Introduction to Design for (Cost Effective) Assembly and Manufacturing

Source: David Stienstra (Rose-Hulman)
Purpose Statement

To provide an overview of Design for Manufacturing and Assembly (DFMA) techniques, which are used to **minimize product cost** through design and process improvements.
Objectives

Participants will understand:

- Differences and Similarities between Design for Manufacturing and Design for Assembly
- Describe how product design has a primary influence
- Basic criteria for **Part Minimization**
- Quantitative analysis of a **design’s efficiency**
- Critique product designs for ease of assembly
- The importance of involving production engineers in DFMA analysis
Design for Assembly

**Definition:** DFA is the method of design of the product for ease of assembly.

‘…Optimization of the part/system assembly’

DFA is a tool used to assist the design teams in the design of products that will transition to productions at a minimum cost, focusing on the number of parts, handling and ease of assembly.
Design for Manufacturing

**Definition:** DFM is the method of design for ease of manufacturing of the collection of parts that will form the product after assembly.

‘*Optimization of the manufacturing process…*’

DFA is a tool used to select the most cost effective material and process to be used in the production in the early stages of product design.
Differences

Design for Assembly (DFA)

- concerned only with reducing product assembly cost
  - minimizes number of assembly operations
  - individual parts tend to be more complex in design

Design for Manufacturing (DFM)

- concerned with reducing overall part production cost
  - minimizes complexity of manufacturing operations
  - uses common datum features and primary axes
Similarities

- Both DFM and DFA seek to reduce material, overhead, and labor cost.
- They both shorten the product development cycle time.
- Both DFM and DFA seek to utilize standards to reduce cost.
Terminology

- Design for Manufacturing (DFM) and Design for Assembly (DFA) are now commonly referred to as a single methodology, Design for Manufacturing and Assembly (DFMA).
What Internal Organization has the most Influence over Price, Quality, & Cycle Time?

- Design: 70 - 80%
- Manufacturing: 20 - 30%
Knowledge and Learning

Marketing Knowledge

DFSS

Knowledge of Design Behavior

Design Freedom to Make Changes

Cost of Change

Process Capability Knowledge

Production
Sequence of Analysis

- Concept Design
  - Design for Assembly
    - Design for Manufacturing
      - Detailed Design
        - Optimize Design for Part Count and Assembly
        - Optimize Design for Production Readiness
Design for Assembly

DFA is a process that **REQUIRES** involvement of Assembly Engineers
Design for Assembly Principles

- Minimize part **count**
- Design parts with **self-locating features**
- Design parts with **self-fastening features**
- Minimize **reorientation** of parts during assembly
- Design parts for **retrieval, handling, & insertion**
- Emphasize ‘**Top-Down**’ assemblies
- **Standardize** parts…minimum use of fasteners.
- Encourage **modular** design
- Design for a **base part** to locate other components
- Design for component **symmetry** for insertion
## DFA Process

### Step 1
- Product Information: *functional requirements*
- Functional analysis
- Identify parts that can be standardized
- Determine part count efficiencies

### Step 2
- Determine your *practical* part count

### Step 3
- Identify *quality* (mistake proofing) opportunities

### Step 4
- Identify *handling* (grasp & orientation) opportunities

### Step 5
- Identify *insertion* (locate & secure) opportunities

### Step 6
- Identify opportunities to reduce *secondary operations*

### Step 7
- Analyze data for *new design*

**Benchmark when possible**
# DFA Analysis Worksheet

Assembly Name: ___________________________ Team: ____________

<table>
<thead>
<tr>
<th>Part</th>
<th>DFA Complexity</th>
<th>Functional Analysis/Redesign Opportunity</th>
<th>Error Proofing</th>
<th>Handling</th>
<th>Insertion</th>
<th>Secondary Operations</th>
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Product Information: functional requirements

Functional analysis

Identify parts that can be standardized
Determine part count efficiencies
Considerations/Assumptions

- The first part is essential (base part)

- Non-essential parts:
  - Fasteners
  - Spacers, washers, O-rings
  - Connectors, leads

- Do not include liquids as parts (e.g., glue, gasket sealant, lube)
Part Identification

- List parts in the order of assembly
- Assign/record part number

DFA Analysis Worksheet

<table>
<thead>
<tr>
<th>Part Name</th>
<th>DFA Complexity</th>
<th>Number of Parts (Np)</th>
<th>Number of Interfaces (Ni)</th>
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</thead>
<tbody>
<tr>
<td>Lower Arm Sub.</td>
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<tr>
<td>Base Part - Lower Arm</td>
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<td>Lower Arm cover</td>
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<td>Rivet</td>
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<td>Upper Arm Sub.</td>
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<td>Spring</td>
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<td>Pivot</td>
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Totals
So take it apart!

