin sheets</td>
<td>Stretch forming, peen forming, fabricating</td>
</tr>
<tr>
<td>Openings in thin sheets</td>
<td>Blanking, chemical blanking, photochemical blanking</td>
</tr>
<tr>
<td>Reducing cross-sections</td>
<td>Drawing, extruding, shaving, turning, centerless grinding</td>
</tr>
<tr>
<td>Producing Square edges</td>
<td>Fine blanking, machining, shaving, belt grinding</td>
</tr>
<tr>
<td>Producing small holes</td>
<td>Laser, electrical-discharge machining, electrochemical machining</td>
</tr>
<tr>
<td>Producing surface textures</td>
<td>Knurling, wire brushing, grinding, belt grinding, shot blasting, etching</td>
</tr>
<tr>
<td>Detailed surface features</td>
<td>Coining, investment casting, permanent mold casting</td>
</tr>
<tr>
<td>Threaded parts</td>
<td>Thread cutting, thread rolling, thread grinding, chasing</td>
</tr>
<tr>
<td>Very large parts</td>
<td>Casting, Forging, fabricating</td>
</tr>
<tr>
<td>Very small parts</td>
<td>Investment casting, machining</td>
</tr>
<tr>
<td>Parts with holes, and/or threads</td>
<td>Drilling, Reaming, Boring, Tapping, Countersinking</td>
</tr>
</tbody>
</table>
Schematic

*Case study – Baseplate assembly for electric motor*
Case study – Baseplate assembly for electric motor (cont.)

Engineering Drawing
Engineering Drawing

Example

☐ An engineering drawing should accurately state the geometric features of a product or its components.

☐ The goal is to clearly define requirements in accordance with conventions for layout nomenclature, size, etc. to enable its production.

☐ This can include (not limited to):
  — Bill of material
  — General notes
  — Material specifications
  — Drawing origin and version
  — Multiple view
  — Hole specifications

Enlarged on next page
Engineering Drawing

Example – Interpreting the blueprint
### Engineering Specifications

**Case study – Baseplate assembly for electric motor (cont.)**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Part Name</th>
<th>Description</th>
<th>Dimensions (mm) (L x B x H)</th>
<th>Tolerance</th>
<th>Surface Finish (µm)</th>
<th>Quantity</th>
<th>Any Special Features?</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCP211-AST</td>
<td>PILLOW BLOCK BEARING</td>
<td>AST - METRIC SERIES</td>
<td>219 x 60 x 125</td>
<td>8 – 28 µm</td>
<td>0.8</td>
<td>1</td>
<td>N.A.</td>
</tr>
<tr>
<td>3GAA103001-BSE</td>
<td>ELECTRIC MOTOR</td>
<td>ABB - M2AA100L 6 1.5 KW</td>
<td>351 x 200 x 237</td>
<td>±0.5 mm</td>
<td>0.8</td>
<td>1</td>
<td>N.A.</td>
</tr>
<tr>
<td>91292A241</td>
<td>SOCKET HEAD SCREWS</td>
<td>MCMASTER-CARR</td>
<td>M16 x 2 mm Thread, 45 mm long</td>
<td>--</td>
<td>--</td>
<td>2</td>
<td>N.A.</td>
</tr>
<tr>
<td>91292A274</td>
<td>SOCKET HEAD SCREWS</td>
<td>MCMASTER-CARR</td>
<td>M20 x 2.5 mm Thread, 45 mm long</td>
<td>--</td>
<td>--</td>
<td>4</td>
<td>N.A.</td>
</tr>
<tr>
<td>7493250</td>
<td>BEARING MOUNTING PAD</td>
<td>MACHINED AND FABRICATED</td>
<td>312.5 x 100 x 312.5</td>
<td>±0.015 mm</td>
<td>0.8</td>
<td>1</td>
<td>2 Holes with Ø16 dia 20 mm deep</td>
</tr>
<tr>
<td>7493251</td>
<td>BASE FRAME</td>
<td>MACHINED AND FABRICATED</td>
<td>400 x 300 x 50</td>
<td>±0.25 mm</td>
<td>0.8 – 12.5</td>
<td>1</td>
<td>N.A.</td>
</tr>
<tr>
<td>7493252</td>
<td>MOTOR SHAFT</td>
<td>MACHINED AND FABRICATED</td>
<td>Ø55 diam 770 length</td>
<td>±0.015 mm</td>
<td>0.8</td>
<td>1</td>
<td>N.A.</td>
</tr>
</tbody>
</table>
Manufacturing Process Selection

