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.

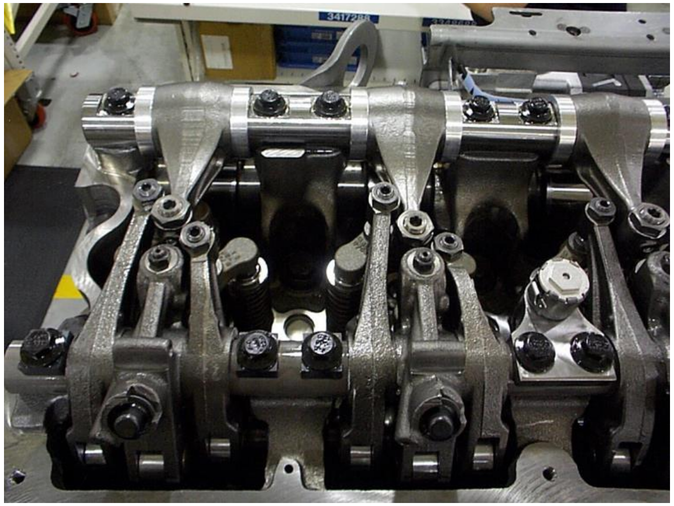
Objectives

- 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'

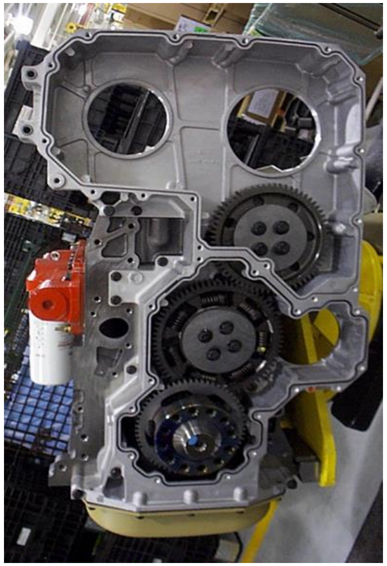


DFA is a tool used to assist the design teams in the design of products that will transition to productions at a minimum cost, focusing on the number of parts, handling and ease of assembly.

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

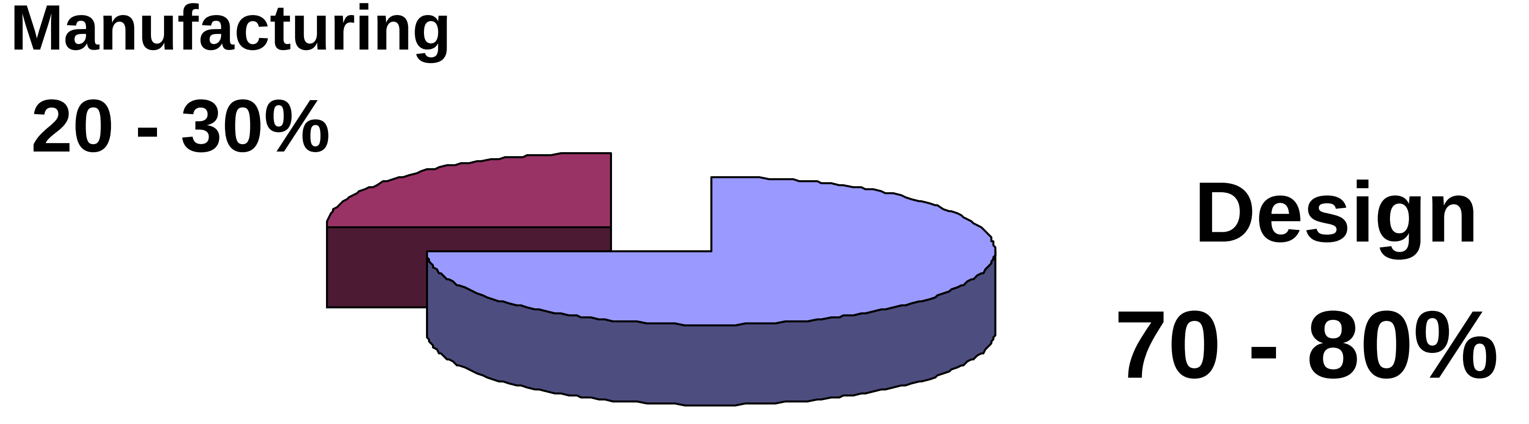
Similarities

- 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

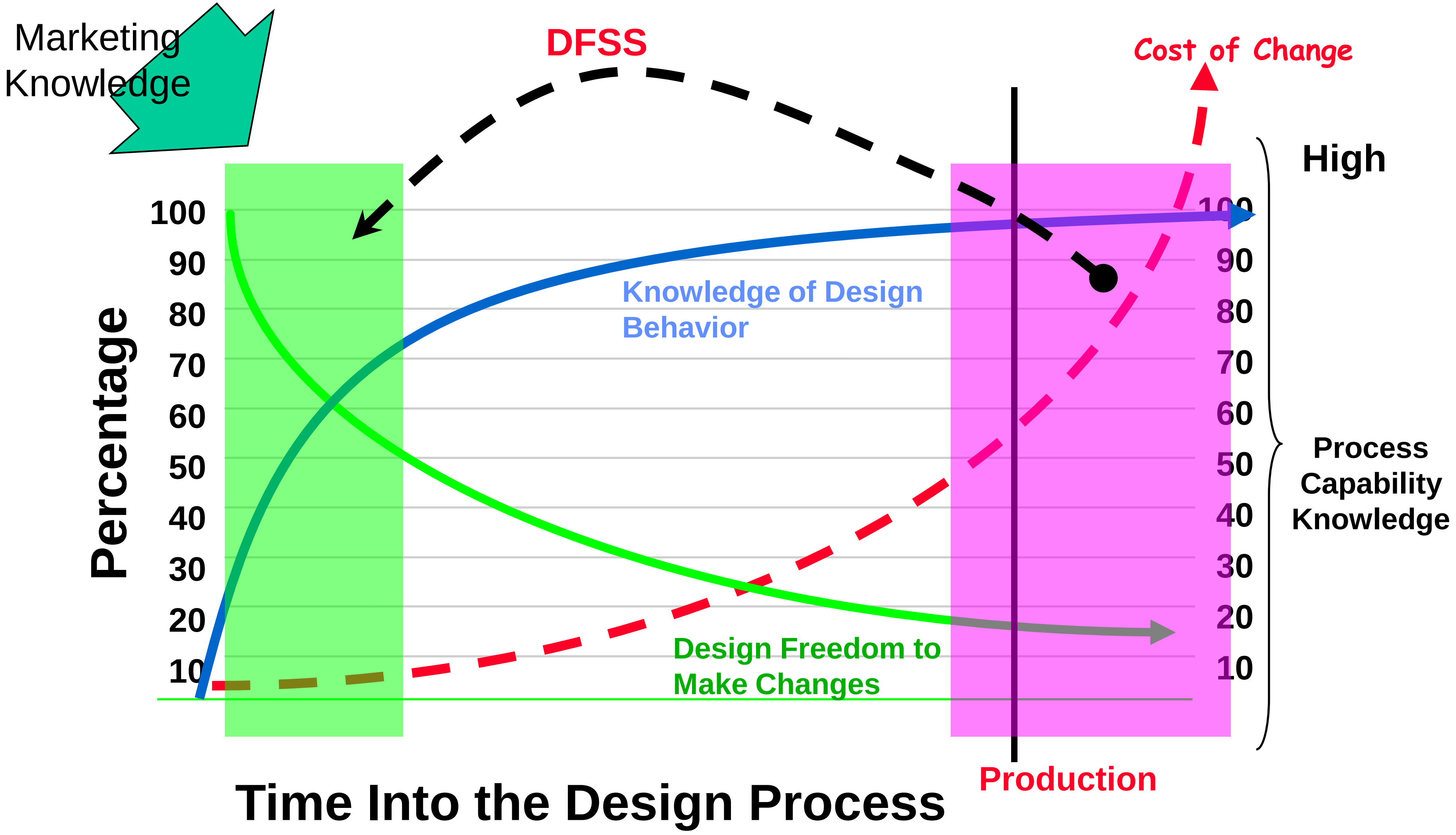
Terminology

- 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 <u>Price, Quality, & Cycle Time</u>?



