Reminders and Announcements

• HW7 due Today (or Friday)
• HW8 assigned today, due Wednesday
  — Optional bonus homework
• Project 3 due May 5\textsuperscript{th}
  — Design II students may turn in on May 7\textsuperscript{th}
• Faculty Course Evaluations now open
• Project 2 reports graded
  — Individual feedback by email
  — Grippers in B2 SH (except 10, 11, 15, 16)
  — Reimbursement forms
Manufacturing and Cost

- Review of Dieter and Schmidt
  - (Figures & Charts are from Ch. 13 & 16
- Exercise using IPD worksheet
- Exercise using custompart.net

Manufacturing

- What is manufacturing?
  - Converting design into product
- Manufacturing and design
  - Serial ordering is inefficient, interplay necessary
- Multilevel process
  - Process, tool, work, plant, administration
- Area of active improvement
  - Utilization: Small-lot 5%, Automated: 90%
  - Shrinking but vital portion of economy
Categorization of Man. Processes

- Primary
  - Form general shape
- Secondary
  - Modify and add features
- Finishing
  - Polish, coat or paint
- Assembly
### Primary Manufacturing Processes

- Create general shape
- Casting processes
  - Molten liquid (metal) solidifies in mold cavity
- Polymer molding
  - Viscous polymer compressed/injected into mold
- Deformation processes
  - Material (metal) forged, rolled, extruded, bent
- Powder processing
  - Particles (metal, ceramic, polymer) sintered

### Secondary Manufacturing Processes

- Modify shape to add features
- Material removal (machining)
  - Controlled fracture: turning, milling, grinding
- Joining processes
  - Welding, soldering, riveting, bonding
- Heat treatment
  - Material properties: hardening, carburizing
### Manufacturing Systems

- **Different styles:**
  - Job shop: small quantities, ever-changing
  - Batch: intermittent runs of similar parts
  - Assembly line: creation of sets of parts
  - Continuous flow: very specialized

- **Typically mechanized**
  - Machines do primary work, not people

- **Varying degrees of automation**
  - Machines manage process, not people

### Manufacturing Selection

- **Steps in selecting a manufacturing process**
  - Identify constraints
  - Identify objectives
  - Screen possibilities
  - Compare estimated costs

- **Important factors:**
  - Quantity
  - Complexity
  - Material
  - Quality requirements
  - Cost and timing constraints
Quantity and cost

- Two types of manufacturing costs
  - Fixed: overhead for entire process independent qty
  - Variable: per-part costs, dependent on qty
- Examples of fixed costs
  - Cost of making molds, purchasing machines
  - Renting warehouse space
- Examples of variable costs
  - Cost of material, electricity, renting machines
  - Labor costs
- Total cost = Fixed + Variable \cdot Qty

Quantity and batch size

- Volume: number of pieces
- Economic batch size: min practical volume
Quantity and batch size

<table>
<thead>
<tr>
<th>Process</th>
<th>Mold cost</th>
<th>Labor input/unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection molding</td>
<td>$450,000</td>
<td>3 min = $1</td>
</tr>
<tr>
<td>Reaction injection molding</td>
<td>$90,000</td>
<td>6 min = $2</td>
</tr>
<tr>
<td>Compression molding</td>
<td>$55,000</td>
<td>6 min = $2</td>
</tr>
<tr>
<td>Contact molding</td>
<td>$20,000</td>
<td>1 h = $20</td>
</tr>
</tbody>
</table>

Cost per part

<table>
<thead>
<tr>
<th>Process</th>
<th>1000 parts</th>
<th>10,000 parts</th>
<th>100,000 parts</th>
<th>1,000,000 parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection molding</td>
<td>$451</td>
<td>$46</td>
<td>$5.50</td>
<td>$1.45</td>
</tr>
<tr>
<td>Reaction injection molding</td>
<td>$92</td>
<td>$11</td>
<td>$2.90</td>
<td>$2.09</td>
</tr>
<tr>
<td>Compression molding</td>
<td>$57</td>
<td>$7.50</td>
<td>$2.55</td>
<td>$2.06</td>
</tr>
<tr>
<td>Contact molding</td>
<td>$40</td>
<td>$22</td>
<td>$20.20</td>
<td>$20.02</td>
</tr>
</tbody>
</table>

Economic batch size vs. Process
Shape and Feature Complexity

- What is complexity?
  - Information content
    - Number of dimensions, relative tolerances
  - Type of shape
- Implications for manufacturing?
  - Some processes incapable of forming some shapes
  - Some uneconomical for some complexities
### Ability of Manufacturing Processes to Produce Shapes in Fig. 13.6

