# Unit-3
# Chapter-4

# Part-1

Dr. Dhiren R. Patel

## What Is Design for Manufacture and Assembly?

- In this chapter we shall assume that “to manufacture” refers to the manufacturing of the individual component parts of a product or assembly and “to assemble” refers to the addition or joining of parts to form the completed product.
- Hence, the term “design for manufacture” (or DFM) means the design for the ease of manufacture of the collection of parts that form the product after assembly and “design for assembly” (or DFA) means the design of the product for the ease of assembly.
- Design for manufacture and assembly (DFMA) is a combination of DFA and DFM.

DFMA is used for three main activities:

1. As the basis for concurrent engineering studies to provide guidance to the design team in simplifying the product structure to reduce manufacturing and assembly costs, and to quantify the improvements.

2. As a benchmarking tool to study competitors' products and quantify manufacturing and assembly difficulties.

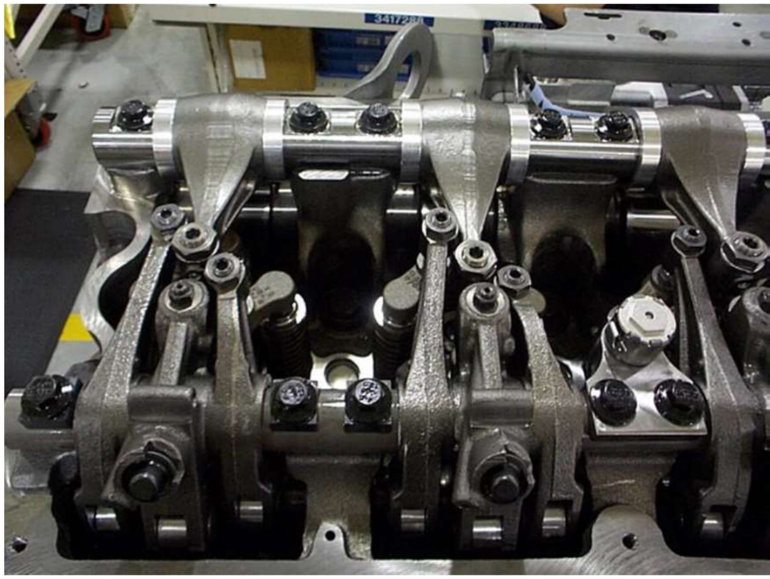
3. As a should-cost tool to help control costs and to help negotiate suppliers contracts.

# 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.

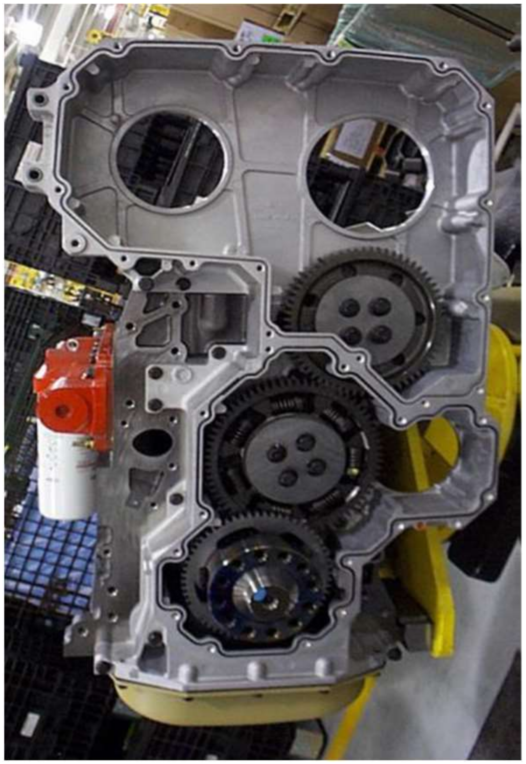


## Design for Manufacturing

- **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

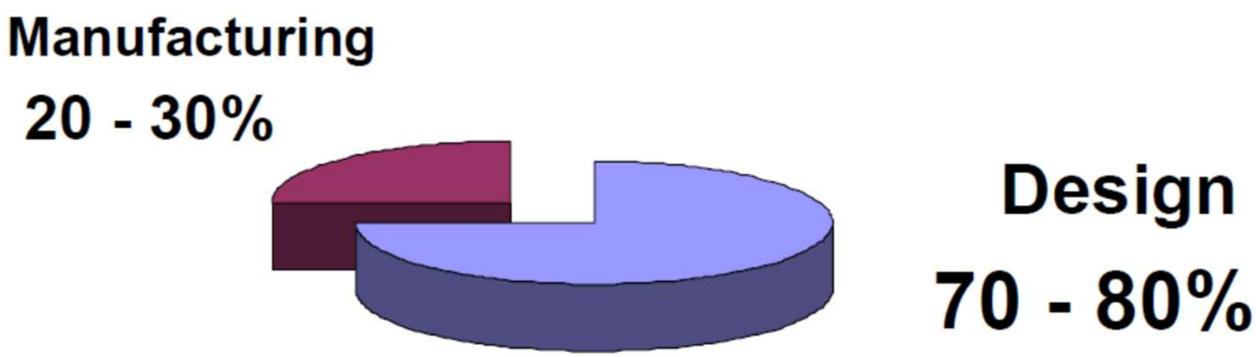
## Similarities

- 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?



# Sequence of Analysis

*Concept Design*

↓

**Design for Assembly**

↓

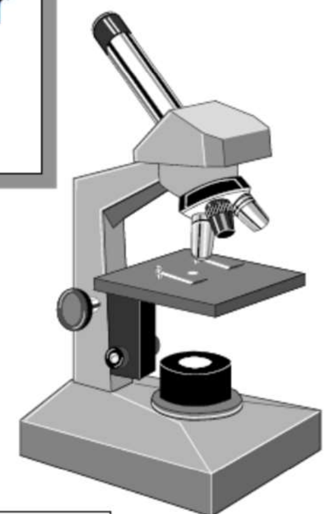
**Design for Manufacturing**

↓

*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

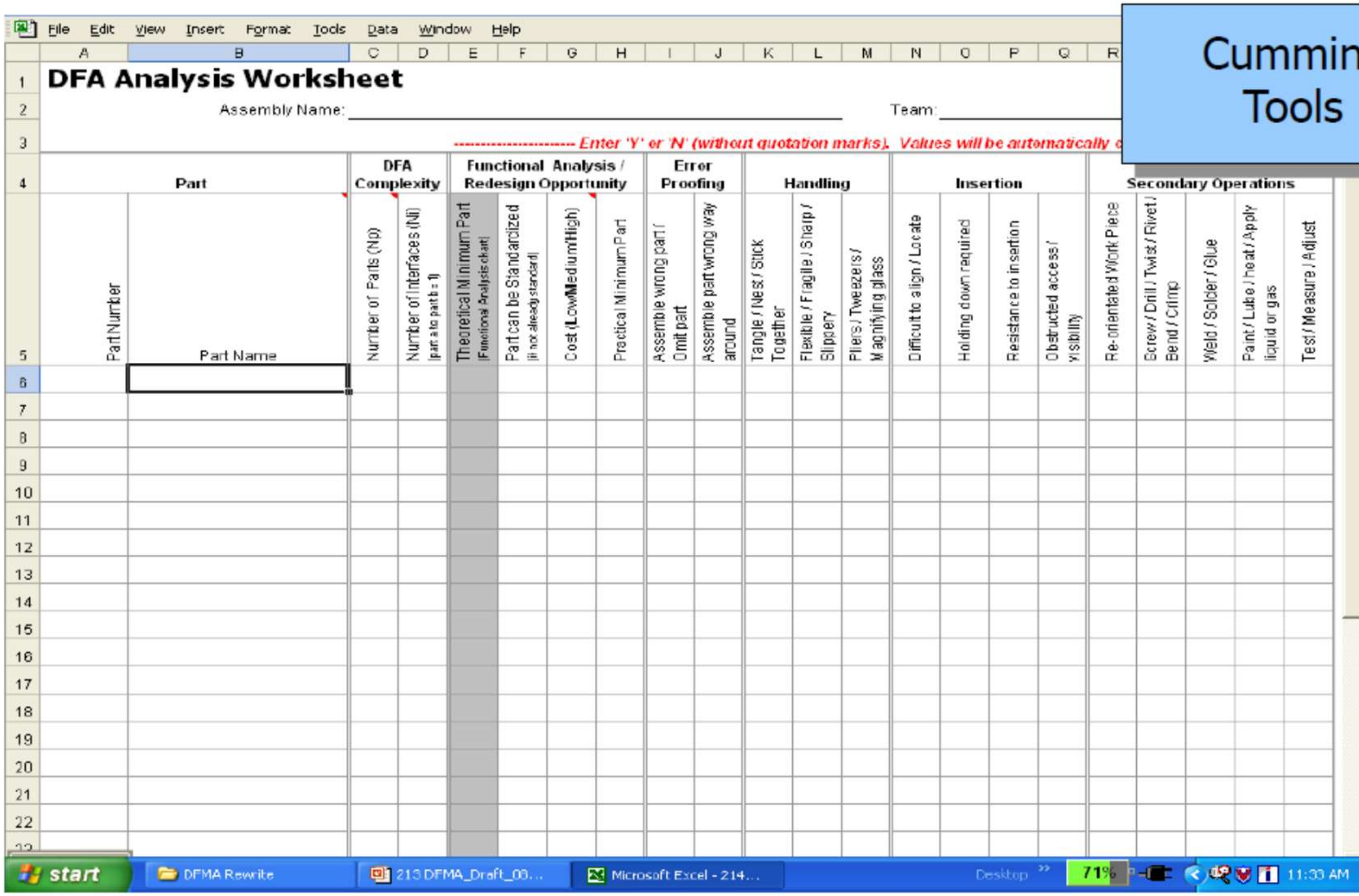
**Step 5** ❑ Identify **insertion** (locate & secure) opportunities

