Mechanical Assembly

• Goals of this class:
  – Explain the basics of assembly as a manufacturing process
  – Show some examples
  – Explain Design for Assembly

• Not included:
  – Design processes for creating assemblies
  – Computer representations of assemblies
  – The “reach” of assembly into company operating processes and strategies
  – Relationship to modularity and product architecture
Historical Aspects of Assembly

- All assembly was manual until about 50 years ago
- Little scientific knowledge existed about what happens during assembly operations: people “just do it”
- All fabrication techniques have been mechanized for 100 to 5000 years and a lot is known about them
- Assembly included fitting, adjustment, and selection until the 1830s
- Technology and methods to create interchangeable parts evolved during 1765-1900
- Mass production requires interchangeable parts
- Interchangeable parts enable use of low skill assemblers
- Supply chain implementation of manufacturing requires interchangeable parts and supporting technologies
Interchangeable Parts
Enable Mass Consumption

- Parts Interchange
- Assembly is quick and easy
- Low skill People Can do it
- They are cheap
- Lots of Assemblies Get made
- They are cheap
- Lots of People can Afford them
- Including The Assemblers
- Investment in equipment And design
- Everyone Makes money
- Lots of Assemblies Get sold
- There is High demand
- Investment in Tools and Knowledge
Technical Aspects

• Assembly creates product functions or sub-functions
• Results of assembly can be tested
  – Results of fabrication can be inspected but not tested
• Assembly requires coordination of many parts, tools, fixtures, packages, people, companies
• Assembly step times are short compared to manufacturing process step times
  – Non-assembly actions take proportionately much more time
  – Time is needed to move the assembly from one station to the next or to change tools
  – People and space are needed for incoming parts and outgoing boxes
“Chain of Delivery” of Quality

Customer Feature: Hood Fit to Fender

Hood (Ford-Chicago)

Fender (Part: Budd-Shelbyville Check Fixture Vendor D)

Fender Skin (Budd-Shelbyville)

Parts Vendor B Fixture Vendor F

Part Vendor C

Inner Fenders (Budd-Philadelphia)

Body Frame (Ford LAP)

Cowl Top Part Vendor A

Structural Check Fixture: Fixture Vendor E

D-pillar Assembly Station: Fixture Vendor B

Assembly Tooling Fixture Vendor C)

Reinforcements

Closure Panel Check Fixture: Fixture Vendor G

Assembly Fixture for Hood: Fixture Vendor A

Assembly Fixture for Fender: Fixture Vendor A

Contact Chain

Organizational Boundary

N. Soman, M. Chang

PART COUNT: 9
PART SOURCES: 7
TOOL COUNT: 5
TOOL SOURCES: 4
CHECK FIXTURE COUNT: 2
CHECK FIXTURE SOURCES: 2
DISPERsal INDEX: 81%

PART COUNT: 9
PART SOURCES: 7
TOOL COUNT: 5
TOOL SOURCES: 4
CHECK FIXTURE COUNT: 2
CHECK FIXTURE SOURCES: 2
DISPERsal INDEX: 81%
More Technical Aspects of Assembly

• Three methods are used
  – Manual (always involved for large items; almost always involved for small items)
  – Specialized equipment (used only for small items made in high volumes - units/year in the millions)
  – Robots (used for small and medium sized items)
• Low volume ~ big items: planes, ships
• High volume ~ small items: cigarettes, small toys
• Takt time for 777 airplane: 3 days
• Takt time for Ford or GM car: 59 seconds
• Takt time for a cigarette: 10 ms
Typical Cam-operated Assembly Machine

Multiple identical base modules bolted together as needed
Cams cut by NC to do the necessary operations

Synchronous parts transport
Cell Phone Assembly Machine

Work stops at each workstation

The machine

The phone

http://www.modular.co.uk/pages/solutions.htm
Typical Dial Machine
Bottle Filling Machine

Work does not stop
Machine Makes Washer Tubs
Typical Small Parts Assembly Machine
Economic Aspects

