Product Development & Entrepreneurship

Design for Manufacturing and Assembly

With input from the MIT-Portugal EDAM Post-graduate Program
Chapter 2: Development Processes and Organizations

Chapter 3: Product Planning

Chapter 4: Identifying Customer Needs

Chapter 5: Product Specifications

Chapter 6: Concept Generation

Chapter 7: Concept Selection

Chapter 8: Concept Testing

Chapter 9: Product Architecture

Chapter 10: Industrial Design

Chapter 11: Design for Manufacturing

Chapter 12: Prototyping
Design for Manufacturing (DFM)

- Customer needs and product specs are hard to link with downstream product development
- Many teams use “design for X” where X means reliability, robustness, environmental impact, manufacturing,...
- Economically successful design is about ensuring high product quality while minimizing manufacturing cost – the goal of DFM
DFM requires a cross-functional team

- One of the most integrative practices in PD
- Inputs to DFM include:
  - sketches, drawings, product specs, design alternatives;
  - detailed understanding of production and assembly processes;
  - estimates of manufacturing costs, production volumes and ramp-up timing.
DFM within Product Development Process

How can we emphasize manufacturing issues throughout the development process?
“The Multiplier” According to Ford and GM or: Why Is DFM/DFA Important?

- 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, dies, robots, transporters, clamps, machine tool elements, etc.

(informal estimates)
The Big Questions

- What good is it if it doesn’t do the job?
- What good is it if it can’t be made in the first place, or if making it costs too much?
- Can we satisfy this inequality:

  Value to customer > Price > Cost
DFM Impacts

- Product architecture
- Development time
  - Part complexity
  - Dealing with suppliers
- Field use, repair, upgrade (architecture)
- Introduction of new technology, learning
Overview of the DFM process

1. Estimate manufacturing costs
2. Reduce costs of components
3. Reduce costs of assembly
4. Reduce costs of supporting production
5. Consider impact on other factors
Proposed design

Estimate manufacturing costs

Reduce component costs
Reduce assembly costs
Reduce supp. Prod. costs

Consider impact other factors

Recompute manufacturing cost

Good enough?
Y

N
Step 1: Estimate manufacturing cost

MANUFACTURING SYSTEM

- Equipment
- Information
- Tooling
- Raw materials
- Labor
- Purchased components
- Energy
- Supplies
- Services
- Finished goods
- Waste
Understanding Manufacturing Costs

- Manufacturing Cost
  - Components
    - Standard
    - Custom
      - Raw Material
      - Processing
      - Tooling
  - Assembly
    - Labor
    - Equipment and Tooling
  - Overhead
    - Support
    - Indirect Allocation
Estimating manufacturing cost

- Fixed costs versus variable costs
- Estimate the costs of standard components
- Estimate the costs of custom components
- Estimate the cost of assembly
- Estimate the overhead costs
Cost Distribution in Engine Plants

- Materials: 75%
- Labor: 9%
- Capital: 8%
- Others: 9%

Components & Subassemblies = 50%
Sources of Cost in the Supply Chain

Source: Daimler Chrysler via Munro and Associates
What Manuf. and Assy. Processes are Needed for these Different Nail Clippers?

Source: Karl Ulrich
Integrality and Modularity

- **Integrality**
  - Less assembly
  - Quality driven by fab
  - Big investment in complex fabtooling
  - Efficient in size, weight, power use
  - You’re stuck with it

- **Modularity**
  - More assembly
  - Quality driven by assembly
  - Less complex fabtools, more of them
  - Size, weight, reliability losses due to interfaces
  - You’re not stuck with it
Step 2: Reduce Cost of Components

- Understand the process constraints
- Redesign the components to eliminate processing steps
- Choose the appropriate economic scale for the part process
- Standardize components and processes
- “Black-box” component procurement
Step 3: Reduce cost of assembly

- Design for assembly (DFA) is a subset of DFM
- Keeping score
  
  \[
  DFA\ index = \frac{(\text{Theoretical minimum number of parts}) \times (3\ seconds)}{(\text{Estimated total assembly time})}
  \]

  - Ask of each part in a candidate design:
    1. Does the part need to move relative to the rest of the device?
    2. Does it need to be of a different material because of fundamental physical properties?
    3. Does it need to be separated from the rest of the device to allow for assembly, access, or repair?
  
  - Parts satisfying one or more of the questions should theoretically be separate.
Reduce cost of assembly (cont)

- Integrate parts
  - Integrated parts do not have to be assembled
  - Integrated parts are often less expensive to fabricate than the separate parts they replace
  - Integrated parts allow for the geometrical dimensions and tolerances to be more precisely controlled
Reduce cost of assembly (cont)

- Maximize ease of assembly
  - Part is inserted from the top of the assembly
  - Part is self-aligning
  - Part does not need to be oriented
  - Part requires only one hand for assembly
  - Part requires no tools
  - Part is assembled in a single, linear movement
  - Part is secured immediately upon insertion
Reduce cost of assembly (cont)

- Consider customer assembly
  - Look into it if purchasing and handling by the customer are substantially easier
  - Substantial challenge to design a product to be assembled by the most inept customers, many of whom will ignore directions
Heavy Duty Staple Gun

Assembly efficiency = 17% before improvements
= 25% after improvements
= 30% with some functional risk
• Assembly efficiency = 31%
• Contains many of the suggested improvements
• But is it a better staple gun?
Design for Assembly

- Key ideas of DFA:
  - Minimize parts count
  - Maximize the ease of handling parts
  - Maximize the ease of inserting parts