Riveted staple remover
- Wide finger pad
- Wide tooth remover
- Narrow tooth remover
- Narrow finger pad

Rivets
- Rivets
- Spring
- Rivet
Count Parts & Interfaces

- List number of parts (Np)
- List number of interfaces (Ni)
Dept. 1310 Process Flow Diagram

- Pleat Paper
- Precure Heater
- Cut Paper Pack
- Bandseal 1st & Last Fold
- Assemble Paper Element and Centertube w/ Rubberband
- Form Centertube
Vision Tester

Assemble Gasket/with Gasket Installers

Decay Leak Test

Polyfilm

Shrink Polyfilm

Pack Carton (or Bulk Pack) — Form Carton
Your Turn

- List parts in the order of assembly.
- Assign part number to keep up with the part.
- List number of parts (Np)
- List number of interfaces (Ni)
Determine Theoretical Min. No. of Parts

<table>
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<tr>
<th>Current Design</th>
<th>Consider Specification</th>
<th>Other Options</th>
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<tr>
<td>Does the part move relative to all other parts already assembled?</td>
<td>Is the movement essential for the product to function?</td>
<td>Must the part be separate to provide the required movement?</td>
</tr>
<tr>
<td>Is the part of a different material, or isolated from, all other parts already assembled?</td>
<td>Is a different material or isolation essential for the product to function?</td>
<td>Must the part be separate to satisfy the different material or isolation requirement?</td>
</tr>
<tr>
<td>Is the part separate to allow for its in-service adjustment or replacement?</td>
<td>Is the adjustment or replacement essential?</td>
<td>Must the part be separate to enable the adjustment or replacement?</td>
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<th>DFA Complexity</th>
<th>Number of Interfaces (N)</th>
<th>Theoretical Minimum Part (Functional Analysis chart)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lower Arm Sub.</td>
<td></td>
<td>6</td>
<td>Y</td>
</tr>
<tr>
<td>1.1</td>
<td>Base Part - Lower Arm</td>
<td>1</td>
<td>6</td>
<td>Y</td>
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<tr>
<td>1.2</td>
<td>Lower Arm cover</td>
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<td>3</td>
<td>N</td>
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<tr>
<td>1.3</td>
<td>Rivet</td>
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<td>4</td>
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<td>Upper Arm Sub.</td>
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<td>N</td>
</tr>
<tr>
<td>3</td>
<td>Spring</td>
<td>1</td>
<td>3</td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>Pivot</td>
<td>1</td>
<td>3</td>
<td>N</td>
</tr>
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<td><strong>Totals</strong></td>
<td><strong>10</strong></td>
<td><strong>32</strong></td>
<td><strong>1</strong></td>
<td></td>
</tr>
</tbody>
</table>
Functional Analysis

Current Design

- Does the part move relative to all other parts already assembled? Y

Consider Specification

- Is the movement essential for the product to function? Y

Other Options

- Must the part be separate to provide the required movement? Y

Movement

- Is the part of a different material, or isolated from, all other parts already assembled? N

Isolation

- Is a different material or isolation essential for the product to function? Y

- Must the part be separate to satisfy the different material or isolation requirement? Y

Adjustment or Replacement

- Is the part separate to allow for its in-service adjustment or replacement? N

- Is the adjustment or replacement essential? Y

- Must the part be separate to enable the adjustment or replacement? Y

Non Essential Part

Essential Part
Determine if Parts Can be Standardized

- Can the current parts be standardized?:
  - Within the assembly station
  - Within the full assembly
  - Within the assembly plant
  - Within the corporation
  - Within the industry

- Should they be?
  (Only put a “Y” if both answers are yes...)
### Theoretical Part Count Efficiency

#### Theoretical Part Count Efficiency

\[
\text{Theoretical Part Count Efficiency} = \left( \frac{\text{Theoretical Min. No. Parts}}{\text{Total Number of Parts}} \right) \times 100
\]