Knowledge and Learning



Sequence of Analysis

Concept Design

↓

Design for Assembly

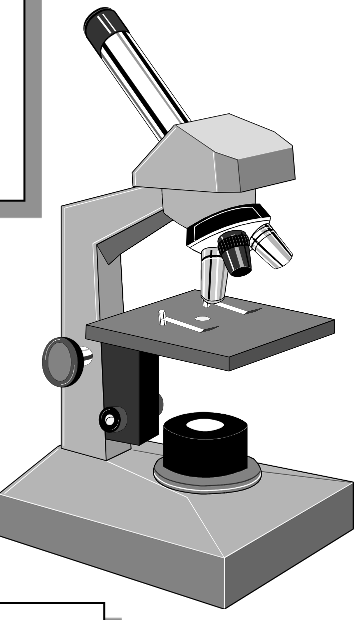
↓

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

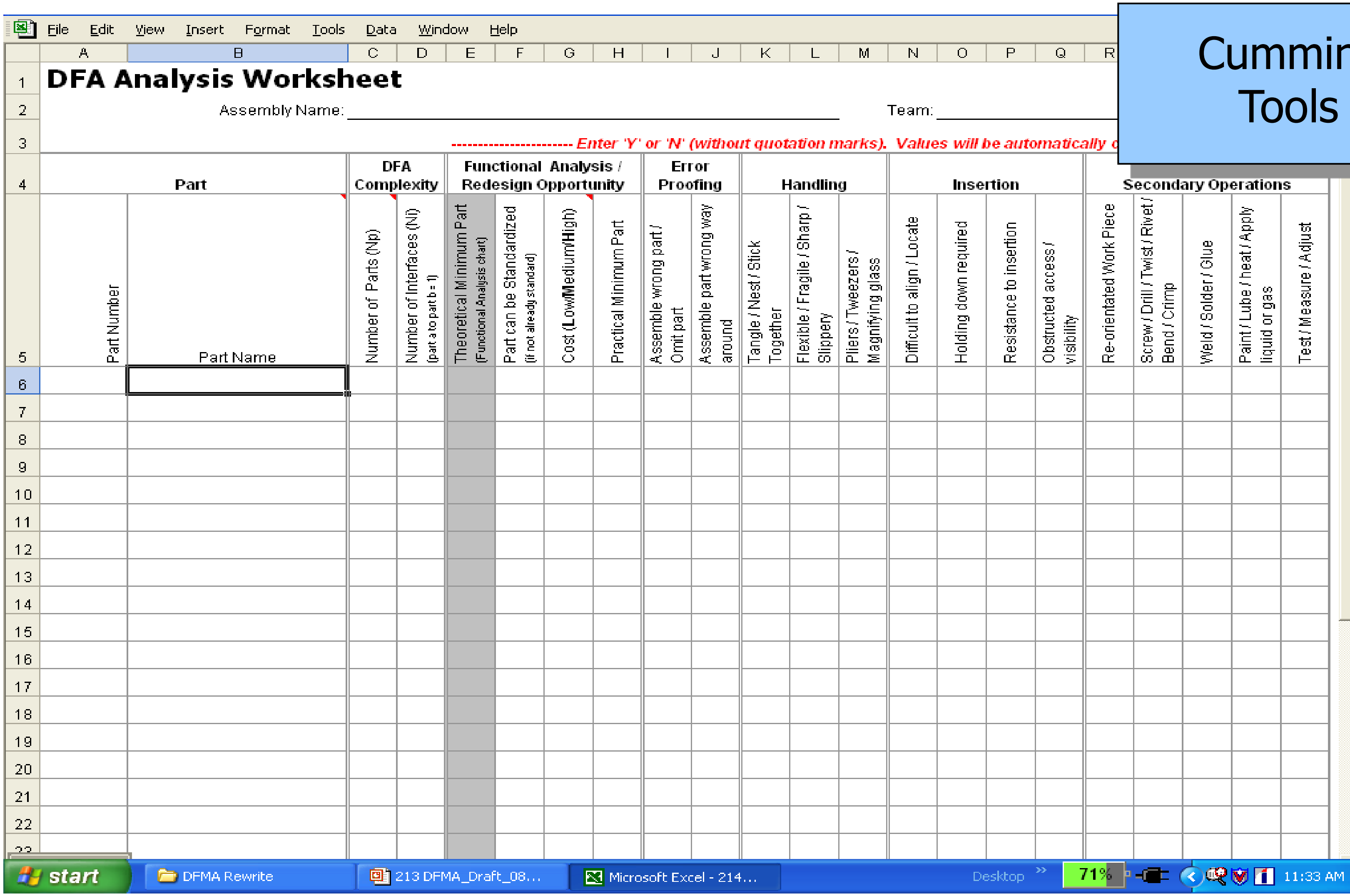
Step 5
- Identify **insertion** (locate & secure) opportunities

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

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

Benchmark when possible

DFA Analysis Worksheet



Cummins Tools

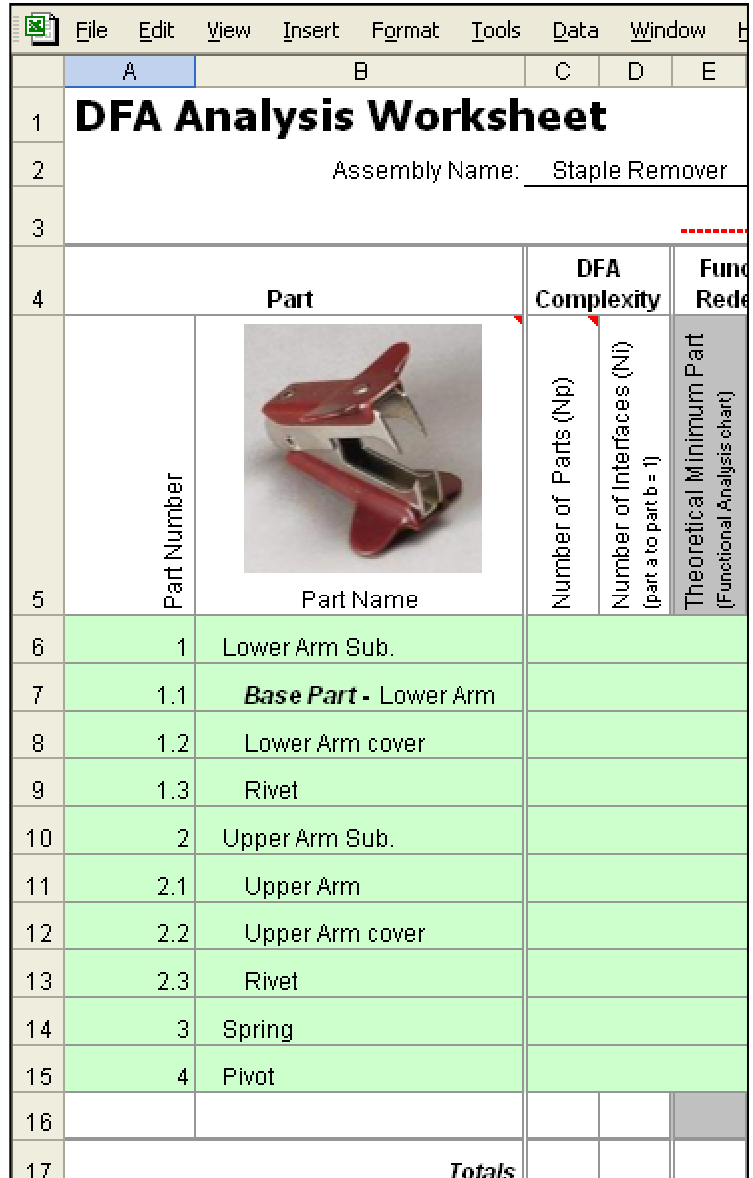
- Product Information: ***functional requirements***
- **Functional analysis**
- Identify parts that can be standardized
- Determine part count efficiencies