**Step 6** ❑ Identify opportunities to reduce **secondary operations**

**Step 7** ❑ Analyze data for **new design**

**Benchmark when possible**

# DFA Analysis Worksheet




Cummins Tools


- ❑ 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

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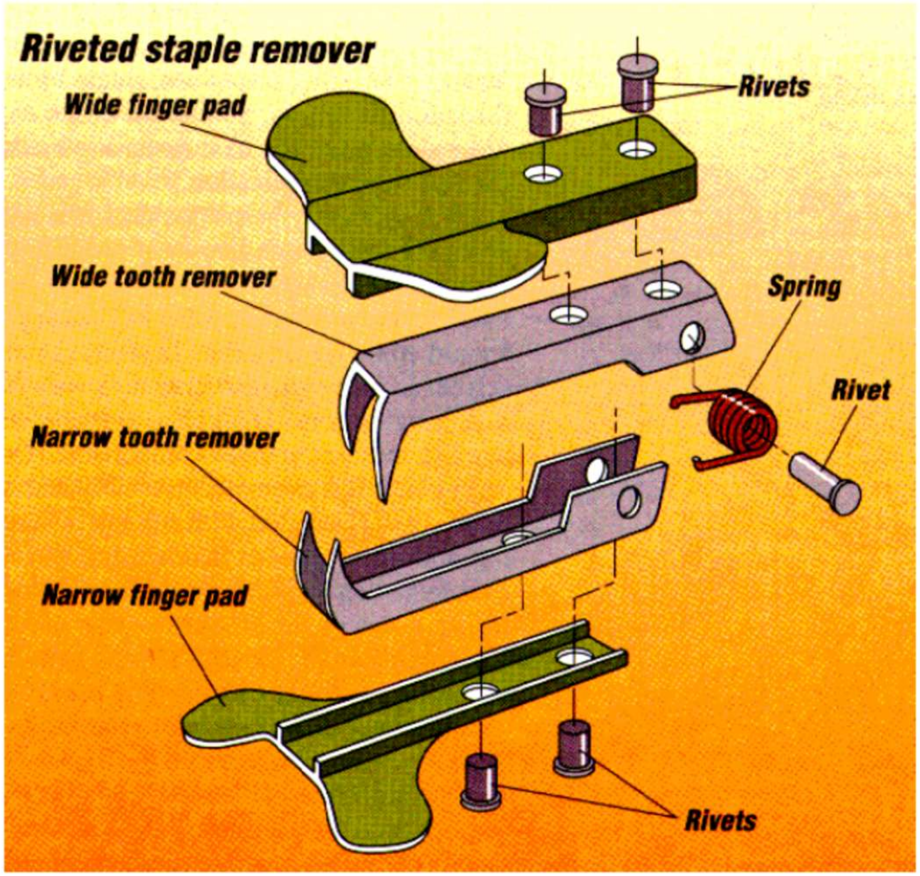
**DFA Analysis Worksheet**

Assembly Name: Staple Remover

| Part | | DFA Complexity | | Func Rede |
|---|---|---|---|---|
| Part Number | Part Name | Number of Parts (Np) | Number of Interfaces (Ni) (part a to part b = 1) | Theoretical Minimum Part (Functional Analysis chart) |
| 1 | Lower Arm Sub. | | | |
| 1.1 | ***Base Part -*** Lower Arm | | | |
| 1.2 | Lower Arm cover | | | |
| 1.3 | Rivet | | | |
| 2 | Upper Arm Sub. | | | |
| 2.1 | Upper Arm | | | |
| 2.2 | Upper Arm cover | | | |
| 2.3 | Rivet | | | |
| 3 | Spring | | | |
| 4 | Pivot | | | |
| | | | | |
| | ***Totals*** | | | |

# So take it apart!



# Count Parts & Interfaces

- List number of parts (Np)
- List number of interfaces (Ni)

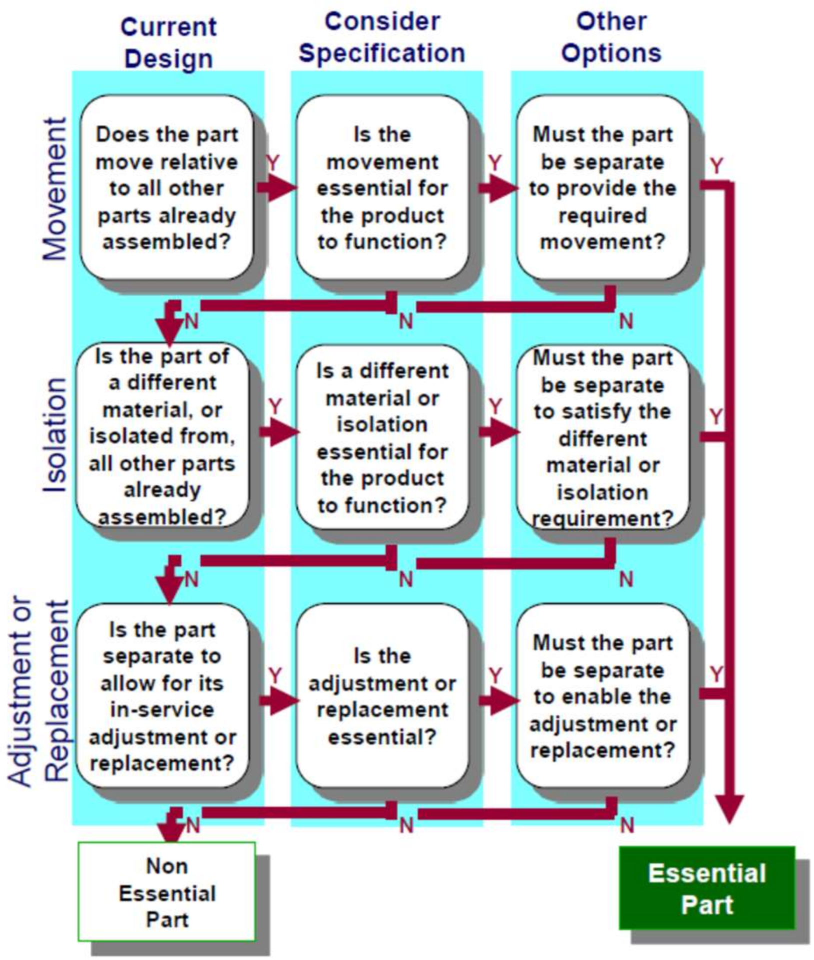
**DFA Analysis Worksheet**

Assembly Name: Staple Remover

| Part Number | Part Name | DFA Complexity: Number of Parts (Np) | DFA Complexity: Number of Interfaces (Ni) (part a to part b = 1) | Func… Rede…: Theoretical Minimum Part (Functional Analysis chart) |
|---|---|---|---|---|
| |  | | | |
| 1 | Lower Arm Sub. | | | |
| 1.1 | ***Base Part -*** Lower Arm | 1 | 6 | |
| 1.2 | Lower Arm cover | 1 | 3 | |
| 1.3 | Rivet | 2 | 4 | |
| 2 | Upper Arm Sub. | | | |
| 2.1 | Upper Arm | 1 | 6 | |
| 2.2 | Upper Arm cover | 1 | 3 | |
| 2.3 | Rivet | 2 | 4 | |
| 3 | Spring | 1 | 3 | |
| 4 | Pivot | 1 | 3 | |
| | ***Totals*** | 10 | 32 | |

I1: Arm to rivet
I2: Arm to rivet
I3: Arm to cover
I4: Arm to pivot
I5: Arm to spring
I6: Arm to Arm

