Design For Manufacturing

MAE 2250
Are you here?

A. Yes
B. No
C. Only physically (but not spiritually)
D. Only spiritually (only my clicker is here)
E. Whatever

“If it’s all random, why are you always here?”
Phases

- Phase 0: Planning
- Phase 1: Conceptual design
- Phase 2: System design
- Phase 3: Detail design
- Phase 4: Testing and refinement
- Phase 5: Production ramp-up

Iterate
Over The Wall
Two things happened

• Manufacturing people were put on the design team
  – “Concurrent engineering”

• Manufacturing requirements were made very specific and became ‘needs’ themselves
  – The ‘new customers’
DFX

- The service people are customers: Design for servicability
- The environment is a customer, ‘Design for environment’
- Design for manufacturing (DFM)
- Design for Assembly (DFA)
- Design for X (DFX)
DFM

**DFM** is a means of addressing producibility issues early in the design cycle, and integrating manufacturing concerns and considerations into a design to obtain a more producible product.
DFM Process

- Estimate the manufacturing costs
  - Reduce cost of components
  - Reduce cost of assembly
  - Reduce cost of supporting production
  - Consider effects on other factors
Custom approximates standard for high enough quantities (e.g. electric motor, > 100,000/year)

Assembly is usually done by humans even for mass produced products, unless very very high quantities (>100,000)
Reducing cost of components

• Understand the limitations of the fabrication processes; do not exceed normal capabilities unless you really have to
  – Geometry (Making a square hole is hard)
  – Accuracy and tolerances of machining
  – Surface finish of casting
Understand cost drivers

• Welding cost is proportional to welding length, fixturing
• Machining cost is proportional to material removed, fixturing
• Injection molding? Thickness of part. Work with experts to find out details
• E.g. produce an tall open box by bending and welding. Where would you put bends and where welds?
Redesign to eliminate process steps

• Use net-shape processes. Forging, casting and molding provide close to final shapes and eliminate machining steps

• E.g. Stamped piece: U shape with two holes. If holes are on base, can be stamped in one go. If holes are on flanges, needs two steps
Chose process with economy of scale

- Injection molding
- Machining
- Additive Manufacturing
Medical Casing - Cost Per Part

\[ y = 1535.4e^{-0.758x} \]
\[ R^2 = 0.99389 \]

http://blog.3sourceful.com/post/45422603072/hedging-your-production-bets-with-3d-printing
Reducing Assembly costs

• DFA index: Theoretical minimum number of components x 3 seconds, divided by actual assembly time
  – Shorter actual assembly time → higher index

• Theoretical minimum
  – Do parts need to move with respect to each other? (ignore compliant mechanisms)
  – Must the parts be made of different materials?
  – Do the parts need to be separate for access/maintenance reasons?
Integrate parts

• Fewer assembly steps (higher DFA)
• Reduced cost of tooling (e.g. fewer dies)
• More control over relative positioning
• Conflicts with modularity!
Integrate parts

- Fewer assembly steps (higher DFA)
- Reduced cost of tooling (e.g. fewer dies)
- More control over relative positioning
- Conflicts with modularity!
Consider customer assembly

• Assemble-it-yourself furniture
• Good also for packing and shipping
• Requires very careful and intuitive assembly plan
Reduce cost of supporting production

- Less equipment – flexible equipment
- “Just in time” production
- Frequent error proofing. Design your product so critical errors are self-evident.
  - E.g. design some notches and protrusions so that if parts are not assembled correctly, next part won’t fit
Guidelines

• Heuristics (rules that are generally true)
  – have been developed for various manufacturing technologies.