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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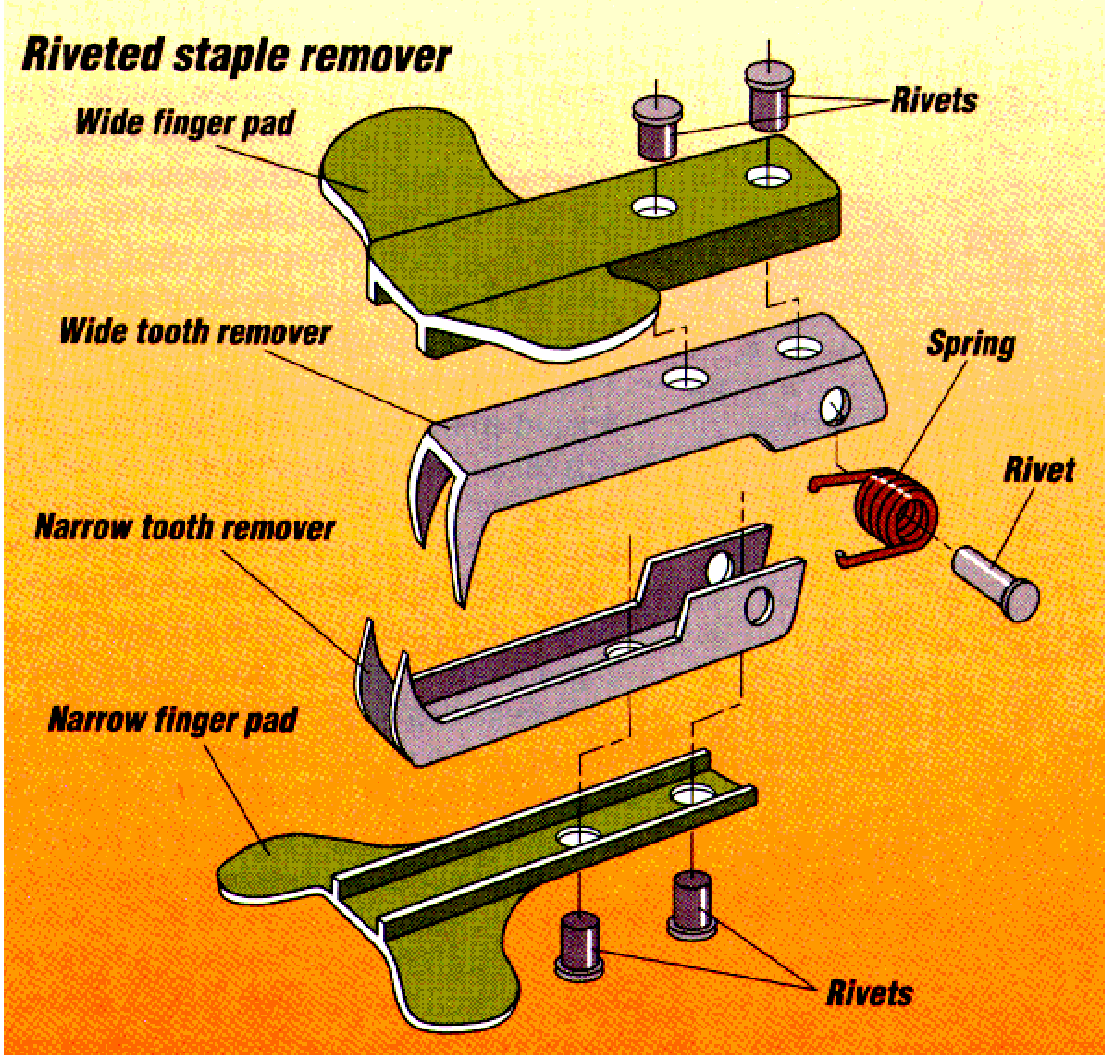
DFA Analysis Worksheet

Assembly Name: Staple Remover

Part 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)

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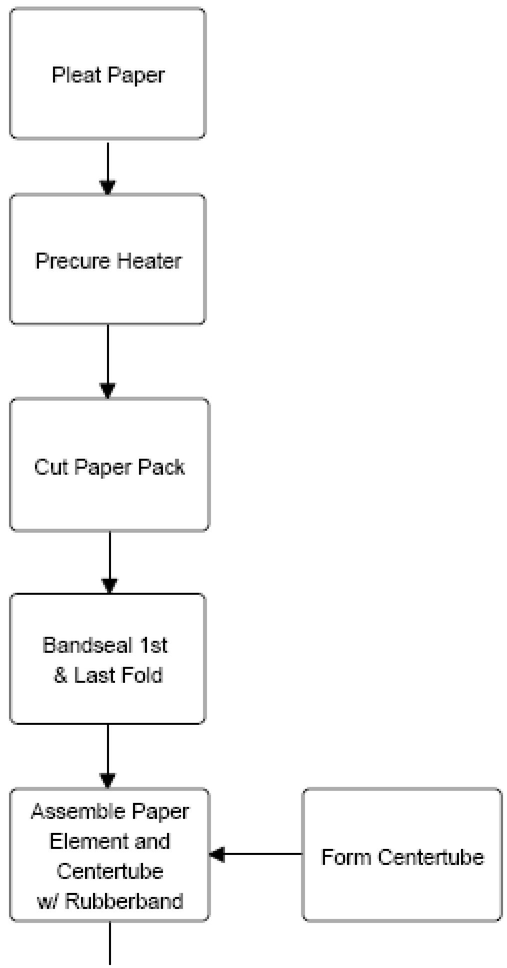
DFA Analysis Worksheet