# Determine Theoretical Min. No. of Parts

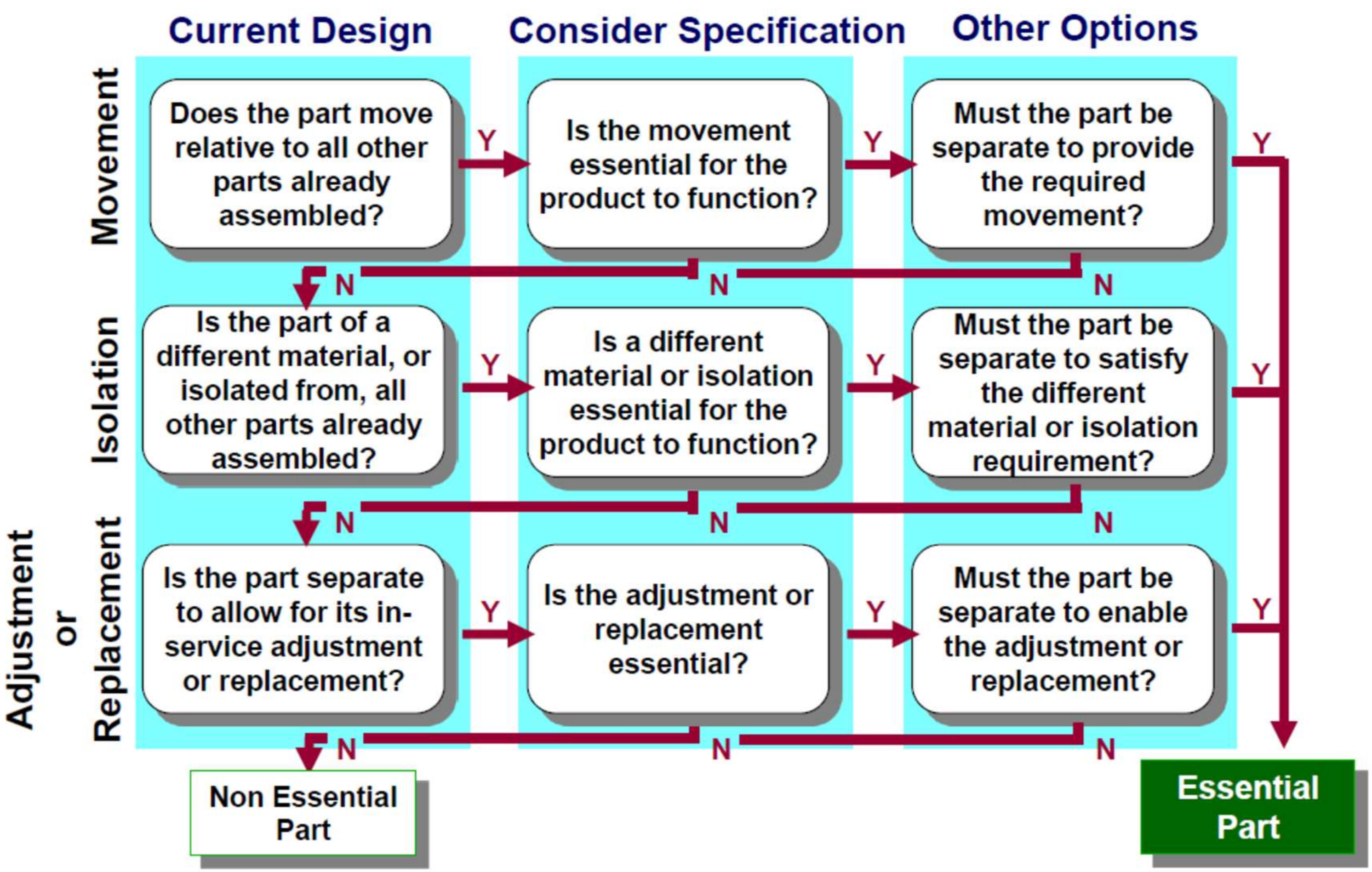



**DFA Analysis Worksheet**

Assembly Name: Staple Remover

| Part | | DFA Complexity | | Func Rede |
|---|---|---|---|---|
| Part Number |  Part Name | Number of Parts (Np) | Number of Interfaces (Ni) (part a to part b = 1) | Theoretical Minimum Part (Functional Analysis chart) |
| 1 | Lower Arm Sub. | | | |
| 1.1 | ***Base Part -*** Lower Arm | 1 | 6 | Y |
| 1.2 | Lower Arm cover | 1 | 3 | N |
| 1.3 | Rivet | 2 | 4 | N |
| 2 | Upper Arm Sub. | | | |
| 2.1 | Upper Arm | 1 | 6 | N |
| 2.2 | Upper Arm cover | 1 | 3 | N |
| 2.3 | Rivet | 2 | 4 | N |
| 3 | Spring | 1 | 3 | N |
| 4 | Pivot | 1 | 3 | N |
| | | | | |
| | ***Totals*** | 10 | 32 | 1 |

# Functional Analysis



# 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…)

**DFA Analysis Worksheet**

Assembly Name: Staple Remover

| Part Number | Part Name | DFA Complexity: Number of Parts (Np) | DFA Complexity: Number of Interfaces (Ni) (part a to part b = 1) | Functional Redesign: Theoretical Minimum Part (Functional Analysis chart) | Functional Redesign: Part can be Standardized (if not already standard) |
|---|---|---|---|---|---|
| 1 | Lower Arm Sub. | | | | |
| 1.1 | ***Base Part*** - Lower Arm | 1 | 6 | Y | N |
| 1.2 | Lower Arm cover | 1 | 3 | N | Y |
| 1.3 | Rivet | 2 | 4 | N | N |
| 2 | Upper Arm Sub. | | | | |
| 2.1 | Upper Arm | 1 | 6 | N | N |
| 2.2 | Upper Arm cover | 1 | 3 | N | Y |
| 2.3 | Rivet | 2 | 4 | N | N |
| 3 | Spring | 1 | 3 | N | N |
| 4 | Pivot | 1 | 3 | N | N |
| | ***Totals*** | 10 | 32 | 1 | 2 |
| | ***Design for Assembly Metrics*** | **17.89** | | **10%** | ← Theo Pract. |
| | ***Targets*** | **0.00** | | **>60%** | **0** |

# Theoretical Part Count Efficiency

$$\text{Theoretical Part Count Efficiency} = \frac{\text{Theoretical Min. No. Parts}}{\text{Total Number of Parts}} * 100$$

$$\text{Theoretical Part Count Efficiency} = \frac{1}{10} * 100$$

$$\text{Theoretical Part Count Efficiency} = \mathbf{10\%}$$

Rule of Thumb – Part Count Efficiency Goal > 60%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**DFA Analysis Worksheet**

Assembly Name: Staple Remover

| Row | A: Part Number | B: Part Name | C: Number of Parts (Np) | D: Number of Interfaces (Ni) (part a to part b = 1) | E: Theoretical Minimum Part (Functional Analysis chart) |
|---|---|---|---|---|---|
| 4 | | Part | DFA Complexity | | Func Redu |
| 6 | 1 | Lower Arm Sub. | | | |
| 7 | 1.1 | ***Base Part -*** Lower Arm | 1 | 6 | Y |
| 8 | 1.2 | Lower Arm cover | 1 | 3 | N |
| 9 | 1.3 | Rivet | 2 | 4 | N |
| 10 | 2 | Upper Arm Sub. | | | |
| 11 | 2.1 | Upper Arm | 1 | 6 | N |
| 12 | 2.2 | Upper Arm cover | 1 | 3 | N |
| 13 | 2.3 | Rivet | 2 | 4 | N |
| 14 | 3 | Spring | 1 | 3 | N |
| 15 | 4 | Pivot | 1 | 3 | N |
| 16 | | | | | |
| 17 | | *Totals* | 10 | 32 | 1 |
| 18 | | *Design for Assembly Metrics* | 17.89 | | 10% |
| 19 | | *Targets* | 0.00 | | >60% |

# DFA Complexity Factor – Definition

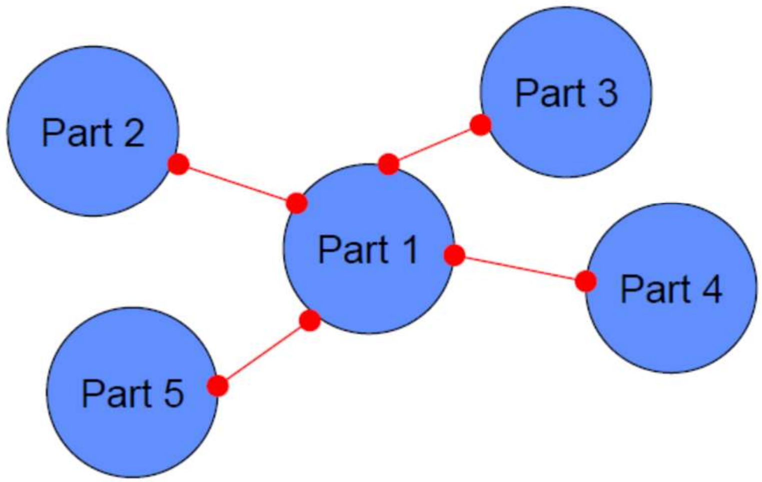
- Cummins Inc. metric for assessing complexity of a product design
- Two Factors
  - Np – Number of parts
  - Ni – Number of part-to-part interfaces

  – Multiply the two and take the square root of the total

$$\sqrt{\Sigma\, Np \times \Sigma\, Ni}$$

  – This is known as the DFA Complexity Factor

# DFA Complexity Factor – Target




$$DCF = \sqrt{\Sigma Np \times \Sigma Ni}$$

$$DCFt = \sqrt{\Sigma Npt \times \Sigma Nit}$$

$$DCFt = \sqrt{5 \times 8} = 6.32$$

- 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

# Determine Relative Part Cost Levels

- Subjective estimate only
- **L**ow/**M**edium/**H**igh relative to other parts in the assembly and/or product line

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| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 | **DFA Analysis Worksheet** | | | | | | |
| 2 | | Assembly Name: Staple Remover | | | | | |
| 3 | | | | | ------------------------ En | | |
| 4 | **Part** | | **DFA Complexity** | | **Functional Analys Redesign Opportu** | | |
| 5 | Part Number |  Part Name | Number of Parts (Np) | Number of Interfaces (Ni) (part a to part b = 1) | Theoretical Minimum Part (Functional Analysis chart) | Part can be Standardized (if not already standard) | Cost (**L**ow/**M**edium/**H**igh) |
| 6 | 1 | Lower Arm Sub. | | | | | |
| 7 | 1.1 | ***Base Part -*** Lower Arm | 1 | 6 | Y | N | L |
| 8 | 1.2 | Lower Arm cover | 1 | 3 | N | Y | L |
| 9 | 1.3 | Rivet | 2 | 4 | N | N | L |
| 10 | 2 | Upper Arm Sub. | | | | | |
| 11 | 2.1 | Upper Arm | 1 | 6 | N | N | L |
| 12 | 2.2 | Upper Arm cover | 1 | 3 | N | Y | L |
| 13 | 2.3 | Rivet | 2 | 4 | N | N | L |
| 14 | 3 | Spring | 1 | 3 | N | N | L |
| 15 | 4 | Pivot | 1 | 3 | N | N | L |
| 16 | | | | | | | |
| 17 | | ***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%