<table>
<thead>
<tr>
<th>Process</th>
<th>Capability for producing shapes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Casting processes</strong></td>
<td></td>
</tr>
<tr>
<td>Sand casting</td>
<td>Can make all shapes</td>
</tr>
<tr>
<td>Plaster casting</td>
<td>Can make all shapes</td>
</tr>
<tr>
<td>Investment casting</td>
<td>Can make all shapes</td>
</tr>
<tr>
<td>Permanent mold</td>
<td>Can make all shapes except T3, T5, F5, U1, U5, U7</td>
</tr>
<tr>
<td>Die casting</td>
<td>Same as permanent mold casting</td>
</tr>
<tr>
<td><strong>Deformation processes</strong></td>
<td></td>
</tr>
<tr>
<td>Open-die forging</td>
<td>Best for R0 to R3; all B shapes; T1, F0, Sp6</td>
</tr>
<tr>
<td>Hot impression die forging</td>
<td>Best for all R, B, and S shapes; T1, T2, Sp</td>
</tr>
<tr>
<td>Hot extrusion</td>
<td>All 0 shapes</td>
</tr>
<tr>
<td>Cold forging/ cold extrusion</td>
<td>Same as hot die forging or extrusion</td>
</tr>
<tr>
<td>Shape drawing</td>
<td>All 0 shapes</td>
</tr>
<tr>
<td>Shape rolling</td>
<td>All 0 shapes</td>
</tr>
<tr>
<td><strong>Sheet-metal working processes</strong></td>
<td></td>
</tr>
<tr>
<td>Blanking</td>
<td>F0 to F2; T7</td>
</tr>
<tr>
<td>Bending</td>
<td>R3, B3, S0, S2, S7, T3, F3, F6,</td>
</tr>
<tr>
<td>Stretching</td>
<td>F4; S7</td>
</tr>
<tr>
<td>Deep drawing</td>
<td>T4, F4, F7</td>
</tr>
<tr>
<td>Spinning</td>
<td>T1, T2, T4, T6, F4, F5</td>
</tr>
<tr>
<td><strong>Polymer processes</strong></td>
<td></td>
</tr>
<tr>
<td>Extrusion</td>
<td>All 0 shapes</td>
</tr>
<tr>
<td>Injection molding</td>
<td>Can make all shapes with proper coring</td>
</tr>
<tr>
<td>Compression molding</td>
<td>All shapes except T3, T5, T6, F5, U4</td>
</tr>
<tr>
<td>Sheet thermoforming</td>
<td>T4, F4, F7</td>
</tr>
<tr>
<td><strong>Powder metallurgy processes</strong></td>
<td></td>
</tr>
<tr>
<td>Cold press and sinter</td>
<td>All shapes except S3, T2, T3, T5, T6, F3, F5, all U shapes</td>
</tr>
<tr>
<td>Hot isostatic pressing</td>
<td>All shapes except T5 and F5</td>
</tr>
<tr>
<td>Powder injection molding</td>
<td>All shapes except T5, F5, U1, U4</td>
</tr>
<tr>
<td>PM forging</td>
<td>Same shape restrictions as cold press and sinter</td>
</tr>
<tr>
<td><strong>Machining processes</strong></td>
<td></td>
</tr>
<tr>
<td>Lathe turning</td>
<td>R0, R1, R2, R7, T0, T1, T2, Sp1, Sp6, U1, U2</td>
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<tr>
<td>Drilling</td>
<td>T0, T6</td>
</tr>
<tr>
<td>Milling</td>
<td>All B, S, SS shapes; F0 to F4, F6, F7, U7</td>
</tr>
<tr>
<td>Grinding</td>
<td>Same as turning and milling</td>
</tr>
<tr>
<td>Honing, lapping</td>
<td>R0 to R2, B0 to B2, B7, T0 to T2, T4 to T7, F0 to F2, Sp</td>
</tr>
</tbody>
</table>

Based on data from J.A. Sehony, *Introduction to Manufacturing Processes.*
Size of parts

• What size aspects are important?
  – Overall envelope: workspace
  – Part area: pressure
  – Minimum thickness: material flow
  – Maximum thickness: cooling time

• Implications for manufacturing?
  – Some processes uneconomical for some sizes

Part mass vs. Process
Part thickness vs. Process

Material

- Processes depend on material properties, e.g.
  - Viscosity: low for casting, high for blow molding
  - Melting point: mold limits
  - Thermal capacity: cooling time
  - Hardness, brittleness: minimum bending radius
### Material vs. Manufacturing process