• Assembly employs more people than any other phase of manufacturing
• Short assembly takt times mean that cost of assembly is a small fraction of manufacturing cost
• Each technical kind of assembly has its own economic features
Unit Cost Example - 2

Unit Assembly Cost by Three Methods

- MANUAL $/UNIT
- FIXED $/UNIT
- FLEX $/UNIT

**Parameters:**
- \( f_{AC} = 0.38 \)
- \( T = 2s \)
- \( L_H = $15/hr \)
- \( S$ = $50000 \)
- \$/tool = $10000
- \( N = 10 \) parts/unit
- \( w = 0.25 \) workers/sta
Operational Organization of Assembly

• One person or station does all assembly operations
• Subassemblies are made and flow into a final assembly process
• Assembly is done in a small area by a team where each member does many operations
• Assembly is done on a long line where each person does a small amount
• As production rates and volumes rise, the line becomes the only efficient way
Operational Aspects - Line Balancing

• Different operations take different lengths of time
• When only one or a few ops are done at each station, large differences in station time can result
• Slow stations make fast stations wait
• Sometimes a different sequence will have better balance
• Sometimes, extra stations in parallel are provided
• Queues can build up behind slow stations
• Fast stations can become starved
• “A cycle lost on the bottleneck station is a cycle lost forever”
Architecture Aspects

• Architecture is the definition and arrangement of the parts with respect to the product’s functions

• Architecture affects
  – Definition of subassemblies
  – Assembly sequence options
  – Testing options
  – Customization and just-in-time operations
  – Design for assembly
Model Mix, Customization, and Changeover Happen During Assembly

- Marketing wants them in 30 colors while manufacturing wants them all to be white
- “Decoupling point” is the last point where the product is the same for everyone
  - Can be at the beginning of assembly
  - Can be during assembly
  - Can be at a distribution point or with the user
- How much variety to offer?
- How to design the product and the production system?
- How to manage it, deliver quickly, avoid being caught with items no one wants, or not having what is wanted?
Nippondenso makes many kinds of panel meters for Toyota. Toyota orders different ones in different amounts every day. ND designed an “assembly family” of meters and can make any quantity of any kind at any time by selecting the right parts. Assembly interfaces were standardized for all parts. The result is ‘assembly-driven manufacturing.’

Inventory of only 16 part types

Each path yields a different kind of meter.

288 different kinds of meters can be made with no additional cost or delay, and almost no changeover time.
Stack Architecture for Power Tools

AXIAL/STACK ARCHITECTURE WITH COMMON MOTOR MODULE
Black & Decker ~ 1981
(still used)

See Lehnerd, Alvin P, “Revitalizing the Manufacture and Design of Mature Global Products”
In Bruce Guile and Harvey Brooks, eds, Technology ad Global Industries, Washington,
Scroller Saw Family

Photo courtesy of Albert Lenherd and James Utterback
Operational Problems

• When a station fails, work stops
• Many cycles are lost
• Deliberate queues (work in process inventory) are used to “protect” against these losses
• Queues then create different problems
  – WIP = money
  – Defects can hide in queues and a whole batch can be spoiled before the defect is detected
  – Changeover to a different model is difficult because the queues have to be cleansed of the old items before the new ones can be launched
  – Queue mentality breeds complacency
Ergonomics and Job Design

• Manual assembly work is boring due to short takt time
  – “I’m retiring tomorrow after 30 years. I’m going to the end of the line to see what we make here.”

• Repetitive strain injuries are possible

• Mistakes are more likely than injuries
  – Wrong part (when there is model mix)
  – Part installed incorrectly, or damaging another part
  – Bad part used instead of being discarded

• Authoritarian management methods are often employed to combat these problems but they do not work
“The Multiplier” According to Ford and GM or: Why Is DFM/DFA Important?