• Some DFM guidelines
  – Guidelines for machining
  – Guidelines for assembly
  – Guidelines for injection molding
  – Guidelines for sheet metal processing
  – Guidelines for sheet die forming
  – Guidelines for casting
  – Guidelines for welding
<table>
<thead>
<tr>
<th>Table 14.1: DFA Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Minimize part count by incorporating multiple functions into single parts. (Iredale 1964)</td>
</tr>
<tr>
<td>2. Modularize multiple parts into single subassemblies. (Crow 1988)</td>
</tr>
<tr>
<td>3. Assemble in open space, not in confined spaces. Never bury important components. (Tipping 1965)</td>
</tr>
<tr>
<td>4. Make parts to identify how to orient them for insertion. (Tipping 1965)</td>
</tr>
<tr>
<td>5. Standardize to reduce part variety. (Tipping 1965)</td>
</tr>
<tr>
<td>6. Maximize part symmetry. (Iredale 1964; Paterson 1965)</td>
</tr>
<tr>
<td>7. Design in geometric or weight polar properties if nonsymmetric. (Tipping 1965)</td>
</tr>
<tr>
<td>8. Eliminate tangly parts. (Iredale 1964; Tipping 1965)</td>
</tr>
<tr>
<td>9. Color code parts that are different but shaped similarly.</td>
</tr>
<tr>
<td>10. Prevent nesting of parts. (Iredale 1964; Tipping 1965)</td>
</tr>
<tr>
<td>11. Provide orienting features on nonsymmetries. (Iredale 1964; Tipping 1965)</td>
</tr>
<tr>
<td>12. Design the mating features for easy insertion. (Iredale 1964; Tipping 1965; Baldwin 1966)</td>
</tr>
<tr>
<td>13. Provide alignment features. (Baldwin 1966)</td>
</tr>
<tr>
<td>14. Insert new parts into an assembly from above. (Tipping 1965)</td>
</tr>
<tr>
<td>15. Insert from the same direction or very few. Never require the assembly to be turned over. (Tipping 1965)</td>
</tr>
<tr>
<td>16. Eliminate fasteners. (Iredale 1964)</td>
</tr>
<tr>
<td>17. Place fasteners away from obstructions.</td>
</tr>
<tr>
<td>18. Deep channels should be sufficiently wide to provide access to fastening tools. No channel is best.</td>
</tr>
<tr>
<td>19. Providing flats for uniform fastening and fastening ease.</td>
</tr>
<tr>
<td>20. Proper spacing ensures allowance for a fastening tool.</td>
</tr>
</tbody>
</table>
DFA Goals

• Reducing costs
• Reducing time
• Reducing errors

In some projects (e.g. aerospace, cost is less important than time and error. In others, e.g. toys, cost is more important than error)
Increase in reliability with application of DFA at Motorola (from Branan 1991).
Guidelines for assembly

(a) Minimize part count by incorporating multiple functions into single parts.
(b) Modularize multiple parts into single sub-assemblies.
(c) Design open enclosures to permit assembly in open space, not in confined spaces. Never bury important components.
(d) Parts should easily indicate orientation for insertion.
(e) Standardized to reduce part variety.
Guidelines for assembly

(a)Maximize part symmetry.

(b)For automated assembly, design in weight polar properties across non-symmetries.

(c)Eliminate tangly parts.

(d)Color code parts that are different but shaped similarly.

(e)Prevent nesting of parts.

(f)Provide orienting features on non-symmetries.
(a) Design the mating features for easy insertion.

(b) Provide alignment features.

(c) Insert new parts into assembly from above.

(d) Insert from the same direction, or very few. Never require the assembly to be turned over.
Design for robotic assembly

Don’t

Do

Eliminate tangly parts.
Guidelines for assembly

(a) Eliminate fasteners.
(b) Place fasteners away from obstructions.
(c) Deep channels should be sufficiently wide to provide access to fastening tools. No channel is best.
(d) Providing flats for uniform fastening and fastening ease.
(e) Proper spacing insures allowance for a fastening tool.
Guidelines for machining

(a) Design holes to the shape of the tool. If a hole is to be tapped, provide space for it.

(b) Use standard dimensions.