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>ALLOY</th>
<th>STAINLESS</th>
<th>CORROSION</th>
<th>ALUMINUM</th>
<th>MAGNESIUM</th>
<th>TITANIUM</th>
<th>INCONEL</th>
<th>NICKEL</th>
<th>CHROMIUM</th>
<th>ZINC</th>
<th>LEAD</th>
<th>COPPER</th>
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<tbody>
<tr>
<td>QUANTITY</td>
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<tr>
<td>VERY LOW</td>
<td>1-100</td>
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<td>LOW</td>
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<tr>
<td>MEDIUM</td>
<td>500-1500</td>
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<td>HIGH</td>
<td>1500-5000</td>
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<tr>
<td><strong>ALL QUANTITIES</strong></td>
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</tbody>
</table>

### Key to Manufacturing Processes

- **Casting Processes**
  - Sand Casting
  - Die Casting
  - Pressure Die Casting
  - Rapid Casting
  - Ceramic Molds Casting
  - Ductile Iron Casting

- **Plastic & Composite Processing**
  - Injection Molding
  - Reaction Injection Molding
  - Compression Molding
  - Transfer Molding
  - Vacuum Molding
  - Molding
  - Injection Molding
  - Compression Molding
  - Transfer Molding
  - Vacuum Molding

- **Forming Processes**
  - Sheet Metal Forming
  - Sheet Metal Stamping
  - Sheet Metal Drawing
  - Sheet Metal Bending
  - Sheet Metal Cutting
  - Sheet Metal Sharpening
  - Sheet Metal Milling
  - Sheet Metal Drilling
  - Sheet Metal Welding
  - Sheet Metal Soldering
  - Sheet Metal Brazing
  - Sheet Metal Gasketing

- **Welding Processes**
  - Arc Welding
  - Resistance Welding
  - Induction Heating
  - Laser Welding
  - Ultrasound Welding
  - Electron Beam Welding
  - Plasma Arc Welding
  - Soldering
  - Brazing
  - Gasketing
  - Adhesive Bonding

### Required Quality

- **Freedom from defects**
  - Voids, cracks, chemical consistency

- **Surface finish**
  - Roughness, lay, waviness, integrity

- **Dimensional accuracy**
Quality vs. Manufacturing Process

Cost vs. Quality
### Design for Manufacture (DFM) Guidelines

- Minimize number of parts
- Standardize components
- Commonize components
- Standardize features
- Keep functional and simple
- Multifunctional parts
- Ease of fabrication (near net shape, fixturing)
- Loose tolerances
- Minimize secondary operations
- Utilize process characteristics (Judo)

### Design for Assembly (DFA) Guidelines

- Minimize number of parts
  - Unique: motion, material, assembly, maintenance
- Minimize assembly surfaces
- Sub-assemblies
- Mistake-proofing
- Handling: Avoid fasteners, Minimize handling
- Insertion: Minimize direction, Provide access
Design for Assembly Examples

**Poor Assembly**
- Difficult to orientate small chamfer on chip with mechanical locking
- Component does not have a stable orientation
- Straight slot will tangle

**Improved Assembly**
- Non-functional longitudinal feature simplifies orientation
- Flats on the sides make it easy to orientate with respect to small holes
- Crank end will not tangle
- Provide guide on surfaces to aid component placing

Design for Manufacture Examples: Machining

**Poor**

**Good**
Design for Manufacture Example: Forging

Design for Manufacture Examples: Casting
Design for Manufacture Examples: Casting

- Poor
- Poor
- Poor
- Poor
- Good
- Good
- Good
- Good

Other Processes We Will Discuss

- Injection molding
- Blow molding
- Composite processing
- Examples to follow
Manufacturing, Cost and Environment

• Cost can be primary constraint
  – Design to cost, Should-cost
• Environmental impact also important
  – Life Cycle Analysis - next week
• How to develop manufacturing cost intuition?
  – Exercises :D
  – Two tools: worksheet and online estimator

Example 1: Shaft

• What type of material and manufacturing?
  – Steel
  – Bulk: extrusion
  – Secondary: perhaps machining or grinding
• Modifications to design?
• Worksheet cost model
  – Extrusion costs
  – Cutoff costs
  – Grinding costs
### Example 2: Motor cap

- See SW model, explanation
- What type of material and manufacturing?
  - Plastic
  - Primary: injection molding
- Modifications to the design?
- Worksheet cost model
  - Tooling costs
  - Variable costs
- Compare to online cost estimate

### Example 3: Bearing cap

- See SW model, explanation
- What type of material and manufacturing?
  - Aluminum
  - Primary: sand casting, die casting
- Modifications to the design?
- Worksheet cost model
  - Tooling costs
  - Variable costs
- Compare to online cost estimate