2.810 Manufacturing Processes and Systems

Prof. Tim Gutowski, gutowski@mit.edu

September 4, 2019

Prereq: 2.001, 2.006, 2.008
(translation: solid & fluid mech, heat transfer, mfg)
Today’s Agenda

• Business
  – Administrative stuff
  – Your background

• Concepts
  – Manufacturing Enterprise – Big Picture
  – Processes
  – Systems
Basic info can be found on the 2.810 webpage

**web page:** http://web.mit.edu/2.810/www

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**T.A.:** John Lewandowski  
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**Tech Inst:** Mr. Paul Carson  
Rm. 35-112  
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**Text:** *Manufacturing Engineering and Technology, 7th Ed.*  
Paul Carson & the Bldg 35 Shop

pcarson@mit.edu
Hands-on Experience

Processes to Systems
# 2.810 Schedule

<table>
<thead>
<tr>
<th>Mondays 1:00 - 2:30</th>
<th>Wednesdays 1:00 - 2:30</th>
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<tbody>
<tr>
<td><strong>Sept.</strong></td>
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<tr>
<td>9 How is this part made?</td>
<td>4 Introduction</td>
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<tr>
<td>16 Process Performance</td>
<td>12 Intro to Processes</td>
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<tr>
<td>23 Casting Processes</td>
<td>18 Removal Processes</td>
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<tr>
<td>30 Sheet Processes</td>
<td>25 Additive Processes</td>
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<td><strong>Oct.</strong></td>
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<tr>
<td>7 Car/Quiz Review**</td>
<td>2 Process Summary</td>
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<tr>
<td>14 No Class (Columbus Day)</td>
<td>9 QUIZ I</td>
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<tr>
<td>21 Additive Mfg. (John Hart)</td>
<td>16 Intro to Mfg. Systems</td>
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<tr>
<td>28 Process Control (Dave Hardt)</td>
<td>23 TPS &amp; Current Practices (J. Pacheco)</td>
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<td><strong>Nov.</strong></td>
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<td>4 System Tools</td>
<td>6 Progress Reports</td>
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<tr>
<td>11 No Class (Veterans Day)</td>
<td>13 Sustainable Manufacturing</td>
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<tr>
<td>18 Systems Review</td>
<td>20 QUIZ II</td>
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<td>25 Digital Mfg. (Brian Anthony)</td>
<td>27 Work on Projects</td>
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<tr>
<td><strong>Dec.</strong></td>
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<tr>
<td>2 Work on Projects</td>
<td>4 Work on Projects</td>
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<tr>
<td>9 Contest (Lobby 13)</td>
<td>11 Reports &amp; Evaluations</td>
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* [https://www.youtube.com/watch?v=ICjQ0UzE2Ao](https://www.youtube.com/watch?v=ICjQ0UzE2Ao)
2.810 team project
## 2.810 Labs (see signup)

*Labs 9-12 M, T, R, F; Building 35 shop*

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<tr>
<th>Week of September 9</th>
<th>Safety, Shop Orientation, Car Review</th>
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<tr>
<td>Week of September 16</td>
<td>Machining /Flashlight Project</td>
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<td>Week of September 23</td>
<td>Machining /Flashlight Project</td>
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<td>Week of September 30</td>
<td>Machining /Flashlight Project</td>
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<tr>
<td>Week of October 7</td>
<td>CAD/CAM (by appointment with Paul)</td>
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<tr>
<td>Week of October 16</td>
<td>Finish up Lab</td>
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<tr>
<td>Week of October 21</td>
<td>Car Project (this continues through term)</td>
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Lab Maximum 16 people
Teams and Labs are Different

• Labs occur at the beginning of the term:
  basic skills some CNC

• Teams are to build cars: you select your team members, usually 4 to 6 per team
# Key dates for project