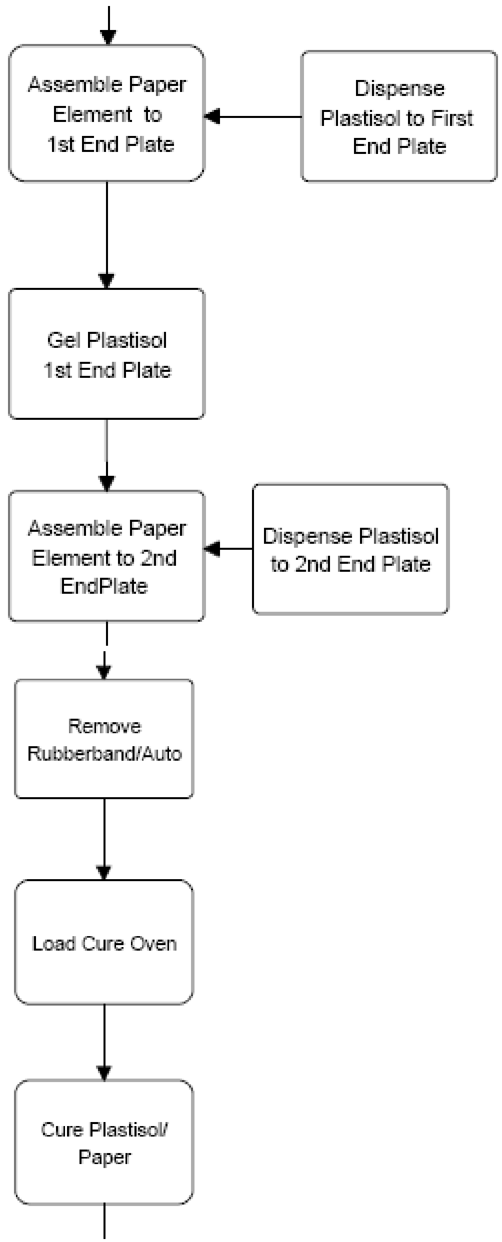
Assembly Name: Staple Remover

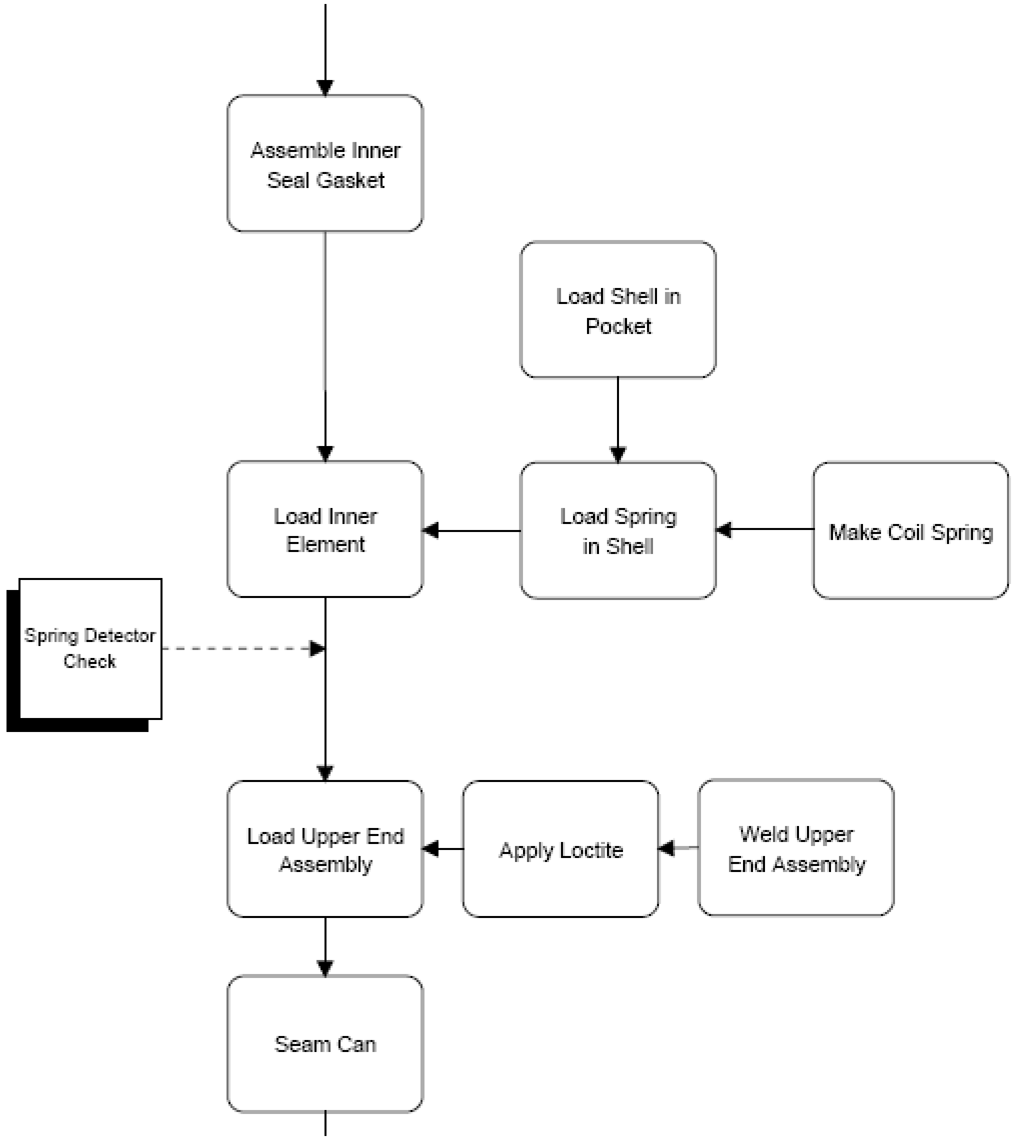
	Part		DFA Complexity		Func Rede
	Part Number	 Part Name	Number of Parts (Np)	Number of Interfaces (Ni) (part a to part b = 1)	Theoretical Minimum Part (Functional Analysis chart)
6	1	Lower Arm Sub.			
7	1.1	*Base Part* - Lower Arm	1	6	
8	1.2	Lower Arm cover	1	3	
9	1.3	Rivet	2	4	
10	2	Upper Arm Sub.			
11	2.1	Upper Arm	1	6	
12	2.2	Upper Arm cover	1	3	
13	2.3	Rivet	2	4	
14	3	Spring	1	3	
15	4	Pivot	1	3	
16					
17		*Totals*	10	32	

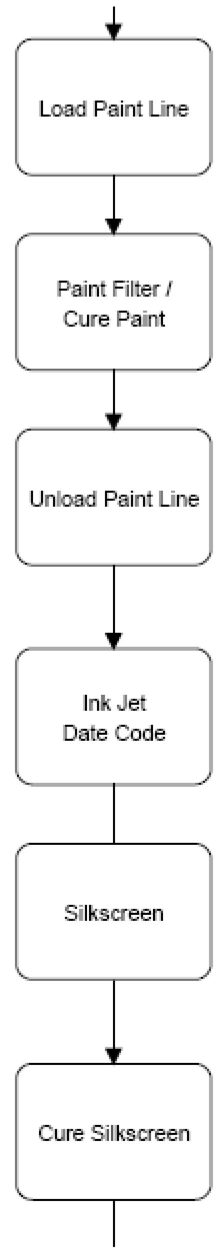
I1: Arm to rivet
I2: Arm to rivet
I3: Arm to cover
I4: Arm to pivot
I5: Arm to spring
I6: Arm to Arm