- For every product part, there are about 1000 manufacturing equipment parts*
- Or, for every tolerated dimension or feature on a product part, there are about 1000 tolerated dimensions or features on manufacturing equipment
- Such “equipment” includes fixtures, transporters, dies, clamps, robots, machine tool elements, etc

*Note: Ford’s estimate is 1000, GM’s is 1800. Both are informal estimates.
Robot Car Welding Lines
Goals of DFM/DFA

• Historically, conventionally
  – reduce costs, simplify processes
  – improve awareness of manufacturing issues during design

• More broadly
  – align fabrication and assembly methods to larger goals
  – ability to automate, systematize, raise quality, be flexible
  – access to assembly-driven business methods like delayed commitment
  – innovative designs, outsourcing (Siemens intake manifold)

• Inevitably pushes DFM/DFA earlier into the product development process where it blends with architecture
Complete Outsourced Subassembly

Courtesy Siemens VDO
Impact of DFA

• Deep background in Group Technology
  – classification schemes
• European design tradition
• Value Engineering
  – each part must be justified
• Boothroyd - educated in the UK
  – part feeding physics - 1960s
  – part handling and insertion experiments- 1970’s
  – DFA methodology and software - 1970’s-80’s
• Today, DFA is part of basic product design, materials choice, and communication between engineering and manufacturing
Characteristics of Traditional DFA

• Uses an easy to understand metrics-driven approach
• Uses a *relative* cost and time metric
• Emphasizes part count reduction
• Tends to focus on
  – single parts
  – manual assembly
  – small parts
• Uses many context-free metrics to assess difficulty levels of feeding and handling
Conventional DFA

• The issues are: (Boothroyd except where noted)
  – assembling each part -
    • feeding/presenting
    • handling/carrying/getting into position (Sony exploded views)
    • inserting without damage, collisions, fumbling
  – reducing part count (driven by local economic analysis)
    • two adjacent parts of same material?
    • do they move wrt each other after assembly
    • is disassembly needed later (use, repair, inspection, upgrade...)
    • is the part a main function carrier? (Fujitsu, Lucas, (Pahl & Beitz))
    • if not, consider combining them (but this affects architecture)
    • are there too many fasteners?
  - identifying cost drivers (Denso)
Sony Exploded View

Number of Parts 48

Parts Placement

Finished Product
How to Do DFA

• Make a structured bill of materials
• Identify every part mate and understand it
• Choose a reasonable assembly sequence
• Use the tables to estimate handling and mating times
• Label theoretically necessary parts, excluding all fasteners
• Calculate
  
  \[
  \text{assembly efficiency} = \frac{3 \times \text{# of theoretically needed parts}}{\text{total predicted assembly time}}
  \]

• This ranges from 5% for kludges to 30% for good designs
Bore * stroke = 25*17

After

Before

Bore * stroke = 27*20

1—snap on cover and stop (plastic)

2—spring (steel)

3—piston (aluminum)

4—main block (plastic)

5—piston (aluminum)

6—main block (plastic)
Redford-Chal Pump Redesign

Figure 8.5 Lucas method—assembly sequence flow-chart example

Figure 8.6 Lucas method—redesigned example
## Manual Handling—Estimated Times (seconds)

### Key:
- **One Hand**
- **Grasping Aids**
- **Manipulation**

### Parts can be grasped and manipulated with the aid of grasping tools:
- Thickness > 2 mm
- Thickness ≤ 2 mm

### Parts require optical magnification for manipulation:
- Parts are easy to grasp and manipulate
- Parts present handling difficulties

### Parts need tweezers for grasping and manipulation:
- Parts can be manipulated without optical magnification
- Parts require optical magnification for manipulation

### Parts can be handled by one person without mechanical assistance:
- Parts do not severely nest or tangle and are not flexible

### Parts are handled with the use of grasping tools if necessary:
- Parts are easy to grasp and manipulate
- Parts present handling difficulties