- Determine Practical Minimum Part Count

# Determine Practical Minimum Part Count

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

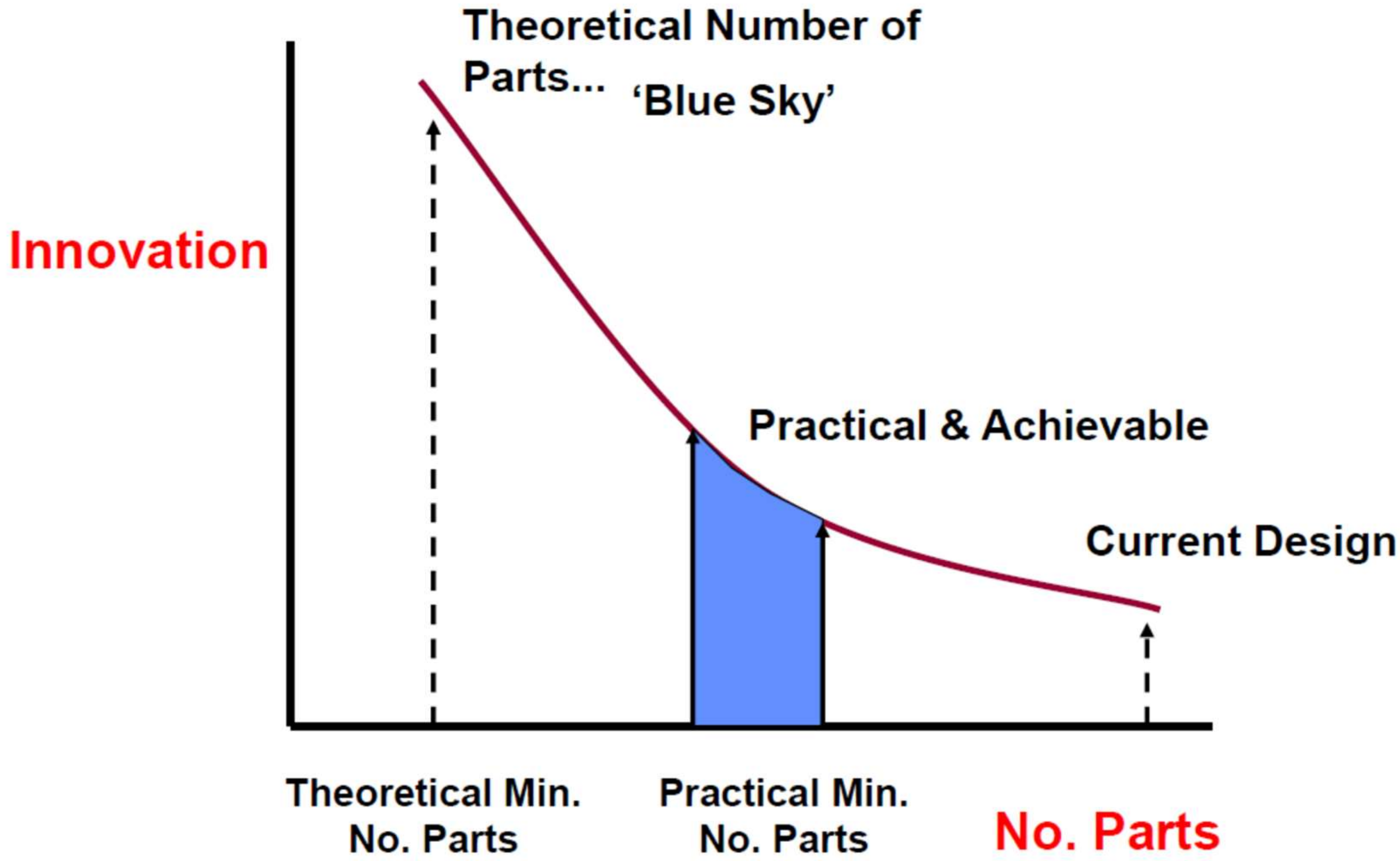
**DFA Analysis Worksheet**

Assembly Name: Staple Remover

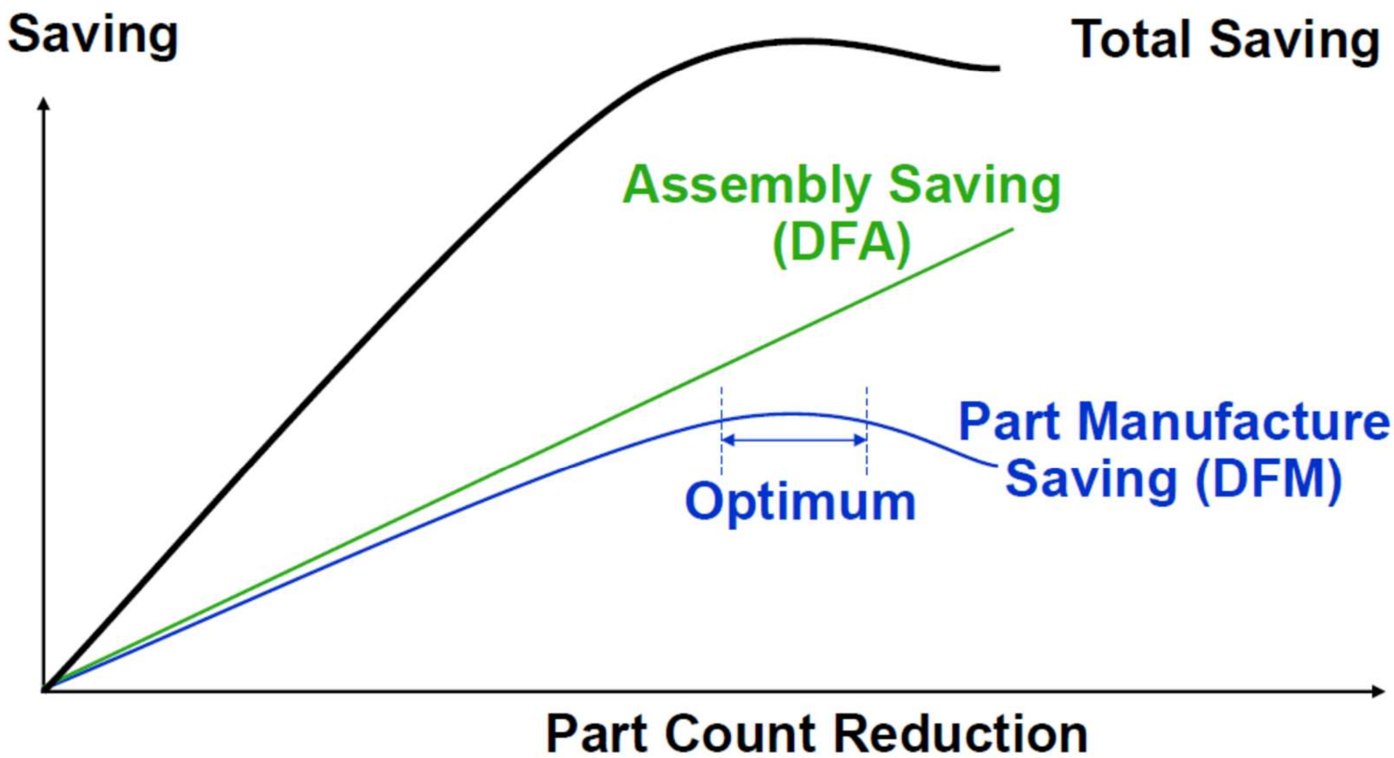
Enter 'Y'

| Part Number | Part Name | DFA Complexity: Number of Parts (Np) | DFA Complexity: Number of Interfaces (Ni) (part a to part b = 1) | Functional Analysis / Redesign Opportunity: Theoretical Minimum Part (Functional Analysis chart) | Part can be Standardized (if not already standard) | Cost (Low/Medium/High) | Practical Minimum Part |
|---|---|---|---|---|---|---|---|
| |  | | | | | | |
| 1 | Lower Arm Sub. | | | | | | |
| 1.1 | ***Base Part*** **-** Lower Arm | 1 | 6 | Y | N | L | Y |
| 1.2 | Lower Arm cover | 1 | 3 | N | Y | L | N |
| 1.3 | Rivet | 2 | 4 | N | N | L | N |
| 2 | Upper Arm Sub. | | | | | | |
| 2.1 | Upper Arm | 1 | 6 | N | N | L | Y |
| 2.2 | Upper Arm cover | 1 | 3 | N | Y | L | N |
| 2.3 | Rivet | 2 | 4 | N | N | L | N |
| 3 | Spring | 1 | 3 | N | N | L | Y |
| 4 | Pivot | 1 | 3 | N | N | L | Y |
| | | | | | | | |
| | ***Totals*** | 10 | 32 | 1 | 2 | | 4 |