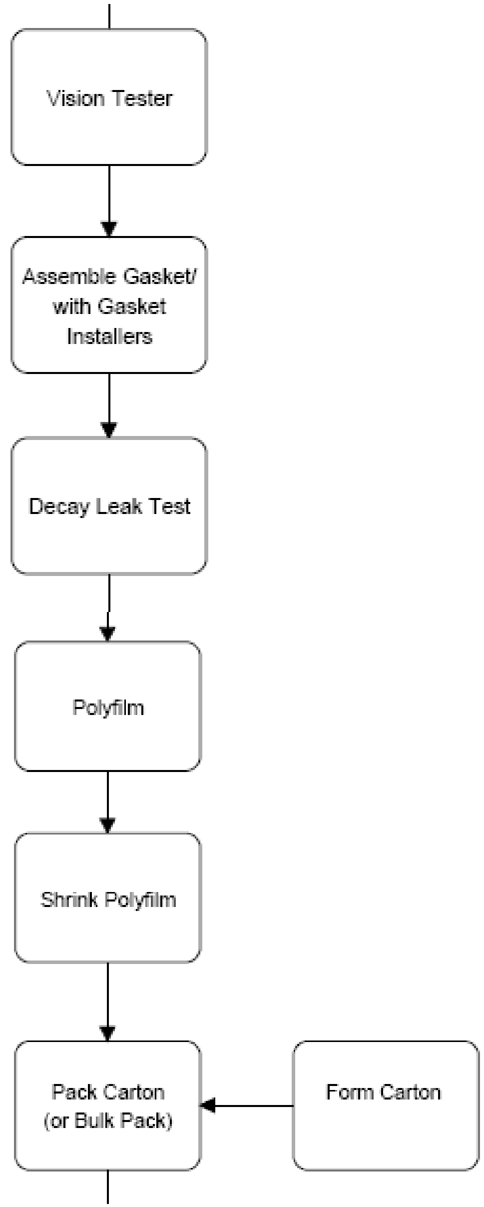
Dept. 1310 Process Flow Diagram

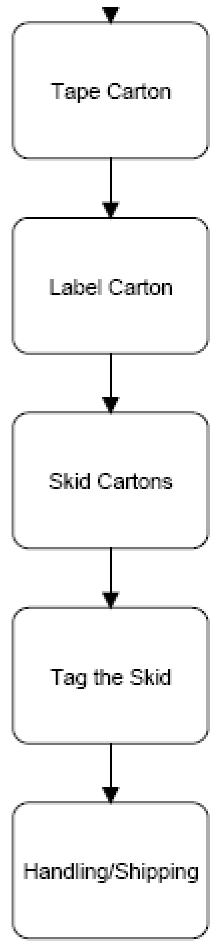



Assemble Paper Element to 1st End Plate
Dispense Plastisol to First End Plate
Gel Plastisol 1st End Plate
Assemble Paper Element to 2nd EndPlate
Dispense Plastisol to 2nd End Plate
Remove Rubberband/Auto
Load Cure Oven
Cure Plastisol/ Paper


Assemble Inner Seal Gasket
Load Shell in Pocket
Load Inner Element
Load Spring in Shell
Make Coil Spring
Spring Detector Check
Load Upper End Assembly
Apply Loctite
Weld Upper End Assembly
Seam Can


Load Paint Line
Paint Filter / Cure Paint
Unload Paint Line
Ink Jet Date Code
Silkscreen
Cure Silkscreen

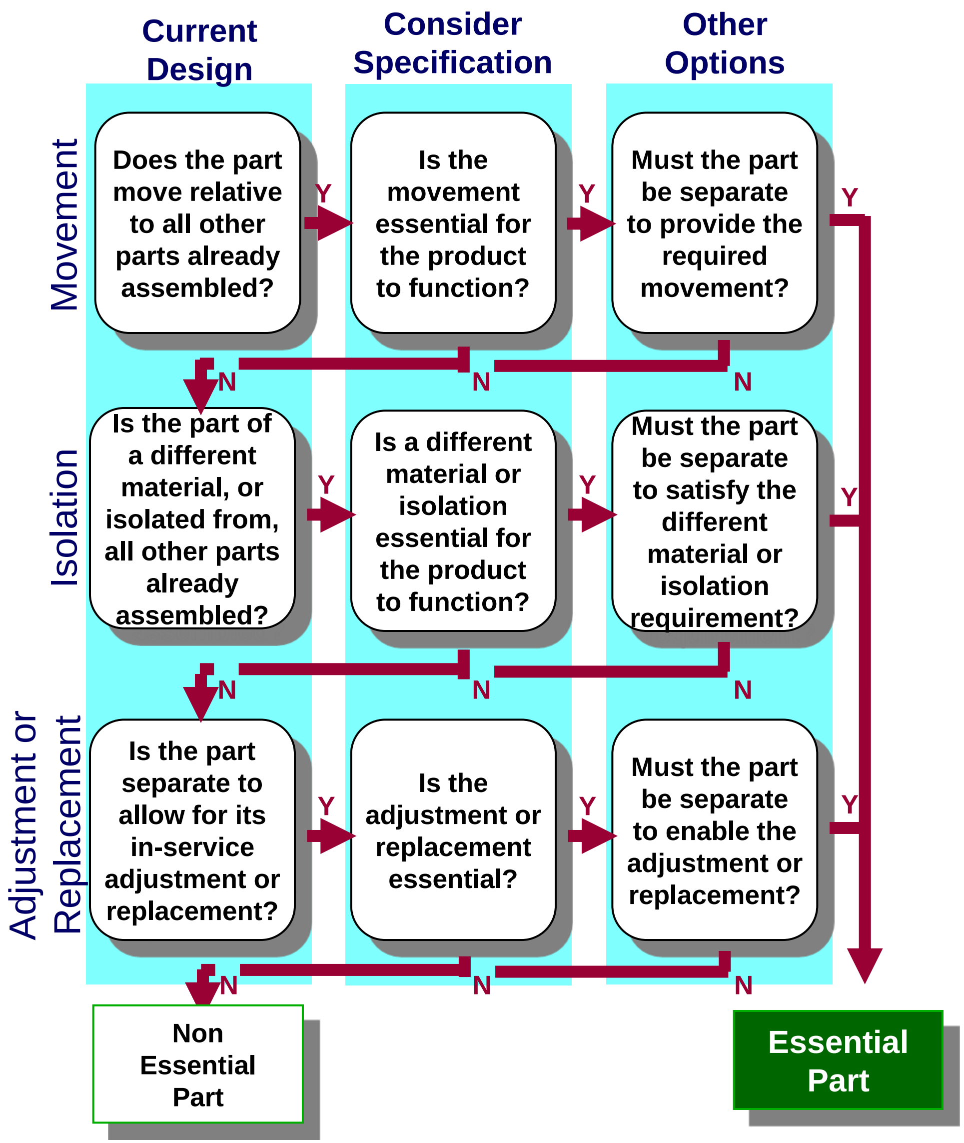

Vision Tester
Assemble Gasket/
with Gasket
Installers
Decay Leak Test
Polyfilm
Shrink Polyfilm
Pack Carton
(or Bulk Pack)
Form Carton


