Objectives
1. Student will know the different types of assembly methods and their advantages/disadvantages
2. Student will know what to consider when designing for assembly for each of the assembly methods
3. Student will understand and be able to explain the need for DFA
4. Student will understand and be able to apply two DFA methods
Aim

• Aim
  – Simplify product so that cost of assembly is reduced

• Secondary benefits
  – Improved quality and reliability
  – Reduction in production equipment and part inventory
Comparison of Assembly Methods

• Manual
  – parts are transferred to workbenches where workers manually assemble the product or components of a product.
  – Hand tools generally used

• Fixed or Hard Automation
  – characterized by custom-built machinery that assembles one and only one specific product.

• Self Automation or Robotic Assembly
  – incorporates the use of robotic assembly systems.
  – single robot or multi-station robotic assembly cell with all activities simultaneously controlled and coordinated by a PLC or computer.
Manual Assembly

• Advantages
  — Flexibility, adaptability

• Disadvantages
  — Upper limit on production volume
  — Labor costs (benefits, workers comp, healthy environment)
Fixed Automation Assembly

• Advantages
  As production volume increases, the fraction of the capital investment compared to the total manufacturing cost
  — decreases

• Disadvantages
  — Large capital investment
  — Inherently rigid due to indexing tables, parts feeders, and automatic controls
Robotic Assembly

• **Advantages**
  - Flexibility often helps offset the expense across many different products.
  
  _________________

  - Production volume maximized, more than one product
  
  _________________

• **Disadvantages**
  
  - Largest capital investment
Different Assembly Method Costs

Relative costs of different assembly methods by type and production volume.

Assembly methods should be chosen to prevent bottlenecks in the process, as well as lower costs!
Design Guidelines for Manual Assembly

• eliminate the need for workers to make decisions or adjustments.
• ensure accessibility and maximize visibility.
• eliminate the need for assembly tools and gauges (i.e. prefer self-locating parts).
• minimize the number of custom parts - use "standard" parts.
• minimize the number of parts.
• avoid or minimize part orientation during assembly (i.e. prefer symmetrical parts).
• prefer easily handled parts that do not tangle or nest within one another.
Design Guidelines for Hard Automation

• reduce the number of different components by considering
  – does the part move relative to other parts?
  – must the part be of a different material or isolated from other parts (electrical, vibration, etc.)?
  – must the part be separate to allow assembly (cover plates, etc.)?
• use self-aligning and self-locating features
• avoid screws/bolts where possible, why?  Expensive and time consuming
• use the largest and most rigid part as the assembly base and fixture. Assembly should be performed in a layered, bottom-up manner.
• use standard components and materials.
• avoid tangling or nesting parts.
• avoid flexible and fragile parts.
• avoid parts that require orientation, why?  Reorientation may require separate station or machine
• use parts that can be fed automatically.
• design parts with a low centre of gravity.
Old (13 parts)

New (2 parts)

Plate (steel, 2 required)
Retainer (2 required)
Bearing (nylon, 2 required)
Shaft (steel)
Fan (nylon)

Old (8 parts)

New (3 parts)

Plate (steel, 2 required)
One-piece fan and shaft (nylon)
Parts feeder video

- Parts feeders
  - Valve lifters
  - Nuts
Design Guidelines for Robotic Assembly

- Same as hard automation plus
- Design the part so that it
  - is compatible with the robot's end effector.
  - can be fed in the proper orientation
How to Do Design for Assembly?

• **Start with a Bill of Materials**
  – Name of each part
  – Quantity of each part
  – Manufacturing method for each part
    • im = injection molded
    • pu = purchased part
    • st = stamped metal part
    • fa = fasteners (e.g., Screws, nuts, clips, tape)
Evaluation Methods for DFA

- Boothroyd-dewhurst method
- Lucas method
Boothroyd-dewhurst method

• This method is based on two principles:
  – the application of criteria to each part to determine if it should be separate from all other parts.
  – estimation of the handling and assembly costs for each part using the appropriate assembly process.