### Chart 2-1

### MANUAL INSERTION—ESTIMATED TIMES (seconds)

<table>
<thead>
<tr>
<th>Assembly Process</th>
<th>Holding Down Required</th>
<th>Resistance to Insertion</th>
</tr>
</thead>
<tbody>
<tr>
<td>After assembly no holding down required to maintain orientation and location (3)</td>
<td>Holding down required during subsequent processes to maintain orientation or location (3)</td>
<td></td>
</tr>
<tr>
<td>Easy to align and position during assembly (4)</td>
<td>Not easy to align or position during assembly (5)</td>
<td></td>
</tr>
<tr>
<td>No resistance to insertion (6)</td>
<td>Resistance to insertion (7)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
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<td>1</td>
<td>4</td>
<td>5</td>
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<tr>
<td>2</td>
<td>5.5</td>
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</table>

### Insertion Times

<table>
<thead>
<tr>
<th>Part Added</th>
<th>Part and Associated Tool (Including Hands) Can Easily Reach the Desired Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Secured</td>
<td>Due to Obstructed Access or Restricted Vision (2)</td>
</tr>
<tr>
<td>Secured</td>
<td>Due to Obstructed Access or Restricted Vision (2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
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</tr>
<tr>
<td>Secured</td>
<td>Due to Obstructed Access or Restricted Vision (2)</td>
</tr>
</tbody>
</table>

### Screw Tightening Immediately After Insertion

<table>
<thead>
<tr>
<th>Screwing Operation or Plastic Deformation Immediately After Insertion</th>
<th>Riveting or Similar Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic deformation immediately after insertion (snub press fits, collar, spire, etc.)</td>
<td></td>
</tr>
<tr>
<td>Plastic bending or torsion</td>
<td></td>
</tr>
<tr>
<td>Not easy to align or position during assembly (4)</td>
<td>Not easy to align or position during assembly (5)</td>
</tr>
<tr>
<td>No resistance to insertion (6)</td>
<td>Resistance to insertion (7)</td>
</tr>
<tr>
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<tr>
<td>1</td>
<td>4</td>
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<tr>
<td>2</td>
<td>5.5</td>
</tr>
</tbody>
</table>

### Mechanical Fastening Processes (Parts Already in Place but Not Secured Immediately After Insertion)

<table>
<thead>
<tr>
<th>Mechanical Fastening Processes</th>
<th>Non-Mechanical Fastening Processes (Parts Already in Place but Not Secured Immediately After Insertion)</th>
<th>Non-Fastening Processes (Parts Not in Place)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None or Localized Plastic Deformation</td>
<td>Metallurgical Processes</td>
<td>Additional Material Required</td>
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<tr>
<td>Bonding or similar processes</td>
<td>Soldering processes</td>
<td>Chemical bonding (e.g., adhesive bonding, etc.)</td>
</tr>
<tr>
<td>Nailing or similar processes</td>
<td>Welding processes</td>
<td>Physical insertion (e.g., adhesives, etc.)</td>
</tr>
<tr>
<td>Screwing (fully threaded or other fasteners)</td>
<td>Additional material required</td>
<td>Mechanical processes</td>
</tr>
<tr>
<td>Snap fit, snap clips, etc.</td>
<td>Additional material required</td>
<td>Non-Fastening Processes</td>
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<td>9</td>
<td>4</td>
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DFA Spreadsheet

• On class website there is a folder called DFA Software
• In it is DFA05.xls with the handling and insertion data from the previous two slides
• Enter your code numbers and labor rate ($/sec) and the sheet will calculate times and costs
### DFA Spreadsheet

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<th>Cost per sec</th>
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<th>Insertion codes in column K</th>
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</table>

**Handling Cost:**
- Cost per handling
- Part handling times
- Insertion Cost
- Repeated this many times
- Total time
- Total cost

**Insertion Cost:**
- Cost per insertion
- Part insertion times
- Insertion Cost
- Repeated this many times
- Total time
- Total cost

**Total Time:**
- Total time
- Total cost

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Takeaways

• Assembly is the place where the product comes to life
• Assembly reaches from the factory floor to the executive suite
• Assembly reaches from the bottom to the top of the supply chain and beyond to the distribution chain