Tape Carton
Label Carton
Skid Cartons
Tag the Skid
Handling/Shipping

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

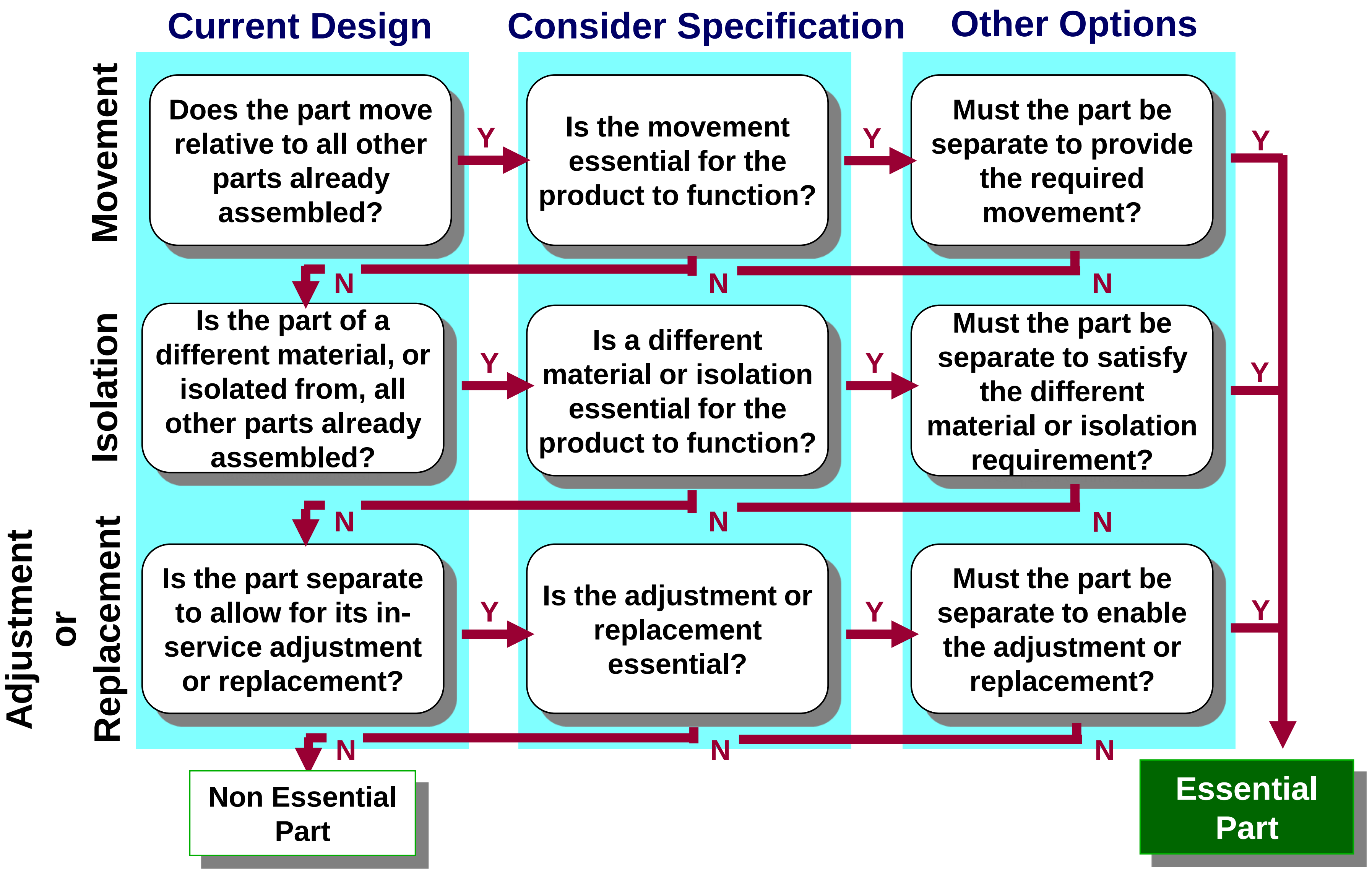


DFA Analysis Worksheet

Assembly Name: Staple Remover

	A	B	C	D	E
4		Part	DFA Complexity		Func Rede
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)
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

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…)

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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 O: Theoretical Minimum Part (Functional Analysis chart)	Functional Redesign O: 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. I
	Targets	0.00		>60%	0

Theoretical Part Count Efficiency

Theoretical Part Count Efficiency =

$$\frac{\textbf{Theoretical Min. No. Parts}}{\textbf{Total Number of Parts}} * 100$$

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

Theoretical Part Count Efficiency **= 10%**

Rule of Thumb – Part Count Efficiency Goal > 60%

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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	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
	Design for Assembly Metrics	17.89		10%
	Targets	0.00		>60%

DFA Complexity Factor – Definition

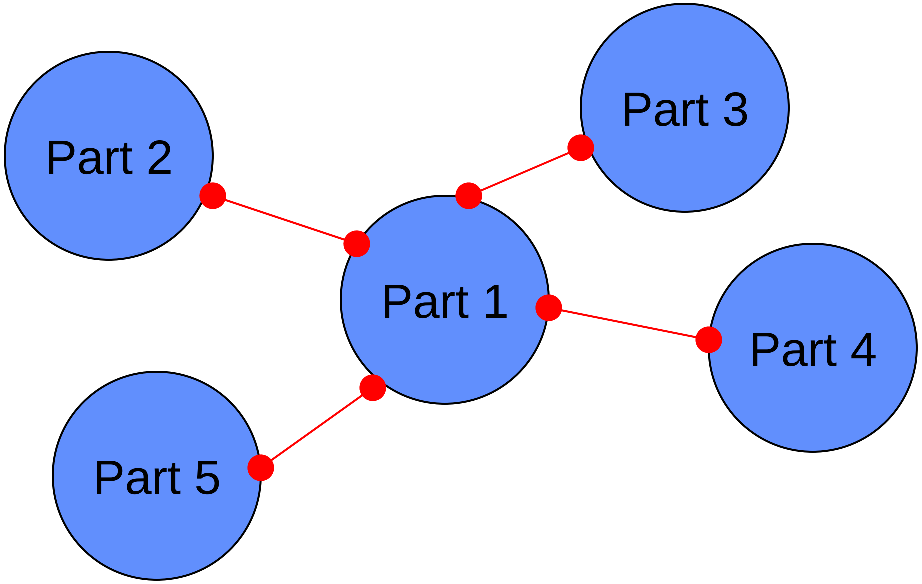
- Cummins Inc. metric for assessing complexity of a product design
- Two Factors
  - Np – Number of parts
  - Ni – Number of part-to-part interfaces

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

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

  – 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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DFA Analysis Worksheet

Assembly Name: Staple Remover

	A	B	C	D	E	F	G
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 (Low/Medium/High)
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%

Step Two

- Determine Practical Minimum Part Count

Determine Practical Minimum Part Count

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

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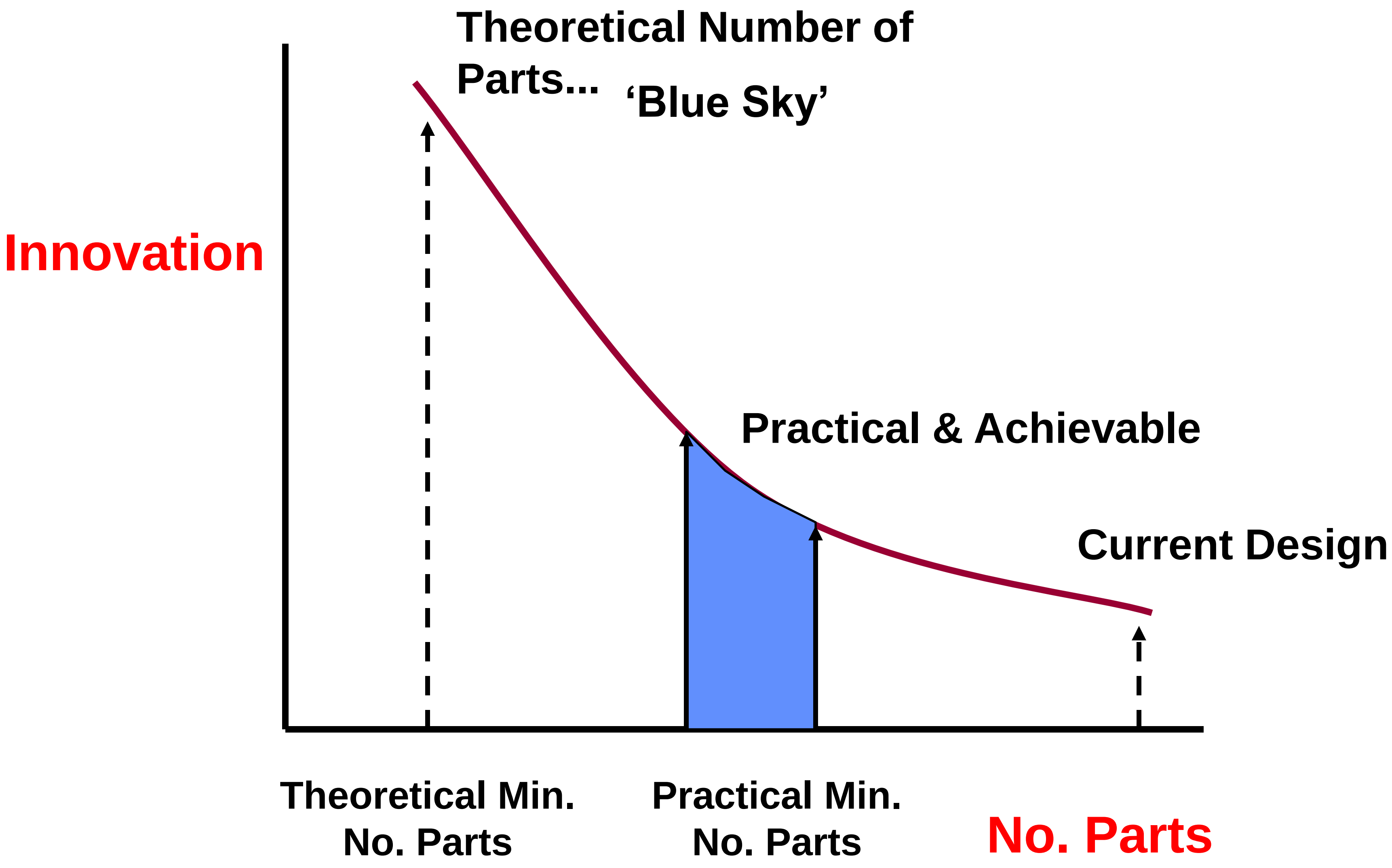
DFA Analysis Worksheet