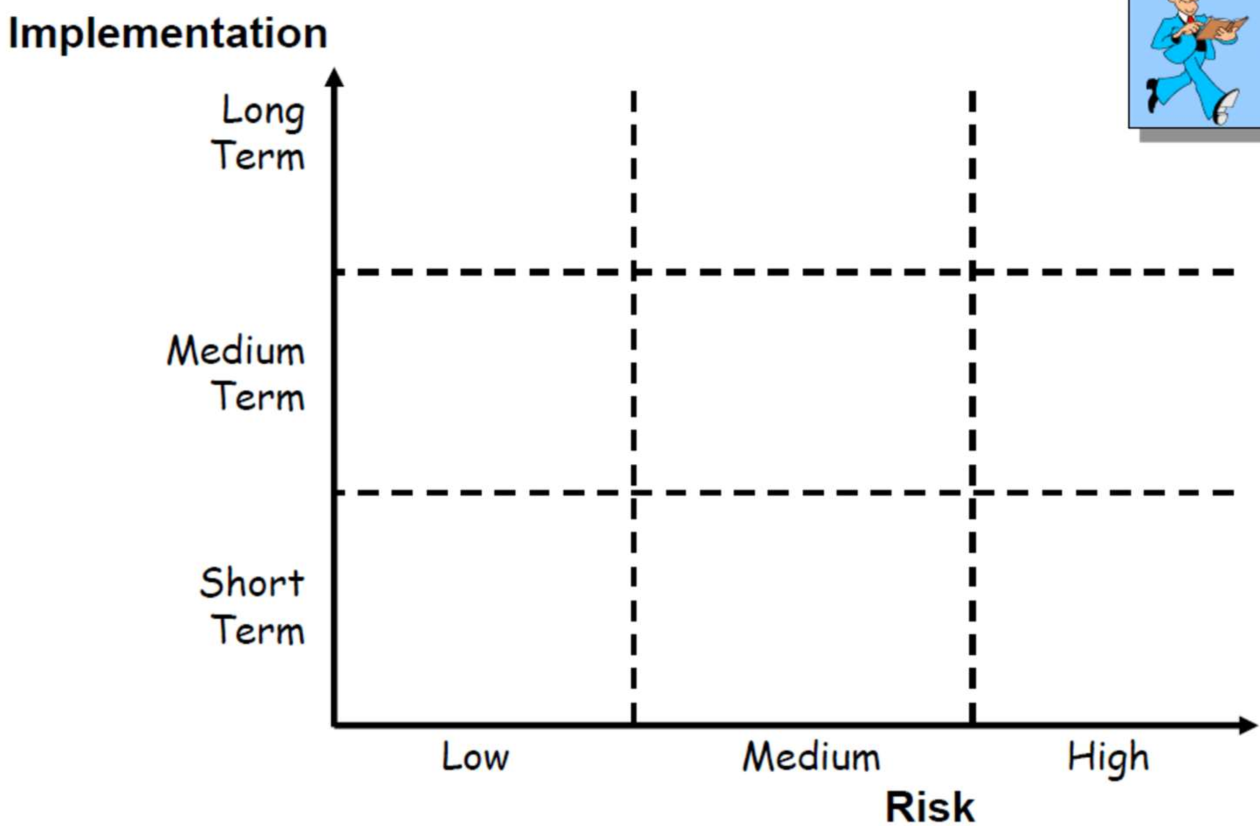
# Creativity & Innovation



# Cost of Assembly Vs Cost of Part Manufacture



# Idea Classification

## 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!

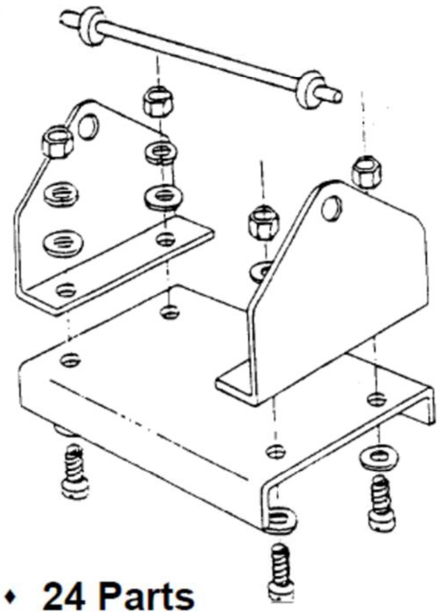
# Fasteners

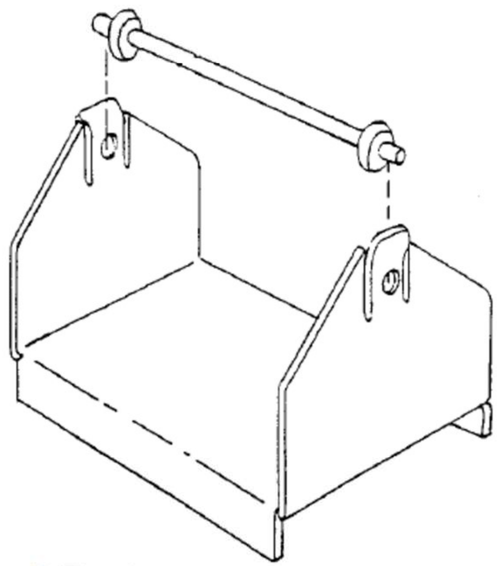

- A study by Ford Motor Co. revealed that threaded fasteners were the most common cause of warranty repairs

- 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.'

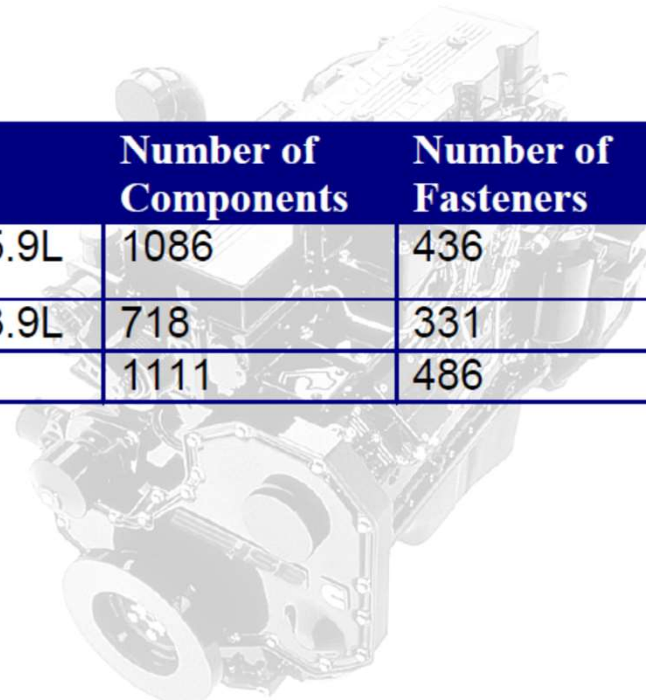




- 24 Parts
- 8 different parts
- multiple mfg. & assembly processes necessary

- 2 Parts
- 2 Manufacturing processes
- one assembly step

# Fasteners: Cummins Engines



| Engine Type | Number of Components | Number of Fasteners | Percent Fasteners |
|---|---|---|---|
| B Series, 6 Cyl 5.9L | 1086 | 436 | 40% |
| B Series, 4 Cyl 3.9L | 718 | 331 | 46% |
| C Series, 8.3L | 1111 | 486 | 44% |

Data from Munroe & Associates October 2002

# Standard Bolt Sizes

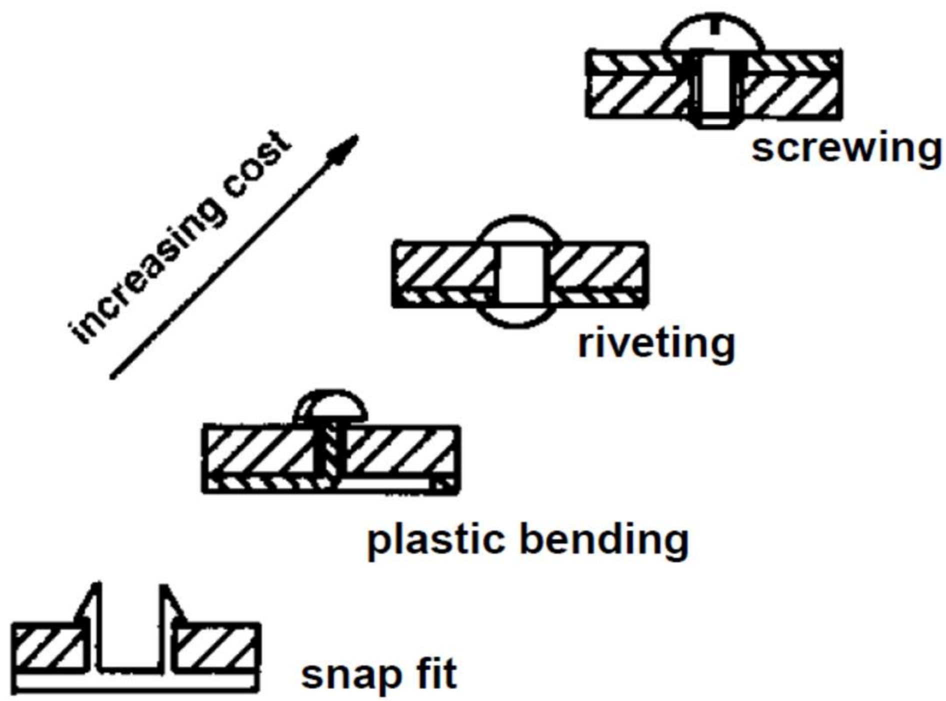
- Minimize extra sizes to both reduce inventory and eliminate confusion during assembly

Candidates for elimination

| | M5 x .8 | M6 x 1.0 | M8 x 1.25 | M10 x 1.5 | M11 x 1.25 | M12 x 1.25 | M12 x 1.75 | M14 x 1.5 | M16 x 2.0 | Qty Required |
|---|---|---|---|---|---|---|---|---|---|---|
| 12mm | | | | | | | | | | 0 |
| 14mm | 2 | | | | | | | | | 2 |
| 16mm | | 3 | | | | | | | | 3 |
| 20mm | | | 4 | 8 | 8 | | | | | 20 |
| 25mm | | | | 6 | 6 | | | | | 12 |
| 30mm | | | 3 | 8 | | | | | | 11 |
| 35mm | | | 10 | 35 | | | | | | 45 |
| 39.5mm | | | 32 | 12 | 10 | 4 | | | | 58 |
| 40mm | | | | 41 | 27 | | 6 | | | 74 |
| 45mm | | | 22 | 9 | | | | | 1 | 32 |
| 50mm | | 4 | 9 | 25 | 18 | 12 | | | | 68 |
| 60mm | | | 13 | 8 | | | 15 | | | 36 |
| 70mm | | | | | 6 | | | | | 6 |
| Required | 2 | 7 | 93 | 152 | 75 | 16 | 21 | 0 | 1 | 367 |

