Manufacturing Processes
Context: “Prototype” vs. “Product”

<table>
<thead>
<tr>
<th>Quantity</th>
<th>ME72 Device Prototype</th>
<th>Toy RC car Product</th>
<th>Automobile Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,000</td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td>Mfg. cost</td>
<td>$200 in parts + your effort</td>
<td>$5-10</td>
<td>$10,000+</td>
</tr>
<tr>
<td>Variability</td>
<td>Can be a lot</td>
<td>Little</td>
<td>Very little</td>
</tr>
</tbody>
</table>
Prototype -> Product

- *Prototypes* are one-offs
- *Products* are to be manufactured
- What if someone wanted you to make 1,000 of your device for $50 each?
  - What would you change?
- How do you make it to meet scale, cost, and repeatability?
  - “Better, faster, cheaper”
  - Manufacturing Processes
    - What processes should you use?
  - Design for manufacturability
    - How do you design so it is easily made/assembled?
Manufacturing process (page 1)

Source: Gutowski
POLYMER PROCESSES
EXTRUSION
FIBER SPINNING
CALANDERING
FILM BLOWING
COATING
(MELTS, SOLUTION, PLASMA, ELECTROSTATIC, PLASTISOL, UV CURABLE...)
BLOW MOLDING
INJECTION MOLDING
REACTION INJECTION MOLDING (RIM)
COMPRESSION MOLDING
TRANSFER MOLDING
CASTING
THERMOFORMING
ROTATIONAL MOLDING
SOLID STATE FORMING
MACHINING
ETCHING SOLVENT PROCESSING
FOAMING
BONDING
IMPREGNATING
PAINTING

COMPOSITES PROCESSES
(POLYMER COMPOSITES)
PULTRUSION
FILAMENT WINDING
PULL FORMING
BRAIDING
AUTOCLAVE MOLDING
COMPRESSION MOLDING (SMC)
RESIN TRANSFER MOLDING
AUTOCOMP MOLDING
HAND LAY-UP
SPRAY-UP
AUTOMATIC TAPE LAY-UP
STAMPING
DIAPHRAGM FORMING
INJECTION MOLDING
(REINFORCED THERMOPLASTICS, BMC...)
REINFORCED REACTION INJECTION MOLDING (RRIM)
(METAL MATRIX COMPOSITES)
HOT PRESSURE BONDING
HOT ISOSTATIC PRESSING
LIQUID METAL INFILTRATION
ELECTRODEPOSITION
PLASMA SPRAY DEPOSITION

CERAMICS PROCESSES
POWER PROCESSES
• CONSOLIDATION
• SINTERING
MELT PROCESSES
• CRystalline MATERIALS (SILICON)
• GLASSES
• DRAWING, CASTING, BLOWING, TEMPERING (OPTICAL & STRUCTURAL FILTERS)
• COATING
SOL-GEL CERAMICS PROCESSING

MICROELECTRONICS PROCESSING
CRYSTAL GROWTH
• CZOCHRALSKI CRYSTAL GROWTH
• FLOAT-ZONE CRYSTAL GROWTH
WAFER PROCESSING
• SLICING, ETCHING, POLISHING
SURFACE PROCESSES
• CHEMICAL VAPOR DEPOSITION (CVD)
• EPITAXIAL FILM GROWTH
• POLY CRYSTALLINE FILM GROWTH
• S102 FILMS
• OTHER (DIELECTRICS, METALS)
OXIDATION
• ION IMPLANTATION
• PHYSICAL VAPOR DEPOSITION
• SPUTTERING
• EVAPORATION
LITHOGRAPHY
• PHOTORESIST
• ELECTRON BEAM, X-RAY, ION BEAM
WET ETCHING
• CHEMICAL
DHY ETCHING
• PLASMA
• SPUTTER
• REACTIVE ION
PACKAGING
• DICING
• DIE ATTACHMENT
• WIRE BONDING
• ENCAPSULATION

Source: Gutowski

Manufacturing process (page 2)
Materials used in a car

Source: K. H. Grote
Effect of manufacturing on geometry

Source: Magrab
Performance measures

• What makes a good manufacturing process?
  – Rate
    • Material flow through system
  – Time
    • Order to receipt
    • Setup time + part process time
  – Cost
    • Material + Labor + Tooling + Equipment
  – Quality
    • Deviation from target

Source: Gutowski
Manufacturing processes

1. Subtractive
   - Material removal
2. Additive
   - Material addition, often in layers
3. Continuous
   - Continuous output (wire, rod)
4. Net shape
   - Output is the same as (or near) final shape

Source: Gutowski
1. Subtractive Processes

- Machining
  - Turning
  - milling
  - boring
  - grinding

- Non-traditional machining
  - Chemical milling
  - Waterjet machining

- Micro-electronics processes
  - etching processes using either masks or beam
Milling

Basic Types of Milling Cutters and Operations

Source: K. H. Grote and Kalpakjian
Non-traditional machining

- Laser machining
- Waterjet machining

Source: K. H. Grote
2. Additive Processes

- Joining
  - Welding, soldering, adhering

- Rapid Prototyping/Layered manufacturing
  - Stereolithography, 3D printing

- Composites
Welding

- Shielded Metal-Arc Welding Process. 50% of all industrial welding employs this.

Source: K. H. Grote
Stereolithography (SLA)

- Photopolymers are exposed by laser and cured from a liquid to a solid.

Source: http://cybercut.berkeley.edu/mas2/html/processes/stereolith/more.html
3D printing

- Thin layer of powder spread over surface
- Like an ink-jet printer, binder material selectively joins particles to form the object

Source: http://web.mit.edu/tdp/www/whatis3dp.html
Composites

- Hand lay-up of layers of resin and fiber.
- Lightweight & strong, but process is labor intensive.

Source: http://www.saint-gobain-vetrotex.com.br/process_handlay.htm#01
3. Continuous Processes

- Extrusion of metals
- Plastic Extrusion
- Pultrusion of composites
Metal extrusion

Direct extrusion

Indirect

Hydrostatic

Source: K. H. Grote and Kalpakjian
Plastic extrusion

Pultrusion

- For composites
- Fiber reinforcing material is pulled through resin bath and into a die.

Schematic Diagram of the Pultrusion Process

Source: http://users.techline.com/lord/manu.html
4. Net Shape forming

- Solids
  - Metal Forming - stamping, forging
  - Powders
- Liquids
  - Casting
  - Injection Molding, thermoforming, blow molding
- Mixtures
  - Infiltration
  - Viscoelastics
- Tolerances not as tight
Drawing and stretching

- Sheet metal

From: http://www.tms.org/pubs/journals/JOM/9911/Hosford-9911-figure1.html
Forging

- Metal workpiece pressed under great pressure into high strength parts

From: http://www.forging.org/facts/idproc.htm
Investment/lost wax Casting

- A wax pattern is surrounded with investment material (sand), baked out, then metal is poured in the cavity.

1. Create wax pattern
2. Assemble patterns
3. Apply investment
4. Dewax
5. Fill shell
6. Knockout
7. Cutoff
8. Finished castings

From: http://www.hitchiner.com/home.html
Compression Molding

Rubber trivet

Source: Byars 1998
1. Compression molding machine
2. Slabs of HTV silicone rubber
3. Trim excess
4. Finished trivets
Injection Molding

From: http://www.idsa-mp.org/proc/plastic/injection/injection_process.htm
Injection molding example

Cutlery made of biodegradable starch

Source: Byars 1998
1. Starch

2. Pellets are formed

3. Injection molded forks on stem

4. Decomposing cutlery
Thermoforming

- Very inexpensive for low volumes