- HW#1 due today.
- No HW today.
- Reading, Kalpakjian, P177–199
- Monday 2/16, Holiday
- Tuesday 2/17, Monday’s lecture & lab group A
- Wednesday 2/18, Yo-Yo case study

Super bowl 2002

The Law won
The Ravens took a quick lead and held on to beat the Patriots, earning the Super Bowl title.

BIG PICTURE

A University (Manufacturing System)

- High schools
- Colleges
- Etc.
- Faculty, staff, academic programs
- Administration
- Fundamental Knowledge
- Hands-on knowledge
- Graduate schools
- Industry
- Government
- Society
- Suppliers
- Manufacturing system
- Customers
Good Design

- lecture room?
- Boston T?
- Logan Airport?
- Honda Civic?
- Government?

Design Domains

“What” to “How”, “Top” to “Bottom”

No impromptu designs!!

Case study

TMA (thin film micromirror array)

Mirror Array on Piezoelectric Actuator Array Daewoo Electronics

Evolution of TMA Pixels

Functional Requirements of TMA

1st Generation

FR1: light reflection
FR2: mirror tilting
DP1: cantilever top surface
DP2: PZT sandwich
Functional Requirements of TMA

2nd Generation
- FR1: light reflection
- FR2: mirror tilting
- DP1: cantilever top surface
- DP2: PZT sandwich

Functional Requirements of TMA

3rd Generation
- FR1: light reflection
- FR2: mirror tilting
- DP1: cantilever top surface
- DP2: PZT sandwich

TMA

Image by the 3rd Gen. TMA - 1997.12

VGA
640 X 480
307,200 pixels

XGA
1024 X 768
786,432 pixels
Good Design in small scale products?

“What” to “How”, “Top” to “Bottom”

Example: Shower Faucet

Functional Requirements
- Temperature
- Flow rate

Independence Axiom
- Maintain the independence of FRs.

Information Axiom
- Minimize the information content of the design

Functional Requirements
- Al Cans
- 12 FRs
**Systems View—Four Design Domains**

- **Customer Domain**
- **Functional Domain**
- **Physical Domain**
- **Process Domain**

**Isolated domains**

- High walls

**Concurrent Engineering**

- Lower walls
  - Car program manager
  - Project Manager

**Four domains**

<table>
<thead>
<tr>
<th>Manufacturing systems</th>
<th>CA</th>
<th>FR</th>
<th>DP</th>
<th>PV</th>
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<tr>
<td>Marellis</td>
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<td>Micro-structure</td>
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<td>Organization</td>
<td>Customer satisfaction</td>
<td>Functions</td>
<td>Programs offices</td>
<td>People resources</td>
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**Systems Design**

- Customer Satisfaction
- Concurrent Design
- Design for Manufacturing, Assembly and “X”
- Quality Control, Six Sigma
- House of Quality, Takuchi method
- Axiomatic Design

- Any of these efforts in MEMS/Nano?

**Principles of Design**

**Axioms**

- Does scale matter?
  - Multi-scale Systems design, 2.76
    - Culpepper & Kim, Fall 2004
    - Axiomatic Design, 2.882
Manufacturing

Transformation of materials and information into goods for the satisfaction of human needs

Big Picture?

History

1. Greek “manu factus”: made by hand
2. Early mode: piece by piece by skilled artisan
3. In 1750 - 1800: Industrial revolution
   - Early machine tool
   - Concept of factory

History (cont)

4. 1800's Process specialization
   - Division of labor
   - Eli Whitney, etc., Interchangeable parts
5. Early 1900: Optimization (Manufacturing systems)
   - F.W. Taylor
   - Economy of scale
   - Cost reduction for high volume production
   - Henry Ford's Model T
6. 1950's: Numerical control (Information technology)
   - Automation
   - Lean manufacturing, JIT
   - 6 sigma, ppm

Post-Industrial-Revolution History of Manufacturing Technologies

- The Industrial Revolution (1770-1830): Introduction of steam power to replace waterpower and animal-muscle power.
- Decline in yearly hours worked per person: From 3000 hours to 1500 hours in Europe and to 1600 hours in North America.
- Increase in labor productivity.
- Increase in GDP per worker: 7 fold in U.S.A., 10 fold in Germany, and 20 fold in Japan.
Automotive Manufacturing Industry

- The Ford Motor Co. has been the most studied and documented car manufacturing enterprise.
- The 1909 Model T car was easy to operate and maintain.
- By 1920, Ford was building half the cars in the world (more than 500K per year).

Table. Motor vehicle production numbers per year per country (in thous.)

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Manufacturing Industry

- $4 Trillion, shipments, 1997
  - 1997 Economic Census, U.S. Census Bureau
  - Whole Sale $4 T, Retail $2.5 T
- 459 SIC industries (NAICS)

http://libraries.mit.edu/subjects/course.html

Gross State Product

<table>
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<th>1992 Economic Census Coverage by Sector</th>
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Big Picture

- Information Technology (digital)
- Globalization
- New Manufacturing Technology
- New Materials
Key Issues

• Engineering disciplines
  • Materials
  • Manufacturing processes
  • Manufacturing equipment
  • Design for manufacturing (DFM)
• Management disciplines
  • Work force
  • Societal obligation
  • For-profit organization
  • 2.96
• Integration
  • Manufacturing systems

Processes of 2.008

Metal components
- Removal
- Squeezing
- Melting
- Milling, turning, drilling
- Forging, stamping
- Casting

Plastic components
- Injection molding
- Thermo forming
- Squeezing
- Welding
- Soldering/brazing
- Gluing

Joining processes
- Deposition
- Etching
- CVD, PVD
- Wet, dry

Silicon

Manufacturing Attributes for Decision Making

- Cost
- Rate
- Quality
- Flexibility

Material removal – the oldest

Cost:
- Expensive $100 - $10,000

Quality:
- Very high

Flexibility:
- Any shape under the sun

Rate:
- Slow

Metal squeezing

Cost:
- Cheap, $0.1 - $100

Quality:
- Very high

Flexibility:
- Shapes limited constant cross-section

Rate:
- Fast (cycle time in sec), high volume

Melting

Cost:
- Expensive $100 - $10,000

Quality:
- Requires post finishing

Flexibility:
- Very flexible, good for large parts

Rate:
- Very slow
**Plastics processing**

- **Cost:** Expensive mold and die, over $10,000
- **Quality:** Very high
- **Flexibility:** Opening for ejection
- **Rate:** Very fast

**Joining**

- **Cost:** Cheap, but expensive labor
- **Quality:** Wide range
- **Flexibility:** Manual vs automated
- **Rate:** Slow in general

**Thinfilm fabrication**

- **Cost:** Very expensive $Millions
- **Quality:** Very high
- **Flexibility:** Any shape in 2-D
- **Rate:** Slow

300nm dual stage lithography system capable of 110nm resolution

**Typical Cost Breakdown**

![Cost Breakdown Diagram]

- **Selling Price**
- **Manufacturing Costs**
  - Direct labor: 26%
  - Indirect labor: 12%
  - Plant, Machinery: 12%
  - Parts, Material: 38%
  - Engineering: 14%
  - Admin, sales: 28%

**Performance Measures**

- Capital cost
- Production rate or capacity
- Cycle time
- Lead time
- Machine utilization
- Work-in-process
- On-time deliveries