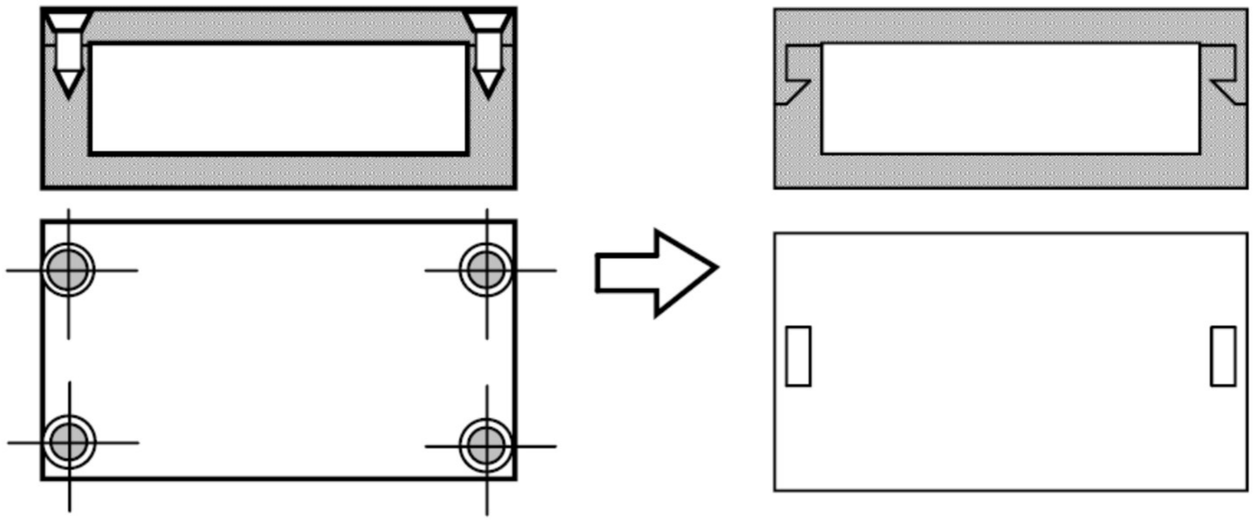
# Fastener Cost

- Select the most inexpensive fastening method required



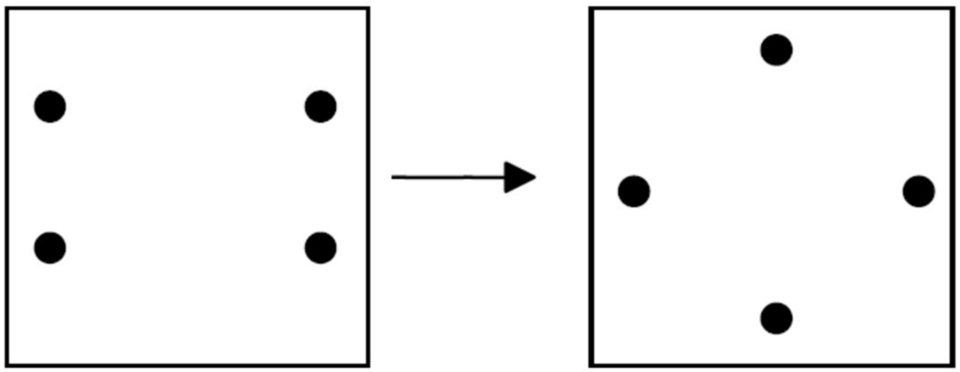
# General Design Principles

## Self-fastening features



# General Design Principles

## Symmetry eliminates reorientation

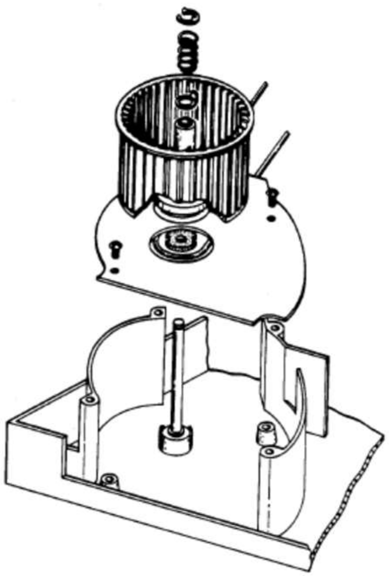


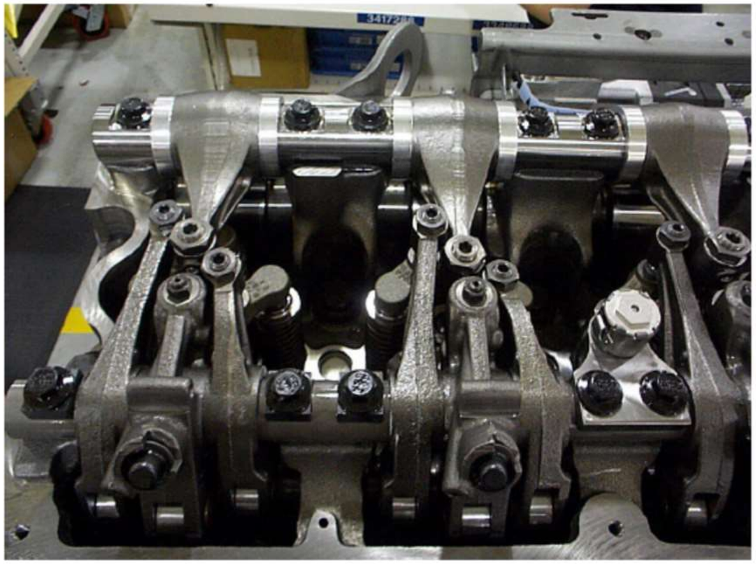
Asymmetric Part

Symmetry of a part makes assembly easier

# General Design Principles

## Top-Down Assembly

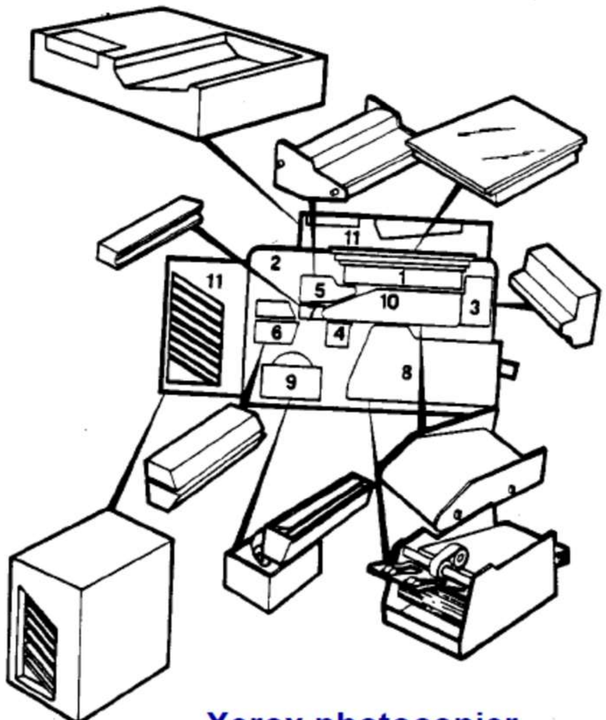




# General Design Principles

## 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

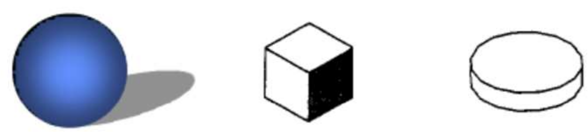
# Eliminated Parts are NEVER…

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


- 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

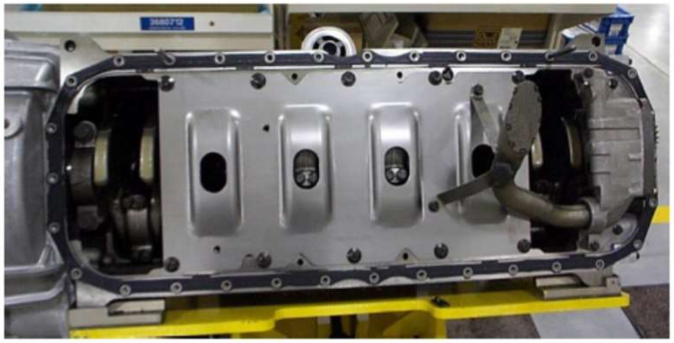

72 Wiring Harness Part Numbers

CDC - Rocky Mount, NC


- Identify handling (grasp & orientation) opportunities

# Quantitative criteria

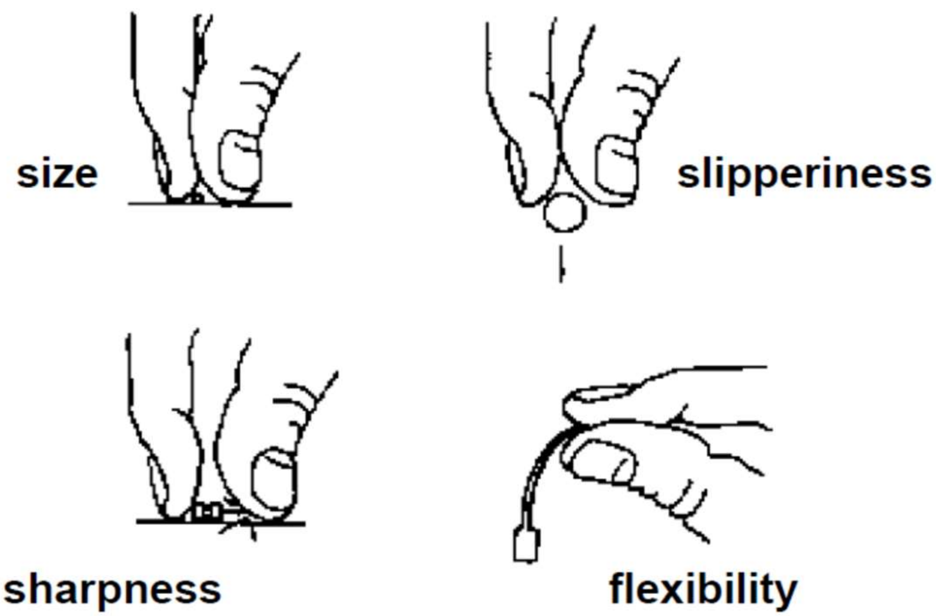
- **Handling Time:** based on assembly process and complexity of parts
  - How many hands are required?
  - Is any grasping assistance needed?
  - What is the effect of part symmetry on assembly?
  - Is the part easy to align/position?