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<th>Date</th>
<th>Event Description</th>
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<tr>
<td>Sept 16</td>
<td>Teams finalized</td>
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<tr>
<td>Sept 30</td>
<td>Kits assembled</td>
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<tr>
<td>Week of Sept 30</td>
<td>Preliminary design concept review (schedule a time for group to meet with Paul)</td>
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<tr>
<td>Week of Oct 14</td>
<td>Injection mold wheels</td>
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<td>October 21</td>
<td>Chassis drawings due (waterjet file and dimensioned drawing)</td>
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<tr>
<td>Week of Oct 28</td>
<td>Production chassis cut on waterjet</td>
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<td>November 6</td>
<td>Oral Progress Reports</td>
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<tr>
<td>December 9</td>
<td>Contest</td>
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<tr>
<td>December 11</td>
<td>Evaluation &amp; Reports</td>
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Available at 2.810 Website
Please fill out information form; background, interests, skills

• Basic information
• Experience in shop
• Experience in mfg
2.810 Manufacturing Processes and Systems

Name: __________________________________________

Year: ____________________ Course: ____________________

Email: ____________________

Prerequisites (Please check off if taken):

- 2.001 or equivalent □
- 2.006 □
- 2.008 □

Previous experience in industry/research/manufacturing, please describe

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

If you have had significant manufacturing experience, would you be interested in giving a short “show & tell” (about 5-10 min) to the class if we can schedule it? □ Y □ N

List the Topic:

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________

2.810 Hands-on Experience Questionnaire

Are you familiar with these tools? Can you use them? □ Y □ N

Are you comfortable using power tools? □ Y □ N

Have you ever built or repaired something? □ Y □ N
Ex: Built a boat, repaired a lawn mower etc.
What specifically did you do? _____________________________________________

Have you ever used - an engine lathe? □ Y □ N
- band saw? □ Y □ N
- drill press? □ Y □ N

Are you comfortable in a machine shop and can operate machine tools without supervision? □ Y □ N

Can you program CNC machine tools? □ Y □ N

Please list any CAD/CAM software you already have experience with:

1. ____________________________________________
2. ____________________________________________
3. ____________________________________________
Lab Sign-up

• See Google Doc: web & email

• State your availability & preference

• See schedule (don’t miss first 5 weeks)
Labs & Copies (9 per sheet Y_ or N_?)

Which Lab sessions are you available to attend?

☐ M 9-Noon
☐ W 9-Noon
☐ Tr 9- Noon
☐ F 9 - Noon

Among the sections you can attend, which is your FIRST preference? Please check only one.

☐ M 9-Noon
☐ W 9-Noon
☐ Tr 9- Noon
☐ F 9 - Noon
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**SUMMARY:** Yr 1: 0  Yr 2: 0  Yr 3: 0  Yr 4: 2  Yr G: 31  TOTAL: 33

2.810  Sec. B01  Mfg Processes and Systems (section list)
Room: 35-125  Time: M9-12
Grading

• Quiz 1  30%
• Quiz 2  30%
• Project  30% (team grade)
• Participation 10%
• Total   100%
The Mfg Enterprise – Big Picture

• Industrialization and Economic Growth
• Big Push Industrialization
• Divergence
• Democracy and Political Development
What caused this surge in per capita income around 1800 AD?

Ref. p 228
INDUSTRIAL REVOLUTION

http://www.historydiscussion.net/history/industrial-revolution/history-of-the-industrial-revolution/1784
The Industrial Revolution

- England 1760 – 1830s
- Coal
- Steam power
- Textile mills
- Steel
- Railroads
- Pollution

https://sites.google.com/a/online.sd71.bc.ca/human-rights-morgan-rachel-rylee/the-industrial-revolution
GDP per capita in England since 1270
Adjusted for inflation and measured in British Pounds in 2013 prices

Source: GDP in England (using BoE, 2017)
Note: Data refers to England until 1700 and the UK from then onwards.
The importance of Manufacturing to economic growth

The plot shows the correlation, both in logs, of current GDP per capita (1820 -1950: Maddison), and past levels of industrialization per capita (50 or 70 years earlier: Bairoch).

The Great Divergence
How do you join the developed?