- Benefits of DFA
  - Lower labor costs
  - Other indirect benefits

- Popular software developed by Boothroyd and Dewhurst.
  - http://www.dfma.com
## DFM-DFA Strategies

<table>
<thead>
<tr>
<th>Low Lifetime Production Volume</th>
<th>High Lifetime Production Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Example Products:</strong></td>
<td><strong>Example Products:</strong></td>
</tr>
<tr>
<td>High performance computers</td>
<td>Notebook computers, Toys</td>
</tr>
<tr>
<td>Telecommunications equipment</td>
<td>DFM Strategy:</td>
</tr>
<tr>
<td>DFM Strategy:</td>
<td>Minimize complexity of most</td>
</tr>
<tr>
<td></td>
<td>complex part</td>
</tr>
<tr>
<td></td>
<td>For complex parts, use processes</td>
</tr>
<tr>
<td></td>
<td>with fast tool fab</td>
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<tr>
<td></td>
<td>Apply traditional DFM to less</td>
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<tr>
<td></td>
<td>time-critical parts</td>
</tr>
<tr>
<td></td>
<td>Example Products:</td>
</tr>
<tr>
<td></td>
<td>Blank videocassettes</td>
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<tr>
<td></td>
<td>Circuit breakers</td>
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<tr>
<td></td>
<td>DFM Strategy:</td>
</tr>
<tr>
<td></td>
<td>Use traditional DFM-DFA</td>
</tr>
<tr>
<td></td>
<td>Combine and integrate parts</td>
</tr>
<tr>
<td></td>
<td>Consider automatic assembly</td>
</tr>
<tr>
<td><strong>Example Products:</strong></td>
<td></td>
</tr>
<tr>
<td>Machine tools</td>
<td></td>
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<tr>
<td>Electrical distribution</td>
<td></td>
</tr>
<tr>
<td>equipment</td>
<td></td>
</tr>
<tr>
<td>DFM Strategy:</td>
<td></td>
</tr>
<tr>
<td>Avoid expensive tooling</td>
<td></td>
</tr>
<tr>
<td>Use standard components</td>
<td></td>
</tr>
<tr>
<td>Other issues likely to dominate</td>
<td></td>
</tr>
</tbody>
</table>
To Compute Assembly Time

\[ \text{Handling Time} + \text{Insertion Time} = \text{Assembly Time} \]
Step 4: Reduce cost of supporting production

- Minimize systemic complexity
- Error proofing
Step 5: Consider impact of DFM decisions on other factors

- Impact of DFM on development time
  - Reduction of $1 on each manifold would be worth $1 million in annual cost savings, but would not be worth a six-month delay in the project

- Impact of DFM on development cost
  - If properly integrated in product development, extra cost is meaningless
Design for Manufacturing Example: GM 3.8-liter V6 Engine

Process applied to the intake manifold
Original intake manifold of cast aluminum

Redesigned intake manifold of molded thermoplastic composite
### Cast aluminum

<table>
<thead>
<tr>
<th><strong>Variable Cost</strong></th>
<th><strong>Fixed Cost</strong></th>
<th><strong>Total Unit Cost</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>5.7 kg aluminum at $2.25/kg</td>
<td>$12.83</td>
</tr>
<tr>
<td>Processing (casting)</td>
<td>150 units/hr. at $530/hr.</td>
<td>3.53</td>
</tr>
<tr>
<td>Processing (machining)</td>
<td>200 units/hr. at $340/hr.</td>
<td>1.70</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Total Direct Cost</strong></th>
<th></th>
<th><strong>$18.56</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead charges</td>
<td></td>
<td>$12.09</td>
</tr>
</tbody>
</table>

| **Total Unit Cost**         |                                                     | **$30.65**          |

### Thermoplastic

<table>
<thead>
<tr>
<th><strong>Variable Cost</strong></th>
<th><strong>Fixed Cost</strong></th>
<th><strong>Total Unit Cost</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials (manifold housing)</td>
<td>1.4 kg glass-filled nylon at $2.75/kg</td>
<td>$ 3.85</td>
</tr>
<tr>
<td>Materials (intake runner insert)</td>
<td>0.3 kg glass-filled nylon at $2.75/kg</td>
<td>0.83</td>
</tr>
<tr>
<td>Molding (manifold housing)</td>
<td>80 units/hr. at $125/hr.</td>
<td>1.56</td>
</tr>
<tr>
<td>Molding (intake runner insert)</td>
<td>100 units/hr. at $110/hr.</td>
<td>1.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Fixed Cost</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mold tooling (manifold housing)</td>
<td>$350,000/tool at 1.5M units/tool</td>
<td>$ 0.23</td>
</tr>
<tr>
<td>Mold tooling (intake runner insert)</td>
<td>$150,000/tool at 1.5M units/tool</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Total Direct Cost</strong></th>
<th></th>
<th><strong>$ 7.67</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead charges</td>
<td></td>
<td>$ 5.99</td>
</tr>
</tbody>
</table>

| **Total Unit Cost**                      |                                              | **$13.66**          |
Impact of DFM decisions on other factors (cont)

- Impact of DFM on product quality
  - Usually DFM results in improved serviceability, ease of disassembly, and recycling
  - Can cause adverse effects in product reliability and robustness

- Impact of DFM on external factors
  - Component reuse
  - Life cycle cost
The effect of DFMA in a study of an electric saw:
(a) Original design, 41 parts and 6.37 min of assembly time.
(b) Modified design, 29 parts and 2.58 min of assembly time. [Boothroyd (1992)].
Exercise: Reduce the manufacturing costs of a pencil
That's all folks!