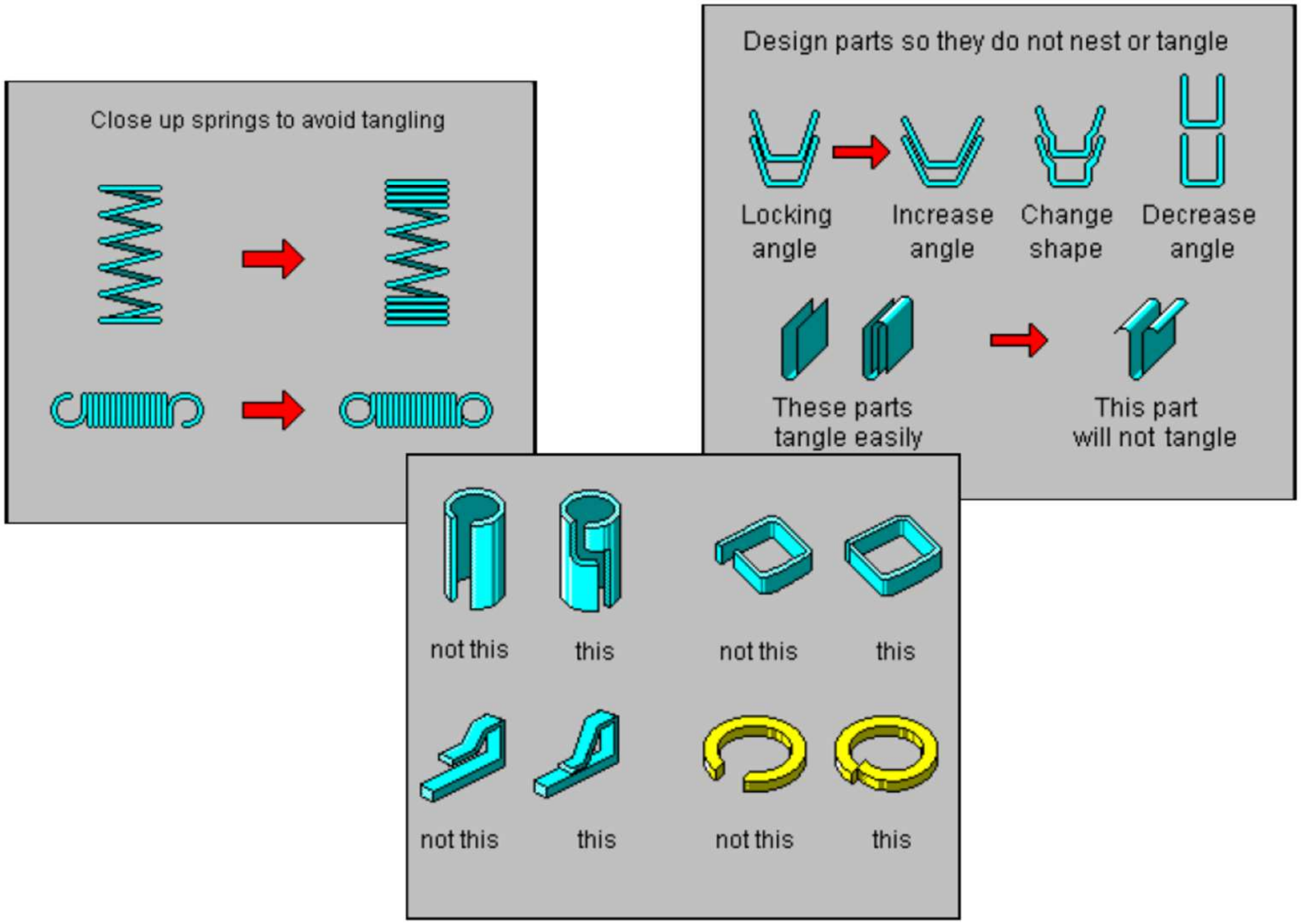
# Handling Difficulty

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

# Handling Difficulty



# Eliminate Tangling/Nesting



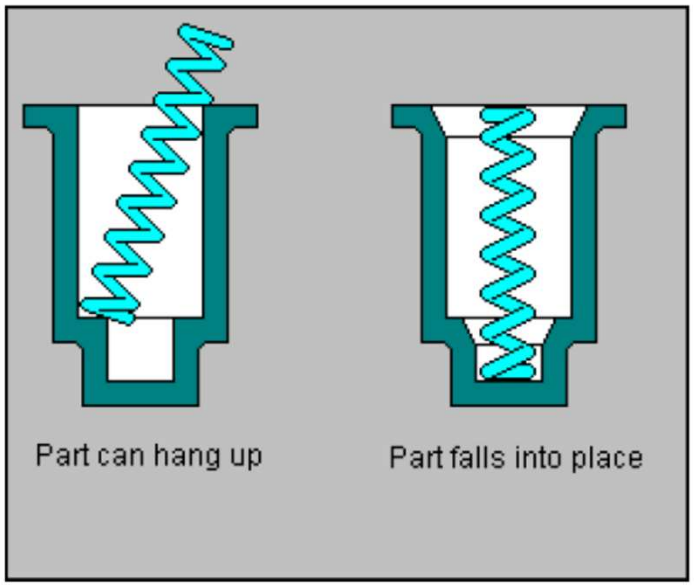

- ❑ Identify insertion (locate & secure) opportunities

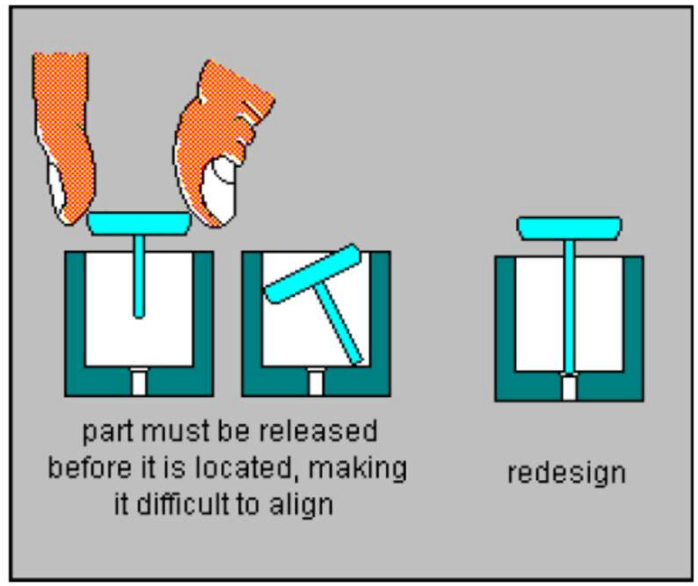
# Quantitative criteria

- **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

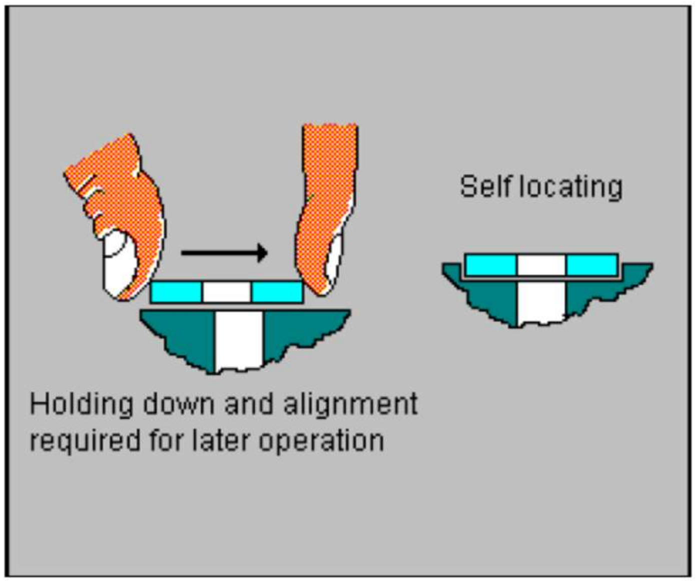
- Provide self-aligning & self locating parts

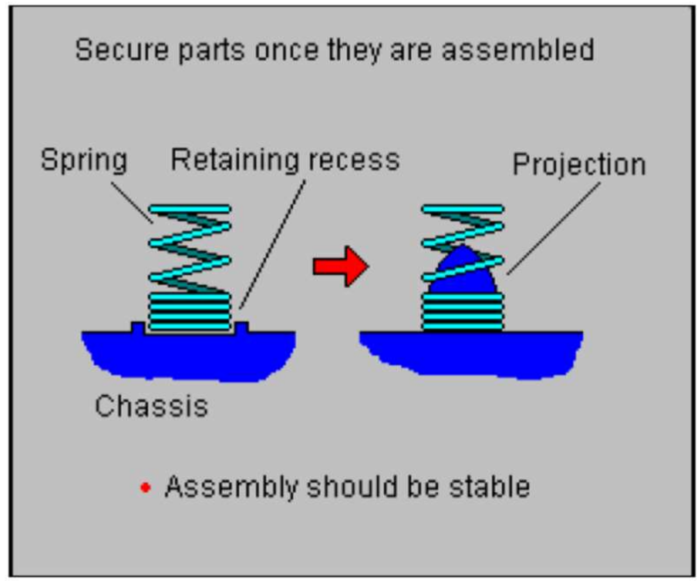


# Insertion Issues

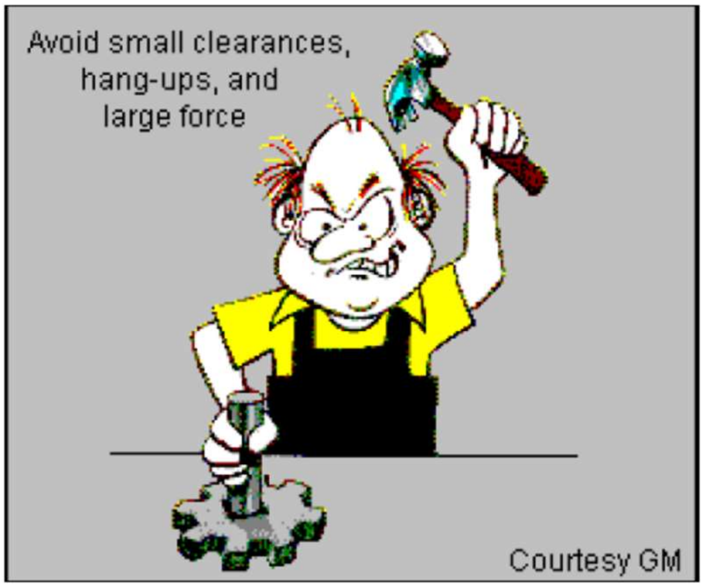
- Ensure parts do not need to be held in position