#### Rule of Thumb – Part Count Efficiency Goal

- **Goal**: > 60%

---

#### DFA Analysis Worksheet

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Part Name</th>
<th>DFA Complexity</th>
<th>Number of Interfaces (Ni)</th>
<th>Theoretical Minimum Part (Functional Analysis Chart)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Lower Arm Sub.</td>
<td></td>
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<td><strong>Base Part - Lower Arm</strong></td>
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</tr>
<tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>1.3</td>
<td>Rivet</td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td><strong>Upper Arm Sub.</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1</td>
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<td>Rivet</td>
<td></td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>Spring</td>
<td></td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>Pivot</td>
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</tr>
<tr>
<td>5</td>
<td></td>
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<tr>
<td><strong>Totals</strong></td>
<td></td>
<td></td>
<td>10</td>
<td>32</td>
</tr>
</tbody>
</table>

**Design for Assembly Metrics**

- **17.89**
- **10%**

**Targets**

- **0.00**
- **>60%**
DFA Complexity Factor – Definition

- Cummins Inc. metric for assessing complexity of a product design

- Two Factors
  - \( N_p \) – Number of parts
  - \( N_i \) – Number of part-to-part interfaces

  - Multiply the two and take the square root of the total
    \[
    \sqrt{\sum N_p \times \sum N_i}
    \]

  - This is known as the DFA Complexity Factor
DFA Complexity Factor – Target

- Smaller is better (Minimize Np and Ni)
- Let Npt = Theoretical Minimum Number of parts
  - from the Functional Analysis
  - Npt = 5
- Let Nit = Theoretical minimum number of part to part interfaces
  - Nit = 2(Npt-1)
  - Nit = 2(5-1) = 8

DCF

\[
DCF = \sqrt{\Sigma Np \times \Sigma Ni}
\]

DCFt

\[
DCFt = \sqrt{\Sigma Npt \times \Sigma Nit}
\]

DCFt

\[
DCFt = \sqrt{5 \times 8} = 6.32
\]
Determine Relative Part Cost Levels

- Subjective estimate only
- Low/Medium/High relative to other parts in the assembly and/or product line

### DFA Analysis Worksheet

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Part Name</th>
<th>DFA Complexity</th>
<th>Functional Analysis</th>
<th>Redesign Opportunity</th>
<th>Cost (Low/Medium/High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Base Part - Lower Arm</td>
<td>1</td>
<td>Y</td>
<td>N</td>
<td>L</td>
</tr>
<tr>
<td>1.2</td>
<td>Lower Arm cover</td>
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<td>N</td>
<td>L</td>
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<tr>
<td>4</td>
<td>Pivot</td>
<td>1</td>
<td>N</td>
<td>N</td>
<td>L</td>
</tr>
</tbody>
</table>

**Totals**: 10 32 1 2
Cost Breakdown

- Media paper 21.4%
- Centertube 3.6%
- Endplates (2) 3.0%
- Plastisol 2.6%
- Inner Seal 4.0%
- Spring 0.9%
- Shell 31.4%
- Nutplate 21.0%
- Retainer 4.8%
- Loctite 0.3%
- End Seal 7.0%
Step Two

- Determine Practical Minimum Part Count
Determine Practical Minimum Part Count

- Team assessment of practical changes
- Tradeoffs between part cost and assembly cost

![DFA Analysis Worksheet](image)

<table>
<thead>
<tr>
<th>Part Number</th>
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</tr>
<tr>
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<td>3</td>
</tr>
</tbody>
</table>

![Part Image]
Creativity & Innovation

Theoretical Number of Parts... 'Blue Sky'

Innovation

Practical & Achievable

Current Design

Theoretical Min. No. Parts  Practical Min. No. Parts  No. Parts
Cost of Assembly Vs Cost of Part Manufacture

Saving

Part Count Reduction

Total Saving

Assembly Saving (DFA)

Optimum

Part Manufacture Saving (DFM)
Idea Classification

Implementation

- Long Term
- Medium Term
- Short Term

Risk

Low
Medium
High

Step Two
Don’t constrain yourself to incremental improvement unless you have to!

This style doesn’t tear paper like the claw style and is much cheaper to produce!
Your Turn...