*Step-by-step – How to select a suitable option*

1. Understand design requirements
2. Analyze critical processing factors
3. Review relevant process-attributes tables
4. Identify suitable processes
Manufacturing Process Selection

*Step 1* - *Understand design requirements*

- There are three parts that need to be machined or fabricated, which include bearing mounting pad, base frame, and motor shaft.
- Component materials: all low-carbon steel.
- Component shapes:
  - Mounting pad and base frame have flat surfaces with rectangular shapes.
  - Motor shaft has round surface.
- Special manufacturing features: two holes on bearing mounting pad.
- Manufacturing requirements:
  - Design tolerances range from 8–28 micrometers, and surface finish is also in the range of 8–12.5 micrometers for all parts including holes.
  - Motor shaft needs to be hardened to withstand the torsional stress.
Based on the geometry, material, and manufacturing requirements mentioned in Step 1, the initial process required must satisfy the following criteria:

- Be suitable to machine low-carbon steel
- Be able to produce a flat surface and rectangular shapes
- Be able to produce a round surface with a diameter of 55 mm
- Be able to meet the general dimensional tolerance of +/-8 micrometers (µm)
- Be able to meet the surface finish requirements of 12.5 µm
- Be able to produce holes with the above-mentioned tolerance of +/-8 µm
Based on the geometry, material, and manufacturing requirements mentioned in Step 1, the initial process required must satisfy the following criteria: (cont.)

- Be able to economically produce in batches of 100 (assumed) (It is also assumed that the shape of the raw material will be flat)
- Be able to meet the specific dimensional and geometric tolerances stated on the drawing
- Be able to improve the hardness of motor shaft

Based on these requirements, the initial candidate processes are broaching or milling for flat surface of mounting pad and base frame, turning for the motor shaft, and drilling a hole on the mounting pad
Manufacturing Process Selection

**Step 3 - Review relevant process-attributes tables**

- Reviewing the machining process attributes tables (S27-28; see relevant rows below), all four processes can meet general tolerance and surface-finish requirements

<table>
<thead>
<tr>
<th>Process</th>
<th>Material</th>
<th>Size Range</th>
<th>Tolerance (mm)</th>
<th>Surface Finish (µm)</th>
<th>Costs</th>
<th>EOQ</th>
<th>Production rate per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Labor</td>
<td>Equipment</td>
<td>Tooling</td>
</tr>
<tr>
<td>Turning</td>
<td>All except some ceramics</td>
<td>&lt;φ3000 mm</td>
<td>±0.05</td>
<td>0.025-25</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Milling</td>
<td>All except some ceramics</td>
<td>&lt;1000 mm²</td>
<td>±0.1</td>
<td>0.2-25</td>
<td>Medium-high</td>
<td>Medium</td>
<td>Medium-high</td>
</tr>
<tr>
<td>Drilling</td>
<td>All except some ceramics</td>
<td>&lt;φ250 mm</td>
<td>±0.05</td>
<td>0.8-12.5</td>
<td>Low-medium</td>
<td>Low</td>
<td>Low-medium</td>
</tr>
<tr>
<td>Broaching</td>
<td>All metals</td>
<td>25 mm – 3m long</td>
<td>±0.005</td>
<td>0.4-6.3</td>
<td>Low-high</td>
<td>High</td>
<td>Low-Medium</td>
</tr>
<tr>
<td>Grinding</td>
<td>All metals</td>
<td>&lt;φ0.5 mm - 2 m</td>
<td>±0.005</td>
<td>0.025-6.3</td>
<td>Low-high</td>
<td>Medium</td>
<td>Medium-high</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 m long</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note**: Although broaching and milling can produce flat surfaces, their production rates and cost structures are different (Broaching has a higher production rate and can achieve tighter tolerances than milling, but it is also more expensive than the milling operation)
Manufacturing Process Selection