(c) Do not design impossible to machine hollows or overhangs.

(d) Avoid long narrow holes.

(e) Design for reasonable internal pockets radii.

(f) Avoid thin walls that break when machining.

(g) Avoid drilling inclined faces.

(h) Place holes away from corners and edges.
Guidelines for machining

(i) Provide access for tools.

(j) Avoid long thin sections that cause vibration.

(k) Deep pockets also cause vibration of the tool.

(l) Holes can’t change direction.

(m) Design parts that are easy to fixture.

(n) Avoid outside rounds, which are difficult unless CNC-machined.
Guidelines for injection molding

(a) Don't: $t \geq 4\text{mm}$
Do: Use ribs instead
$$0.065'' \leq t \leq 0.5''$$
Minimize section thickness, cooling time is proportional to the square of the thickness of the part(s), and reducing the cooling time directly reduces costs.

(b) Don't: No draft
Do: Add thickness for draft
Always provide a draft angle for easier mold removal.

(c) Don't: Avoid sharp corners, they produce stress concentrations and obstruct material flow.
Do: $R + t$
$$R = 3/8t \geq 0.06''$$

(d) Don't: Sink marks
Do: Keep rib thickness less than 60% of the part thickness to prevent voids and sinks.
$$t_{rib} = \frac{1}{3}t$$
$$3t \text{ min}$$

(e) Don't: Potential sink marks and voids
Do: Attach bosses to walls with ribs
Gusset free standing ribs
Keep section thickness uniform around bosses.

(f) Don't: Stepped thickness transition
Do: Better
$$3t \text{ min}$$
Best
Make all transitions smooth and avoid changes in thickness when possible.

(g) General Tolerances (mm)

<table>
<thead>
<tr>
<th>FROM</th>
<th>TO</th>
<th>±</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25</td>
<td>±0.5</td>
</tr>
<tr>
<td>25</td>
<td>125</td>
<td>±0.8</td>
</tr>
<tr>
<td>125</td>
<td>300</td>
<td>±1.0</td>
</tr>
<tr>
<td>300</td>
<td></td>
<td>±1.5</td>
</tr>
</tbody>
</table>

Use standard dimensional variation capability: do not tolerance.

(h) Use standard thickness variation capability; do not over tolerance.
$$0.005''$$
Guidelines for sheet forming

(a) Don’t
On Paper
Web
What will happen
Bulge

Ear

A narrow web will cause bulging. Provide an ear in the blank or include the hole as a notch.

(b) Do
Offset bends.

Don’t

Tear

Do

R

R

(c) If $D \geq 2t$, a cutout is needed to bend flange.

(d) Use separated straight flanges when possible.
Guidelines for sheet forming

Design for ease of blanking:
- \( W = 0.040" \) min for materials thinner than 0.047" – wider if possible.
- \( W_t \geq \) material thickness; wider if possible.
- \( L = 5W \) maximum depth; less if possible.
- \( L_1 = 5W \) maximum length; less if possible.

Tolerance in a pierced hole is only attained for 25% of its length. Hole must not be smaller than thickness of blank.

Avoid sharp corners, or the material will tear.

Shear and form operations should have a minimum height \( (h) \) of 2 1/2 the blank thickness.

Position holes away from bends.

Position openings away from bends.
Guidelines for casting

(a) Avoid sharp corners.

(b) Provide a draft angle to help removal from mold.

(c) Maintain section thickness uniform.

(d) Non-uniform section thickness caused hot spots that causes shrinkage defects. Design T-junctions to prevent hot spots.

(e) Stagger ribs to prevent hot spots.

(f) Avoid abrupt changes in section thickness.

(g) Restraining a part of the casting produces tensile stresses that can result in hot tears.

(h) Design bosses with uniform thickness.
Are you still here?

A. Yes
B. No
C. Only physically (but not spiritually)
D. Spiritually (only my clicker is here)
E. What-e-ver