• This method relies on an existing design which is iteratively evaluated and improved.
  1. Select an assembly method for each part
  2. Analyze the parts for the given assembly methods
  3. Refine the design in response to shortcomings identified by the analysis
  4. Loop to step 2 until the analysis yields a sufficient design
Boothroyd-dewhurst method

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  – the application of criteria to each part to determine if it should be separate from all other parts.
  – estimation of the handling and assembly costs for each part using the appropriate assembly process.

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Boothroyd-dewhurst method

• Part *handling* and part *insertion* time estimated using Tables and Charts.
  – "lookup tables" are based on a two-digit code based on a part's size, weight, and geometric characteristics.
  – Non-assembly operations are also included in the worksheet. For example, extra time is allocated for each time the assembly is re-oriented.
Boothroyd-dewhurst method

• Parts are evaluated as to whether it is really necessary (in the assembly) by asking three questions:
  – does the part move relative to another part?
  – are the material properties of the part necessary?
  – does the part need to be a separate entity for the sake of assembly?
Boothroyd-dewhurst method

The method then assumes that the assembly time for a part is 3 seconds

Design efficiency $= \frac{(3s \times N_m)}{T_m}$. 
Lucas Method

• Boothroyd-Dewhurst method
  – based on timing each of the handling and insertion motions.
  – Although tables/software are available, the most accurate numbers are compiled through time studies in particular factories.

• Lucas method
  – Uses "point scale" which gives a relative measure of assembly difficulty
  – Three separate and sequential analysis
Assembly Flow Chart

1. Specification
2. Design
3. Functional analysis (this is the first Lucas analysis) Possibly loop back to step 2 if the analysis yields problems
4. Feeding analysis (this is the second Lucas analysis)
5. Fitting analysis (this is the third Lucas analysis)
6. Assessment
7. Possibly return to step 2 if the analyses identify problems
• **Functional Analysis**
  
  – Divided into groups A (essential for product function) and B (not essential for product function)
  
  – Design efficiency, $E_d = \frac{A}{(A+B)} \times 100\%$

  design efficiency is used to pre-screen a design alternative before more time is spent on it.
Feeding Analysis

• part handling and insertion times are also examined
• problems associated with the handling of the part are scored (feeding index) using an appropriate table. Generally, the target index for a part is 1.5.
• Feeding Ratio = (Total Feeding Index) / (Number of Essential Components)
Feeding Index

Lucas DFA method - Manual Handling Analysis

Handling Index = A+B+C+D

<table>
<thead>
<tr>
<th>A. Size &amp; Weight of Part</th>
<th>Handling Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>One of the following</td>
<td></td>
</tr>
<tr>
<td>Very small - requires tools</td>
<td>1.5</td>
</tr>
<tr>
<td>Convenient - hands only</td>
<td>1</td>
</tr>
<tr>
<td>Large and/or heavy</td>
<td>1.5</td>
</tr>
<tr>
<td>requires more than 1 hand</td>
<td></td>
</tr>
<tr>
<td>Large and/or heavy</td>
<td>3</td>
</tr>
<tr>
<td>requires hoist or 2 people</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Handling difficulties</th>
</tr>
</thead>
<tbody>
<tr>
<td>All that apply</td>
</tr>
<tr>
<td>Delicate</td>
</tr>
<tr>
<td>Flexible</td>
</tr>
<tr>
<td>Sticky</td>
</tr>
<tr>
<td>Tangible</td>
</tr>
<tr>
<td>Severely nest</td>
</tr>
<tr>
<td>Sharp/Abrasive</td>
</tr>
<tr>
<td>Untouchable</td>
</tr>
<tr>
<td>Gripping problem / slippery</td>
</tr>
<tr>
<td>No handling difficulties</td>
</tr>
</tbody>
</table>

| C. Orientation of Part | Handling Index |
| One of the following:  |               |
| Symmetrical, no orientation req’d | 0         |
| End to end, easy to see     | 0.1          |
| End to end, not visible     | 0.5          |

| D. Rotational Orientation of Part |
| One of the following           |
| Rotational Symmetry            | 0             |
| Rotational Orientation, easy to see | 0.2     |
| Rotational Orientation, hard to see | 0.4      |
## Fitting Index