*Step 4 - Identify suitable processes*

Based on the review of the process-attributes table, the following processes are recommended for the given jobs:

- **Bearing mounting pad**: Milling for flat surface, drilling for hole
- **Base frame**: Milling for flat surface
- **Motor shaft**: Turning for diameter or round surface, surface hardening and grinding to meet the hardness and tolerance requirements respectively.

*Note*: Although broaching offers a greater production rate and can produce tighter tolerance, the desired production quantity can be achieved along with the required tolerance and surface-finish specifications with lower investments. Therefore, milling is recommended over broaching for producing the flat surfaces. However, if there are more options with less obvious choices, one can calculate the average TC for the option using the methods described previously to determine the lowest cost option.
Resources

- Turning
  https://v.ftcdn.net/01/07/59/25/700_F_107592507_IsVzgJs5saZlPa1AEp6EuM3yWQLEx5N5_ST.mp4

- Milling
  https://v.ftcdn.net/01/34/51/13/700_F_134511365_G546DqFESvnoB4P5lGUbKldrSgNjNWp_ST.mp4

- Drilling
  https://v.ftcdn.net/01/27/58/86/700_F_127588642_XTAto7UoBr1tvEuhD6lRE5WqhAwXExu_ST.mp4

- Grinding
  https://v.ftcdn.net/00/36/97/31/700_F_36973197_XNCHEwNjD1WtlhTYRLr0PDfhwd2CGvqd_ST.mp4

- 3D printing
  https://v.ftcdn.net/01/44/42/33/700_F_144423391_TXIUBLUFu2fN2mfuRRAtkonzN8HCdIGw_ST.mp4
Resources (cont.)

- Casting  https://www.youtube.com/watch?v=LmjAQGvSrF0
- Roll forming  https://www.youtube.com/watch?v=uGEYZHriKZk
- Injection molding  https://www.youtube.com/watch?v=b1U9W4iNDiQ
- Forging  https://www.youtube.com/watch?v=hSUpe7zu0g
- Threading  https://www.youtube.com/watch?v=9IvWuXjCVbg
- Reaming  https://v.f.tcdn.net/00/79/23/02/700_F_79230212_xsxgXmVD3ORY5eLoigojeUhqpYbp5OloC_ST.mp4
- Boring  https://v.f.tcdn.net/01/07/57/45/700_F_107574502_9ADKfORVouLtvKQLtv3V62rTDDsFIxhl_ST.mp4
- Drilling boring reaming  https://www.youtube.com/watch?v=ZGU1zP7KPbY
Resources (cont.)

- Counter sinking [https://www.youtube.com/watch?v=kLbX8ISF5UA](https://www.youtube.com/watch?v=kLbX8ISF5UA)
- Electrical discharge machining [https://www.youtube.com/watch?v=kSIFiWSRpBw](https://www.youtube.com/watch?v=kSIFiWSRpBw)
- Sheet metal stamping [https://www.youtube.com/watch?v=Fid1r3tG538](https://www.youtube.com/watch?v=Fid1r3tG538)
- Wire+ arc Am [https://youtu.be/_WrhWf9XLHM](https://youtu.be/_WrhWf9XLHM)
- Planing [https://www.youtube.com/watch?v=W8-__ziKiao](https://www.youtube.com/watch?v=W8-__ziKiao)
- Slotting [https://www.youtube.com/watch?v=hE2aKmINIU4](https://www.youtube.com/watch?v=hE2aKmINIU4)
## Fixed cost for production over 40000 units