Instructions

- Product Information: *functional requirements*
- Functional analysis
- Identify parts that can be standardized
- Determine part count efficiencies
- Determine your *practical* part count
Fasteners

- A study by Ford Motor Co. revealed that threaded fasteners were the most common cause of warranty repairs

- This finding is echoed in more recent survey of automotive mechanics, in which 80% reported finding loose or incorrect fasteners in cars they serviced
Component Elimination

Example: **Rollbar Redesign**

‘..If more than 1/3 of the components in a product are fasteners, the assembly logic should be questioned.’

- 24 Parts
- 8 different parts
- multiple mfg. & assembly processes necessary

- 2 Parts
- 2 Manufacturing processes
- one assembly step
# Fasteners: Cummins Engines

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Number of Components</th>
<th>Number of Fasteners</th>
<th>Percent Fasteners</th>
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</thead>
<tbody>
<tr>
<td>B Series, 6 Cyl 5.9L</td>
<td>1086</td>
<td>436</td>
<td>40%</td>
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<tr>
<td>B Series, 4 Cyl 3.9L</td>
<td>718</td>
<td>331</td>
<td>46%</td>
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<tr>
<td>C Series, 8.3L</td>
<td>1111</td>
<td>486</td>
<td>44%</td>
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</table>

Data from Munroe & Associates October 2002
Standard Bolt Sizes

- Minimize extra sizes to both reduce inventory and eliminate confusion during assembly.

<table>
<thead>
<tr>
<th></th>
<th>M5 x .8</th>
<th>M6 x 1.0</th>
<th>M8 x 1.25</th>
<th>M10 x 1.5</th>
<th>M11 x 1.25 M12 x 1.25</th>
<th>M12 x 1.75</th>
<th>M14 x 1.5</th>
<th>M16 x 2.0</th>
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<td>6</td>
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<tr>
<td>Required</td>
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<td>93</td>
<td>152</td>
<td>75</td>
<td>16</td>
<td>21</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Select the most inexpensive fastening method required.
General Design Principles

Self-fastening features
General Design Principles

Symmetry eliminates reorientation

Asymmetric Part

Symmetry of a part makes assembly easier
General Design Principles

Top-Down Assembly
General Design Principles

Modular Assemblies

1. Imaging
2. Drives
3. Development
4. Transfer/Stripping
5. Cleaning
6. Fusing
7. Charge/Erase
8. Copy Handling
9. Electrical Distribution
10. Photoreceptor
11. Input/Output Devices

Xerox photocopier
Eliminated Parts are NEVER...

- Designed
- Detailed
- Prototyped
- Produced
- Scrapped
- Tested
- Re-engineered
- Purchased
- Progressed
- Received
- Inspected
- Rejected
- Stocked
- Outdated
- Written-off
- Unreliable
- Recycled
- late from the supplier!
Step Three

- Identify **quality** (mistake proofing) opportunities
Mistake Proofing Issues

- Cannot assemble wrong part
- Cannot omit part
- Cannot assemble part wrong way around.

symmetrical parts

asymmetrical parts
Mistake Proofing Issues

72 Wiring Harness Part Numbers

CDC - Rocky Mount, NC
Step Four

- Identify handling (grasp & orientation) opportunities
Quantitative criteria

- **Handling Time**: based on assembly process and complexity of parts
  - How many hands are required?
  - Is any grasping assistance needed?
  - What is the effect of part symmetry on assembly?
  - Is the part easy to align/position?
Handling Difficulty

- Size
- Thickness
- Weight
- Fragility
- Flexibility
- Slipperiness
- Stickiness
- Necessity for using 1) two hands, 2) optical magnification, or 3) mechanical assistance
Handling Difficulty

- size
- slipperiness
- sharpness
- flexibility
Eliminate Tangling/Nesting

Close up springs to avoid tangling

Design parts so they do not nest or tangle
- Locking angle
- Increase angle
- Change shape
- Decrease angle

These parts tangle easily
This part will not tangle
Step Five

- Identify insertion (locate & secure) opportunities
Quantitative criteria

- **Insertion time:** based on difficulty required for each component insertion
  - Is the part secured immediately upon insertion?
  - Is it necessary to hold down part to maintain location?
  - What type of fastening process is used? (mechanical, thermal, other?)
  - Is the part easy to align/position?
Insertion Issues

- Provide self-aligning & self locating parts

Part can hang up  Part falls into place

Part must be released before it is located, making it difficult to align  redesign
Insertion Issues