Assembly Name: Staple Remover

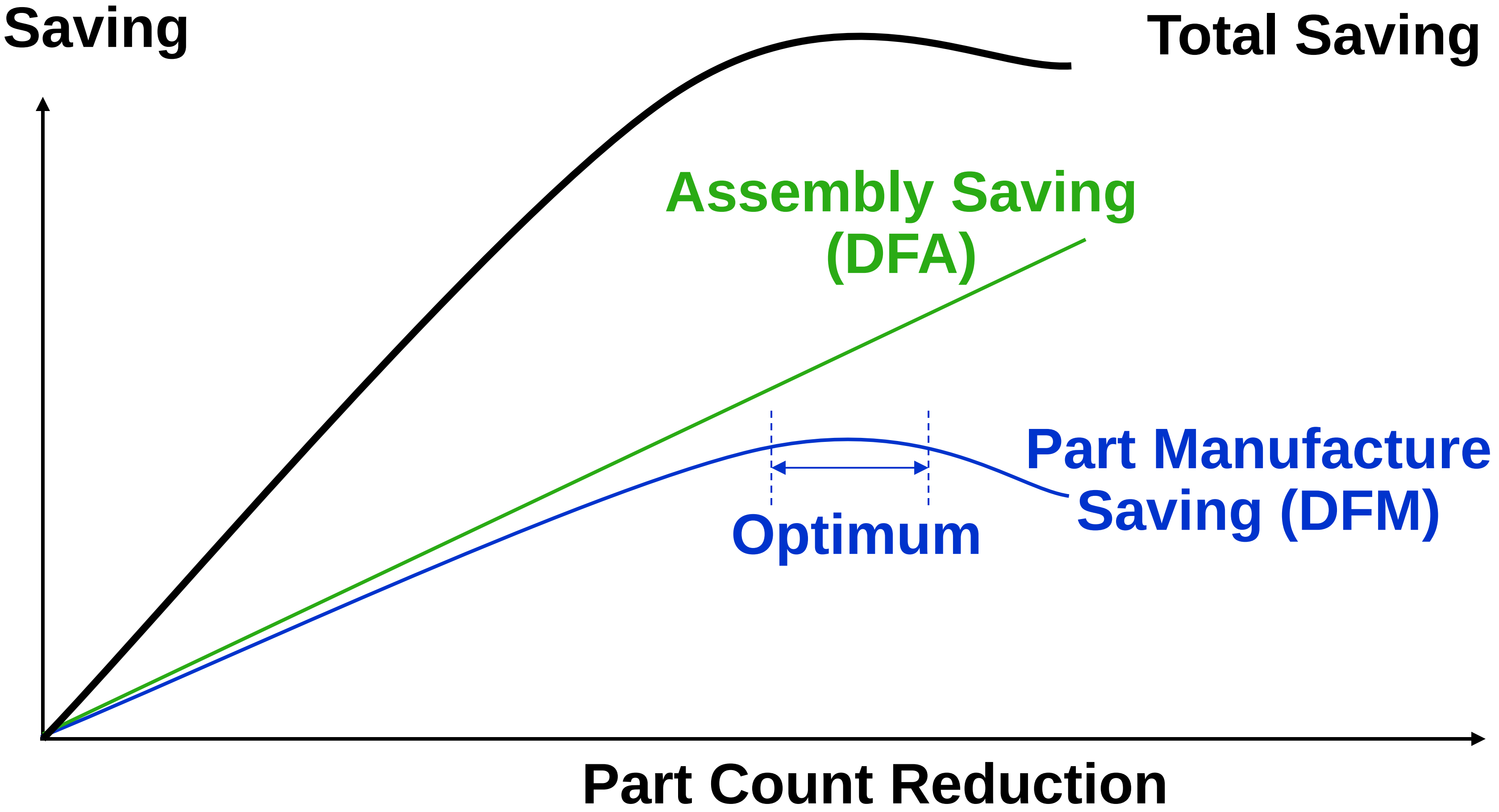
Enter 'Y'

	Part		DFA Complexity		Functional Analysis / Redesign Opportunity			
	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 (Low/Medium/High)	Practical Minimum Part
6	1	Lower Arm Sub.						
7	1.1	***Base Part*** **-** Lower Arm	1	6	Y	N	L	Y
8	1.2	Lower Arm cover	1	3	N	Y	L	N
9	1.3	Rivet	2	4	N	N	L	N
10	2	Upper Arm Sub.						
11	2.1	Upper Arm	1	6	N	N	L	Y
12	2.2	Upper Arm cover	1	3	N	Y	L	N
13	2.3	Rivet	2	4	N	N	L	N
14	3	Spring	1	3	N	N	L	Y
15	4	Pivot	1	3	N	N	L	Y
16								
17		***Totals***	10	32	1	2		4