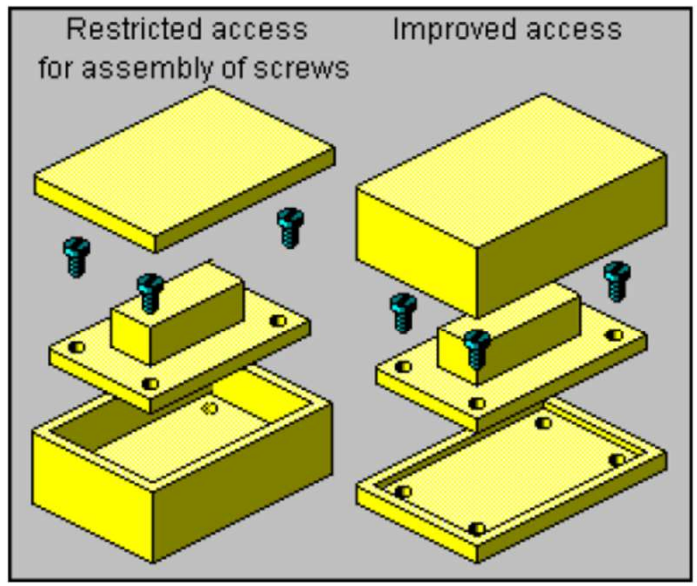


# Insertion Issues

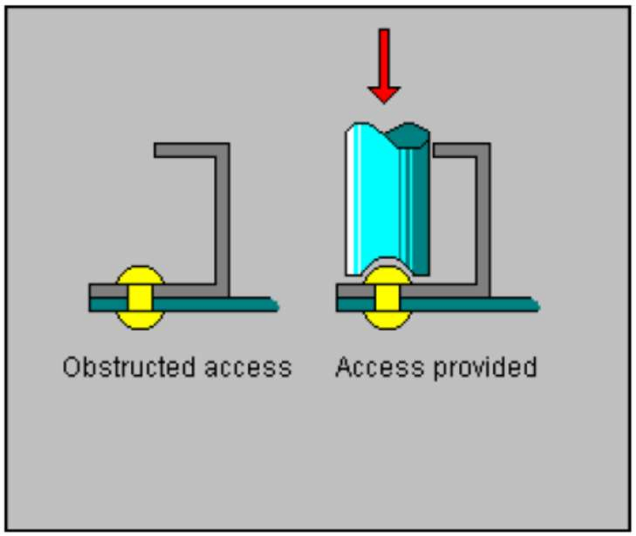
- Parts are easy to insert.
- Provide adequate access & visibility

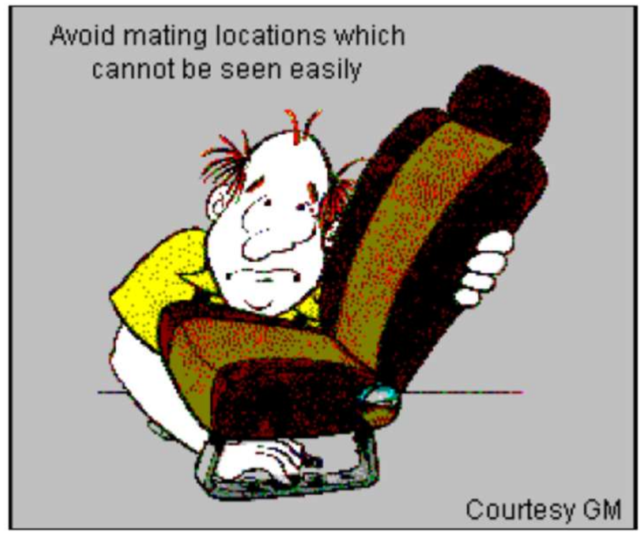


# Insertion Issues

- Provide adequate access and visibility

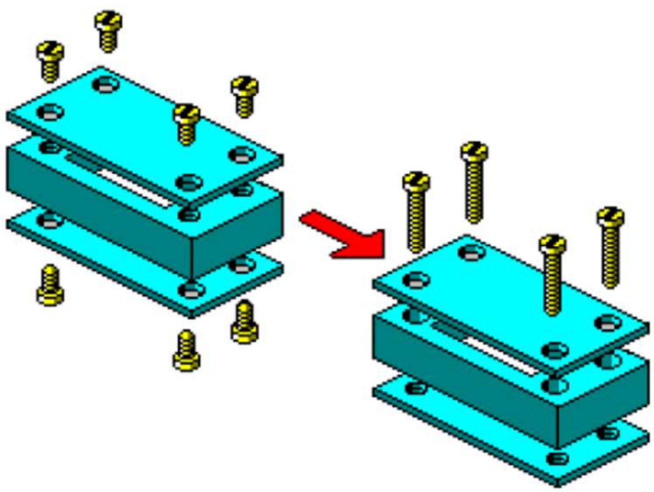


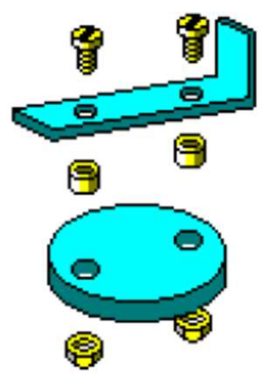




- Identify opportunities to reduce secondary operations

# Eliminate Secondary Operations

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





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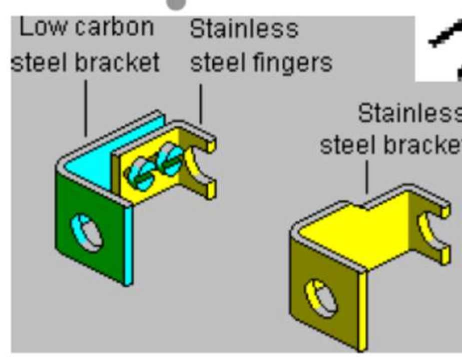
# Eliminate Secondary Operations

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




# Assembly Metrics

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

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

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

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

# Analyze All Metrics

| | |
|---|---|
| ***First*** consider: | |
| Reduce part count & type | Part Count Efficiency & DFA Complexity Factor |
| ***Then*** think about: | |
| Error Proofing | Error Index |
| ***Then*** think about: | |
| Ease of handling | Handling Index |
| Ease of insertion | Insertion Index |
| Eliminate secondary ops. | $2^{nd}$ Op. Index |

**Set Target Values for These Measures**


- ❑ 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**

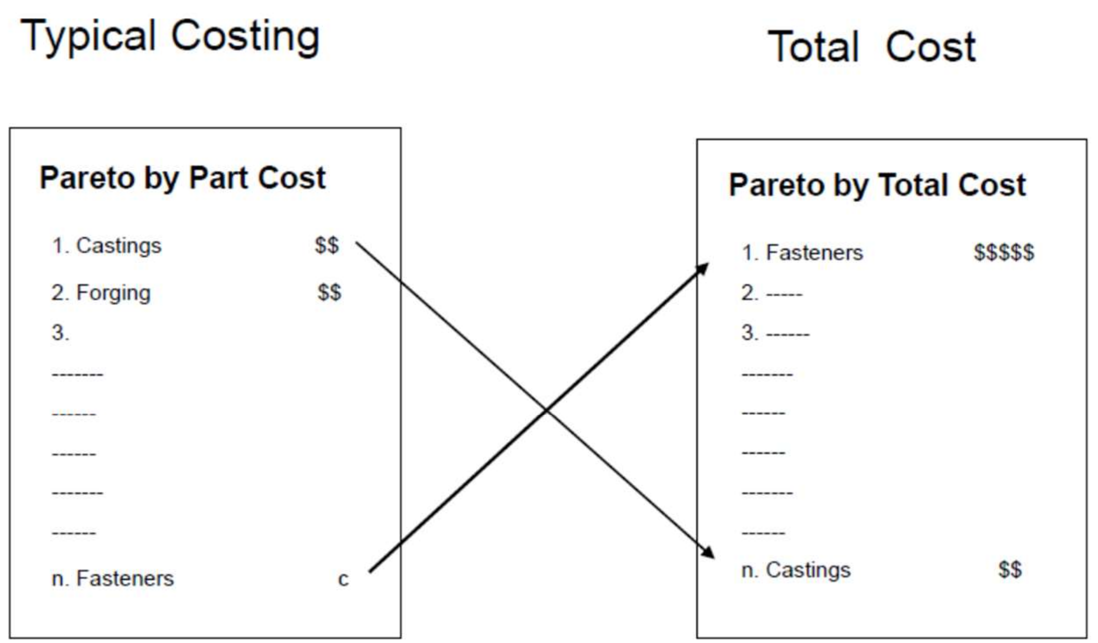
# DFA Guidelines

**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,



# 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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