**Lucas DFA method - Manual Fitting Analysis**

Fitting Index = A+B+C+D+E+F

<table>
<thead>
<tr>
<th>A. Part Placing and Fastening</th>
<th>B. Process Direction</th>
<th>C. Insertion</th>
<th>D. Access and/or Vision</th>
<th>E. Alignment</th>
<th>F. Insertion Force</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>One of the following</strong></td>
<td></td>
<td><strong>One of the following</strong></td>
<td><strong>One of the following</strong></td>
<td><strong>One of the following</strong></td>
<td></td>
</tr>
<tr>
<td>Self-holding orientation</td>
<td></td>
<td>Straight line from above</td>
<td>Easy to align</td>
<td>No resistance to insertion</td>
<td></td>
</tr>
<tr>
<td>Requires holding</td>
<td></td>
<td>Straight line not from above</td>
<td>Difficult to align</td>
<td>Resistance to insertion</td>
<td></td>
</tr>
<tr>
<td><em>Plus 1 of the following</em></td>
<td></td>
<td>Not a straight line</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-securing (i.e. snaps)</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Screwing</td>
<td></td>
<td>0.1</td>
<td>0.7</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Riveting</td>
<td></td>
<td>1.6</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bending</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>1.0</td>
<td></td>
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<td>0</td>
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<td>4.0</td>
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</tr>
</tbody>
</table>
Manufacturing Analysis

- part manufacturing cost index, $M_i = R_c P_c + M_c$

- $R_c = C_c C_{mp} C_s (C_t \text{ or } C_f)$ is the relative cost
  - $C_c$ = complexity factor
  - $C_{mp}$ = Material factor
  - $C_s$ = Minimum section
  - $C_t$ = tolerance factor or $C_f$ = finish factor (whichever is greater)
  - $P_c$ = processing cost

- $M_c = V C_{mt} W_c$ is the material cost
  - $V$ = volume (mm$^3$)
  - $C_{mt}$ = material cost
  - $W_c$ = waste coefficient

- Values are derived from the tables/software
### Flat or Thin-walled Section Envelopes

<table>
<thead>
<tr>
<th></th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
</tr>
</thead>
<tbody>
<tr>
<td>d₃</td>
<td>Uniform section or wall thickness</td>
<td>Non-uniform section or wall thickness</td>
<td>Cup, cone, and box-type parts</td>
<td>Non-uniform or contoured parts</td>
</tr>
<tr>
<td>Blanks, washers, simple bends, forms and through features on or parallel to primary axis</td>
<td>Plain cogs and gears, multiple or continuous bends and forms</td>
<td>Section changes not made up of multiple bends or forms, steps, tapers, and blind features</td>
<td>Components may involve changes in section thickness</td>
<td>Complex or irregular features or series of features which are not represented in previous categories</td>
</tr>
</tbody>
</table>

### Prismatic Part Envelopes

<table>
<thead>
<tr>
<th></th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Basic features only</td>
<td>Regular secondary/repetitive features</td>
<td>Orthogonal or Straight line based features</td>
<td>Simple curved features on a single plane</td>
</tr>
<tr>
<td>Through steps, camfers and grooves, channels, slots and holes, threads on a single axis</td>
<td>Regular through features, T-slots and racks, plain gear sections, etc., repetitive holes, threads, counterbores on a single plane</td>
<td>Regular orthogonal or straight line based pockets, projections on one or more axes, angled holes, threads, and counterbores</td>
<td>Curves in internal or external surfaces</td>
<td>Complex 3D contoured surfaces, geometries that cannot be assigned to previous categories</td>
</tr>
</tbody>
</table>
### Complexity $C_c$ (blank = not feasible)

<table>
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<th></th>
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<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>A1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>2.1</td>
<td>2.3</td>
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<tr>
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<td>1.3</td>
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