<table>
<thead>
<tr>
<th>Fixed Cost Type</th>
<th>Total Cost (A)</th>
<th>% Applicable for This Job (B)</th>
<th>Net Fixed Cost for This Job (A*B/100)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection Molding Machine 1</td>
<td>$100</td>
<td>60%</td>
<td>$60</td>
</tr>
<tr>
<td>Stretch Blow Molding Machine 1</td>
<td>$250</td>
<td>100%</td>
<td>$250</td>
</tr>
<tr>
<td>Injection molding Machine 2</td>
<td>$100</td>
<td>100%</td>
<td>$100</td>
</tr>
<tr>
<td>Stretch Blow Molding Machine 2</td>
<td>$250</td>
<td>100%</td>
<td>$250</td>
</tr>
<tr>
<td><strong>Equipment Subtotal</strong></td>
<td></td>
<td></td>
<td>$660</td>
</tr>
<tr>
<td><strong>Tooling</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection Molds 1</td>
<td>$325</td>
<td>100%</td>
<td>$325</td>
</tr>
<tr>
<td>Blow Molding Dies 1</td>
<td>$155</td>
<td>100%</td>
<td>$155</td>
</tr>
<tr>
<td>Injection Molds 2</td>
<td>$325</td>
<td>100%</td>
<td>$325</td>
</tr>
<tr>
<td>Blow Molding Dies 2</td>
<td>$155</td>
<td>100%</td>
<td>$155</td>
</tr>
<tr>
<td><strong>Tooling Subtotal</strong></td>
<td></td>
<td></td>
<td>$155</td>
</tr>
<tr>
<td><strong>Building</strong></td>
<td>$8,000</td>
<td>20%</td>
<td>$1,600</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>$3,000</td>
<td>20%</td>
<td>$600</td>
</tr>
<tr>
<td><strong>Management and Administrative Overheads</strong></td>
<td>$4,000</td>
<td>20%</td>
<td>$800</td>
</tr>
<tr>
<td><strong>Total Fixed Cost for This job</strong></td>
<td></td>
<td></td>
<td>$4,620</td>
</tr>
</tbody>
</table>
**Module 3C**

**Engineering Validation** measures and analyzes the process, audits and calibrates equipment and creates a document trail that shows the process leads to a consistent result to ensure the highest quality products are produced. *(Repeat from 2C)*

**Design Validation** is testing aimed at ensuring that a product or system fulfills the defined user needs and specified requirements, under specified operating conditions. *(Repeat from 2B)*

**Development** is the systematic use of scientific and technical knowledge to meet specific objectives or requirements. *(Repeat from 2B)*

**Manufacturing Development** or Engineering & Manufacturing and Development (EMD) phase is where a system is developed and designed before going into production. *(Repeat from 2B)*

**Molding Process** is the process of manufacturing by shaping liquid or pliable raw material using a rigid frame called a mold or matrix.

**Make-Versus-Buy Analysis** calculates the benefits between manufacturing a product in-house or purchasing it from an external supplier.

**Total Cost (TC)** describes the total economic cost of production and is made up of variable costs, which vary according to the quantity of a good produced and include inputs such as labor and raw materials, plus fixed costs, which are independent of the quantity of a good produced and include inputs (capital) that cannot be varied in the short term, such as buildings and machinery. *(Repeat from 3A)*

**Total Fixed Cost (FC)** are business expenses that are not dependent on the level of goods or services produced by the business. *(Repeat from 3A)*

**Total Variable Cost (VC)** is costs that change in proportion to the good or service that a business produces. *(Repeat from 3A)*

**Marginal Cost (MC)** is the change in the opportunity cost that arises when the quantity produced is incremented by one unit, that is, it is the cost of producing one more unit of a good.

**Break-Even (BE) Point** is the point at which total cost and total revenue are equal. *(Repeat from 3A)*