• “Big Push Industrialization”
  – Do everything at once
  – Trust
  – Planning Authority
  – Then Transition…

• Required GDP growth
  – ~6% over 60 years
How do you join the developed?

• “Big Push Industrialization”
  – Japan
  – South Korea
  – Taiwan

• Less successful
  – Russia
  – South America
The Importance of Manufacturing for Economic Development

- The rise of China and Manufacturing

Figure 2. Selected Countries’ Shares of Global Manufacturing Value Added


Marc Levinson, Cong. Res. Ser. 2018
Global Mfg Shares 1750-2006

2. Distribution of world manufacturing

R.C. Allen 2011
The Role of Economic Growth in Political Development

Ref. p 43
How Democracy might develop...

Ref. p 43
The Future of Manufacturing

• Technology development
• Social and Political Environment
• The interaction between the two
Technology Development:

- Digital Mfg
- A.I.
- Integrated sensors
- blockchain
- 3D Printing
- Automation
- Industry 4.0
- New Products
Future trends: Jobs & Growth

News

Impact of automation on developing countries puts up to 85% of jobs at risk

27 Jan 2016

A new report from CCI and the Oxford Martin School explores the varying impact that automation of jobs will have on countries and cities around the world, in the near future and the coming decades.
Future trends: “the bounty & the spread”

THE SECOND MACHINE AGE
WORK, PROGRESS, AND PROSPERITY IN A TIME OF BRILLIANT TECHNOLOGIES
ERIK BRYNJOLFSSON
ANDREW McAFFEE
The Environment: Climate Change

- CO2 concentration (PPM)
- Temperature °C

Graph showing the increase in CO2 concentration (PPM) and temperature (°C) over time from 1960 to 2015.
The Nuts and Bolts of 2.810

Processes

Systems

Project
Basic Concepts for 2.810

1. Manufacturing Processes
   - Abstraction and trends
   - Performance Attributes
   - Physics
MANUFACTURING PROCESSES

MACHINING PROCESSES

SINGLE POINT MACHINING
• TURNING
• BORING
• FACEING
• FORMING
• SHAPING, PLANNING

MULTIPOINT MACHINING
• DRILLING
• MILLING
• SAWING, FILING
• BROACHING, THREAD CUTTING

GRINDING
• SURFACE GRINDING
• CYLINDRICAL GRINDING
• CENTERLESS GRINDING
• INTERNAL GRINDING
• FORM GRINDING

ABRASIVE WIRE CUTTING
Honning
Lapping
ULTRASONIC MACHINING
Buffing, Polishing
Urnishing
Tumbling
Grit BLASTING

CHEMICAL MACHINING
• ENGRAVING
• CHEMICAL MILLING
• CHEMICAL BLANKING

ELECTROCHEMICAL MACHINING
ELECTRICAL DISCHARGE MACHINING
LASTER MACHINING
ELECTRON BEAM MACHINING
PLASMA-ARC CUTTING
FLAME CUTTING, WATER JET CUTTING

DEFORMATION PROCESSES

OPEN-DIE FORGING
IMPRESSION-DIE FORGING
CLOSED-DIE FORGING
• PRECISION OR FLASHLESS FORGING
• COINING
• HEADING, PIERCING, HUBBING, COGGING,
FULLERING, EDGING, ROLL FORGING,
SKEW ROLLING

ROLLING
• FLAT, RING, THREAD, GEAR, PIERCING
EXTRUSION
• DIRECT, INDIRECT HYDROSTATIC,
IMPACT, BACKWARD

DRAWING
• ROD & WIRE, FLAT STRIP, TUBES

SWAGING

SHEARING
BENDING
• PRESS-BRAKE FORMING, ROLL FORMING
 TUBE FORMING
BEADING, FLANGING, HEMMING, SEAMING
STRECH FORMING

BULGING

DEEP DRAWING
PRESS FORMING
RUBBER FORMING

SPINNING
EXPLOSIVE FORMING

ELECTROHYDRAULIC FORMING

MAGNETIC-PULSE FORMING
SUPERPLASTIC FORMING

METAL CASTING AND POWDER PROCESSES

CASTING
CASTING OF INGOTS
CONTINUOUS CASTING

SAND CASTING
SHELL MOLDING
SLURRY MOLDING
INVESTMENT CASTING (LOW-WAX PROCESS)