- Ensure parts do not need to be held in position

![Diagram showing self-locating parts and secure assembly once assembled.](image)

- Holding down and alignment required for later operation
- Secure parts once they are assembled

- Spring
- Retaining recess
- Projection
- Chassis

- Assembly should be stable
Insertion Issues

- Parts are easy to insert.
- Provide adequate access & visibility

Avoid small clearances, hang-ups, and large force

Restricted access for assembly of screws

Improved access

Courtesy GM
Insertion Issues

- Provide adequate access and visibility

- Avoid mating locations which cannot be seen easily
Step Six

- Identify opportunities to reduce secondary operations
Eliminate Secondary Operations

- Re-orientation (assemble in Z axis)
- Screwing, drilling, twisting, riveting, bending, crimping.
Eliminate Secondary Operations

- Welding, soldering, gluing.
- Painting, lubricating, applying liquid or gas.
- Testing, measuring, adjusting.
Assembly Metrics

Error Proofing = \frac{\text{Sum all Y's in Error Columns}}{\text{Theoretical Min. No. Parts}}

Handling Index = \frac{\text{Sum all Y's in Handling Columns}}{\text{Theoretical Min. No. Parts}}

Insertion Index = \frac{\text{Sum all Y's in Insertion Columns}}{\text{Theoretical Min. No. Parts}}

2^{nd} \text{ Op. Index} = \frac{\text{Sum all Y's in 2nd Op. Columns}}{\text{Theoretical Min. No. Parts}}
Analyze All Metrics

First consider:
Reduce part count & type

Then think about:
Error Proofing

Then think about:
Ease of handling
Ease of insertion
Eliminate secondary ops.

Part Count Efficiency
& DFA Complexity Factor

Error Index

Handling Index
Insertion Index
2nd Op. Index

Set Target Values for These Measures
Your Turn...

Instructions

Complete the remaining columns & calculate your product’s Assemblability Indices
Step Seven

- Analyze data for new design
DFA Process

Step 1
- Product Information: *functional requirements*
- Functional analysis
- Identify parts that can be standardized
- Determine part count efficiencies

Step 2
- Determine your *practical* part count

Step 3
- Identify *quality* (mistake proofing) opportunities

Step 4
- Identify *handling* (grasp & orientation) opportunities

Step 5
- Identify *insertion* (locate & secure) opportunities

Step 6
- Identify opportunities to reduce *secondary operations*

Step 7
- Analyze data for *new design*

*Benchmark when possible*
DFA Guidelines

In order of importance:

- Reduce part count & types
- Ensure parts cannot be installed incorrectly
- Strive to eliminate adjustments
- Ensure parts self-align & self-locate
- Ensure adequate access & unrestricted vision
- Ensure parts are easily handled from bulk
- Minimize reorientation (assemble in Z axis) & secondary operations during assembly
- Make parts symmetrical or obviously asymmetrical
Understanding Product Costs

Consideration of True Production costs and the Bill of Material Costs,

Typical Costing

<table>
<thead>
<tr>
<th>Pareto by Part Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Castings</td>
<td>$\quad$</td>
</tr>
<tr>
<td>2. Forging</td>
<td>$\quad$</td>
</tr>
<tr>
<td>3.</td>
<td>c</td>
</tr>
<tr>
<td>n. Fasteners</td>
<td>$\quad$</td>
</tr>
</tbody>
</table>

Pareto by Total Cost

| 1. Fasteners | $\quad$ |
| 2.           | d       |
| 3.           | d       |
| n. Castings  | $\quad$ |
Selection of Manufacturing Method

Have we selected the Best Technology or Process to fabricate the parts?

Is hard tooling Required...

Have we selected the best Material needed for function and cost?

Have we looked at all the new Technology that is available
Selection of Manufacturing Method

Has the Design Addressed Automation Possibilities?

Is the Product configured with access for and the parts shaped for the implementation of automation?
Understanding Component Features

Part Features that are ** Critical To the Products Functional Quality**

Every Drawing Call Out is not Critical to Function and Quality
Key DFMA Principles

- Minimize Part Count
- **Standardize** Parts and Materials
- Create **Modular** Assemblies
- Design for **Efficient Joining**
- Minimize Reorientation of parts during Assembly and/or Machining
- Simplify and **Reduce** the number of Manufacturing Operations
- Specify ‘**Acceptable**’ surface **Finishes** for functionality
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