EVAPORATIVE CASTING
DIE CASTING
(GRAVITY-FEED, PRESSURIZED...)
CENTRIFUGAL CASTING
SQUEEZE CASTING
RHEOCASTING

CRYSTAL GROWING
• CRYSTAL-PULLING
• ZONE MELTING

ELECTRO FORMING
Plasma Spraying

POWDER METALLURGY
PRESSING
ISOSTATIC PRESSING
SINTERING

JOINING PROCESSES

MECHANICAL JOINING
• BOLTS, SCREWS, RIVETS
SOLID-STATE WELDING
• DIFFUSION, FORGING, FRICTION,
DEFORMATION
LIQUID STATE WELDING
• RESISTANCE WELDING
• ARC WELDING
• THERMAL WELDING
HIGH-ENERGY BEAM WELDING
• ELECTRONIC BEAM, LASER
LIQUID-SOLID STATE BONDING
• BRAZING
• SOLDERING
ADHESIVE BONDING
• PLASTICS AND COMPOSITES JOINING
(MECHANICAL, HEATING, SOLVENTS,
ULTRASONICS...)

Manufacturing processes, ...
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
  (FILLED 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
  • S,X Films
  • OTHER (DIELECTRICS, METALS)
- OXIDATION
  • ION IMPLANTATION
  • PHYSICAL VAPOR DEPOSITION
  • SPUTTERING
  • EVAPORATION
- LITHOGRAPHY
  • PHOTORESIST
  • ELECTRON BEAM, X-RAY, ION BEAM LITHOGRAPHY
- WET ETCHING
  • CHEMICAL DRY ETCHING
  • PLASMA
  • SPUTTER
  • REACTIVE ION
- PACKAGING
  • DICING
  • DIE ATTACHMENT
  • WIRE BONDING
  • ENCAPSULATION

172 processes + rapid prototyping + etc, etc
ADDITIVE MANUFACTURING TECHNOLOGIES

- SLA Stereolithography
  - Resin
- DLP Digital Light Processing
  - Resin
- CDLP Continuous Digital Light Processing
  - Resin
- FDM Provoed Deposition Modeling
  - Plastic
- MJ Material Jetting
  - Metal
- NPJ NanoPowder Jetting
  - Ceramic
- DOD Drop On Demand
  - Ceramic
- BJ Binder Jetting
  - Resin
  - Powder with binding agent
- MJF MultiJet Fusion
  - Plastic
- SLS Selective Laser Sintering
  - Powder
- DMLS / SLM Direct Metal Laser Sintering / Selective Laser Melting
  - Metal
- EBM Electron Beam Melting
  - Metal
- LENS Laser Engineered Net Shaping
  - Ceramic
- EBAM Electron Beam Additive Manufacturing
  - Ceramic
- LOM Laminated Object Manufacturing
  - Paper

Find out more at www.3dhubs.com/what-is-3d-printing
Some Processes developed out of LMP (bldg 35)
Abstraction of a Mfg Processes

- Raw material
- Energy
- Human Operators
- Information

Process

- Noise
- Hardware
- Scrap & Waste
- Heat
Process Classification

- Materials
- Machines
- Applications

vs

- Geometry
- Time
- Energy
Process Classification

• Geometrical transformation
  – Subtractive / Additive / Net

• Time sequence
  – Serial / Parallel

• Energy domain
  – Mechanical / Thermal / Chemical / Electrical

See “Manufacturing Processes and Process Control,” David E. Hardt
Geometrical classification

![Graph showing part mass (M) over time. The graph illustrates the comparison between additive and subtractive processes. Additive processes start from the net shape and move upward, while subtractive processes start from the part mass and move downward. Subtractive processes are further divided into serial and parallel subtypes.]
* Taken from "Manufacturing Processes and Process Control," David E. Hardt
Basic Concepts for 2.810

2. Manufacturing Systems
   - Physical part
   - Required machines
   - Process steps
   - Equipment arrangements
   - Tools, History
Mfg. System Designs; (a) job shop (b) flow shop
Manufacturing Systems

- Configurations
- Analysis tools (time performance)
- Historical development
- Current practice
- Future trends
From part to system

<table>
<thead>
<tr>
<th>Physical Part</th>
<th>Process Steps</th>
<th>System Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape, Materials, Tolerances</td>
<td>Equipment, Tools, Procedures</td>
<td>Equipment arrangement, Flows, Skill Levels, other Resources</td>
</tr>
<tr>
<td>Representation</td>
<td>Process Plan -</td>
<td>Cell or system -</td>
</tr>
</tbody>
</table>
Process Planning

• Identify machines
• Tools
• Settings
• Steps required to produce a geometry to tolerance
• Time estimation
## Process Plan

### Time Estimation

<table>
<thead>
<tr>
<th>#</th>
<th>Machine</th>
<th>Operation (V = Volume, A = Area, P = Perimeter)</th>
<th>Fixturm</th>
<th>Tool Change</th>
<th>Run (R = Rough, F = Finish)</th>
<th>Deburr / Inspect</th>
<th>Measure</th>
</tr>
</thead>
</table>
| 1 0 | 1 | Saw stock to ~ 4.125”
A = 5.625 in²
P = 9 in | 0.23 | - | - | - | - |
| 2 0 | 2 | Mill two ends to length 4”
V = 0.703 in³
A = 11.25 in²
P = 19 in | 0.20 | 2 | 0.13R 0.75F | 0.63D 0.05I 0.13M |
| 3 0 | 2 | Mill width to 2”
V = 2.5 in³
A = 10 in²
P = 13 in | 0.20 | - | 0.46R 0.67F | 0.43D 0.05I 0.13M |
| | 2 | Mill out 2”x1.5”x4”
V = 12 in³
A = 14 in²
P = 15 in | - | - | 2.19R 0.93F | 0.50D 0.05I 0.13M 0.13M |
| | 2 | Drill hole 1” diameter
- Center drill
- Pilot drill 1/2”
- Pilot drill 63/64”
- Ream | 0.20 | 2 | 0.03 0.05 0.04 0.01 | 0.21D 0.05I 0.17M |
| | 2 | Bore 1” radius
V = 0.79 in³
A = 1.57 in²
P = 7.28 in | 0.20 | 2 | 0.96R 0.10F | 0.24D 0.05I 0.06M |
| 3 | 3 | Sand 0.5” radii
V = 0.05 in³
A = 0.79 in²
P = 3.14 in | 0.08 | - | 0.20R 0.21F | 0.10D 0.05I 0.06M 0.06M |
| | Totals: | | 1.31 | 12.00 | 8.75 | 3.63 | |

---

Rod Support
Engineering Drawing; Connecting Link
See Tolerance hand-out
<table>
<thead>
<tr>
<th>#</th>
<th>Machine</th>
<th>Operation</th>
<th># Dims.</th>
<th>Fixtue</th>
<th>Tool Change</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(V = Volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>A = Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P = Perimeter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>Face end</td>
<td>-</td>
<td>0.17</td>
<td>0.1</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assume V = 0.075 in3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>Turn diameter to 0.827”</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V = 0.105 in3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>Turn diameter</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>finish pass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>A = 23 in²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>Center drill 0.512” dia.</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>Drill with 0.4688” drill</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
<td>0.28</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>Bore to 0.512”</td>
<td>1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V = 0.033 in³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>2</td>
<td>Grind to exact length of 1.635”</td>
<td>1</td>
<td>0.04</td>
<td>-</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assume V = 0.075 in3</td>
<td></td>
<td></td>
<td></td>
<td>0.01F</td>
</tr>
<tr>
<td>80</td>
<td>3</td>
<td>Fixture in collet on indexer to drill holes</td>
<td>-</td>
<td>0.17</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V = 1.65 in³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
<td>Center drill 0.1875” hole</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td>0.05</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>Drill to 11/64”</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td>0.17</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>Ream to 0.1875”</td>
<td>2</td>
<td>-</td>
<td>0.5</td>
<td>0.06</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>Index part</td>
<td>-</td>
<td>0.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>Center drill 0.1875” hole</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td>0.05</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>Drill to 11/64”</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td>0.17</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>Ream to 0.1875”</td>
<td>4</td>
<td>-</td>
<td>0.5</td>
<td>0.06</td>
</tr>
<tr>
<td>16</td>
<td>0</td>
<td>Deburr all edges</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P = 10.77 in</td>
<td></td>
<td></td>
<td></td>
<td>54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Totals:</td>
<td>9</td>
<td>0.48</td>
<td>3.40</td>
<td>3.32</td>
</tr>
</tbody>
</table>
Performance measures

- Rate
- Time
- Cost
- Quality
- Flexibility
- Environment

See “Competitive Attributes...” T. Gutowski
Rate and Time

Little’s law: \( L = \lambda W \) (all average values)

- \( L \) = units in system (inventory)
- \( \lambda \) = rate of material arrival
- \( W \) = time in system
**Time at the Machine**

- Time at the machine
  - Set-up time,
  - Process time, (parallel, serial)
  - Multi-cavity tooling
  - Post processing Time
  - Machine Rate
Time for the Cell or Line

Multiple Machine Systems:
• Batch processing
• Continuous processing
• Bottlenecks and Balancing
• Waiting
• Buffers
Direct Costs

Variable Costs:
- Materials + Waste
- Labor (time & skill level)
- General Purpose Equip (time, capital, maintenance)

Fixed Costs:
- Dedicated Equipment (tooling…)

\[ C/N \]

\[ N^* \]
Direct Costs

Economies of scale

\[ C = F + V \times N \]

- \( C \) = Total cost
- \( F \) = Fixed cost
- \( V \) = Variable cost
- \( N \) = number of units

Diagram showing \( C/N \) vs \( N \) with an inflection point at \( N^* \).
Quality

• Satisfied Customer (systems level)
• Deviation from target (process level)
  – Establishing the target (design)
  – Normal variation (process in control)
  – Observing deviation (SPC)
Quality

Process Capability Index, $C_p$ and $C_{pk}$

- $C_p = \frac{(USL - LSL)}{6\sigma}$
  - $USL = \text{Upper Specification Limit}$
  - $LSL = \text{Lower Specification Limit}$
  - $\sigma = \text{standard deviation of the process output}$

- USL and LSL are something specified by design

- The standard deviation is due to variation in the process
Flexibility

• Ability to accommodate different geometries, materials, production volumes, etc.

• Measured as $\Delta$ cost, $\Delta$ time, etc.
Environmental performance

- Process Level
- Product Level
- Life Cycle Assessment
- Enterprise Level
- Global Level
2.810 Project

- Form Teams
- Cooperate
- Manage
- Design
- Manufacture
- Test
- Compete
- Report and Evaluate
Detailed Prints

Exploded Assembly with BOM

Assembly Exploded View

SolidWorks Student Edition.
For Academic Use Only.

Figure 8 - Exploded Assembly with BOM
CADCAM and CNC

OMAX Instruction-1st team meeting
Needs DXF file
OMAX app available
Check List

- Hand in information sheets
- Fill in Google doc for labs ASAP
- Attend Lab next week
- Read:
  1. “Competitive Attributes…”
  2. “Mfg. Processes and Control”
  3. “Geometric Tolerancing”
  4. skim Kalpakjian Ch 1-9.
- Homework #1
2.810 team project

http://www.youtube.com/watch?v=BcnwGV4tNNY