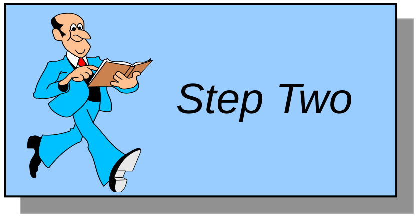
Creativity & Innovation

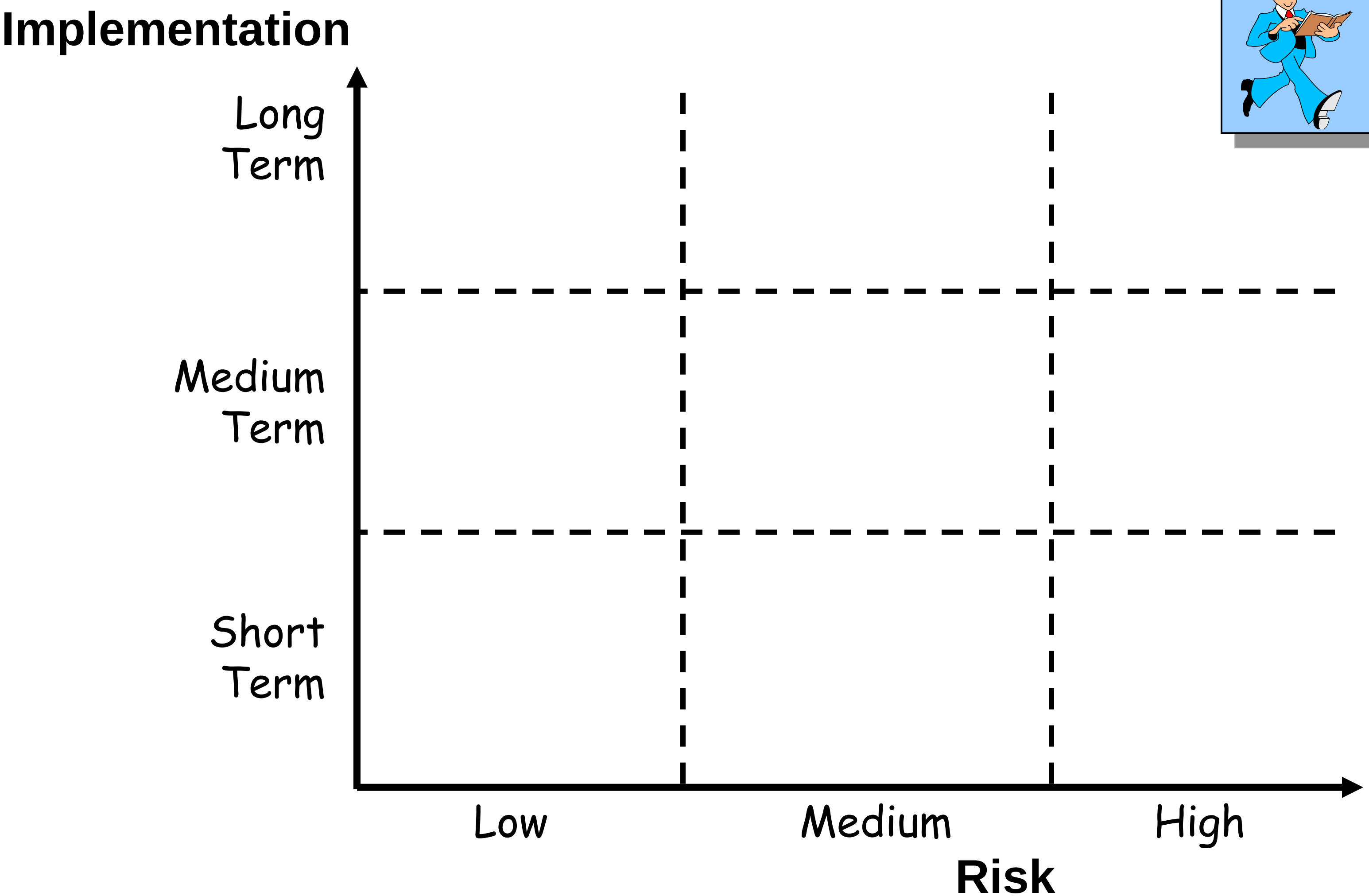


Cost of Assembly Vs Cost of Part Manufacture



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!

Your Turn...

Instructions

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

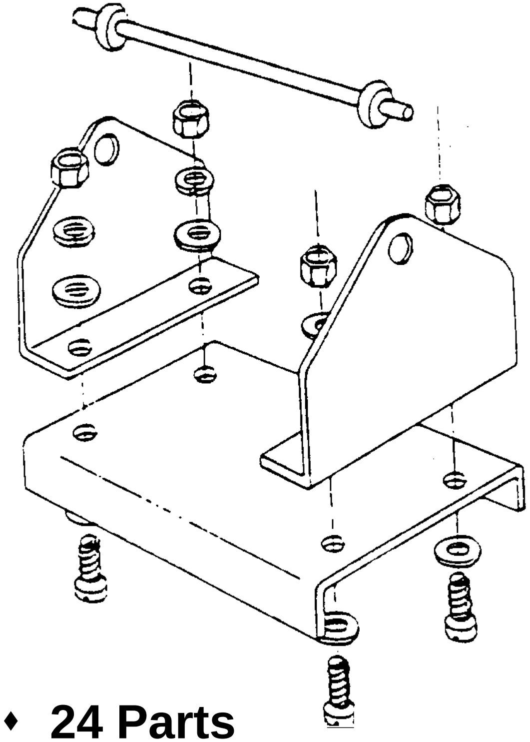
Fasteners

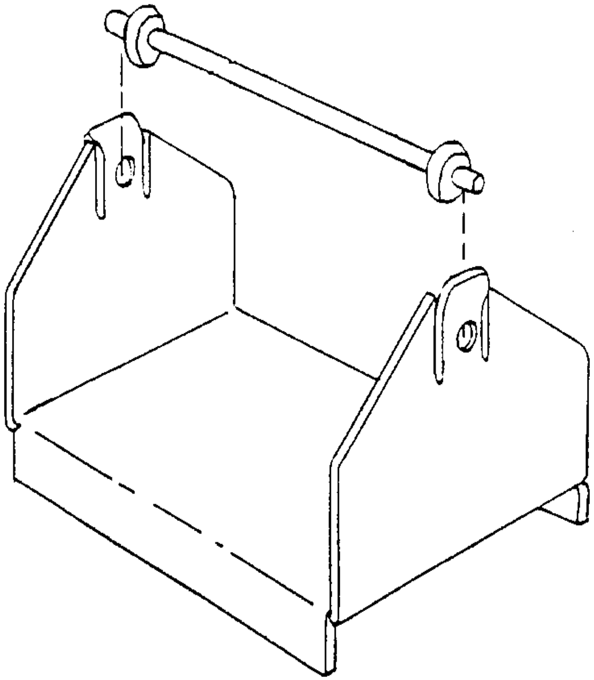
- A study by Ford Motor Co. revealed that threaded fasteners were the most common cause of warranty repairs

- 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.'

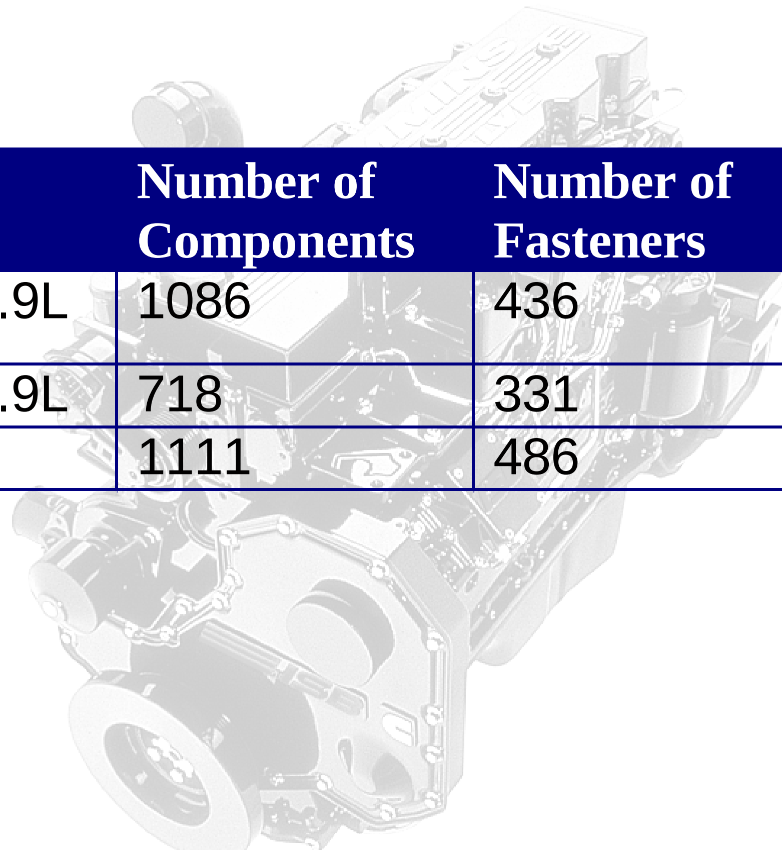




- 24 Parts
- 8 different parts
- multiple mfg. & assembly processes necessary

- 2 Parts
- 2 Manufacturing processes
- one assembly step

Fasteners: Cummins Engines



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

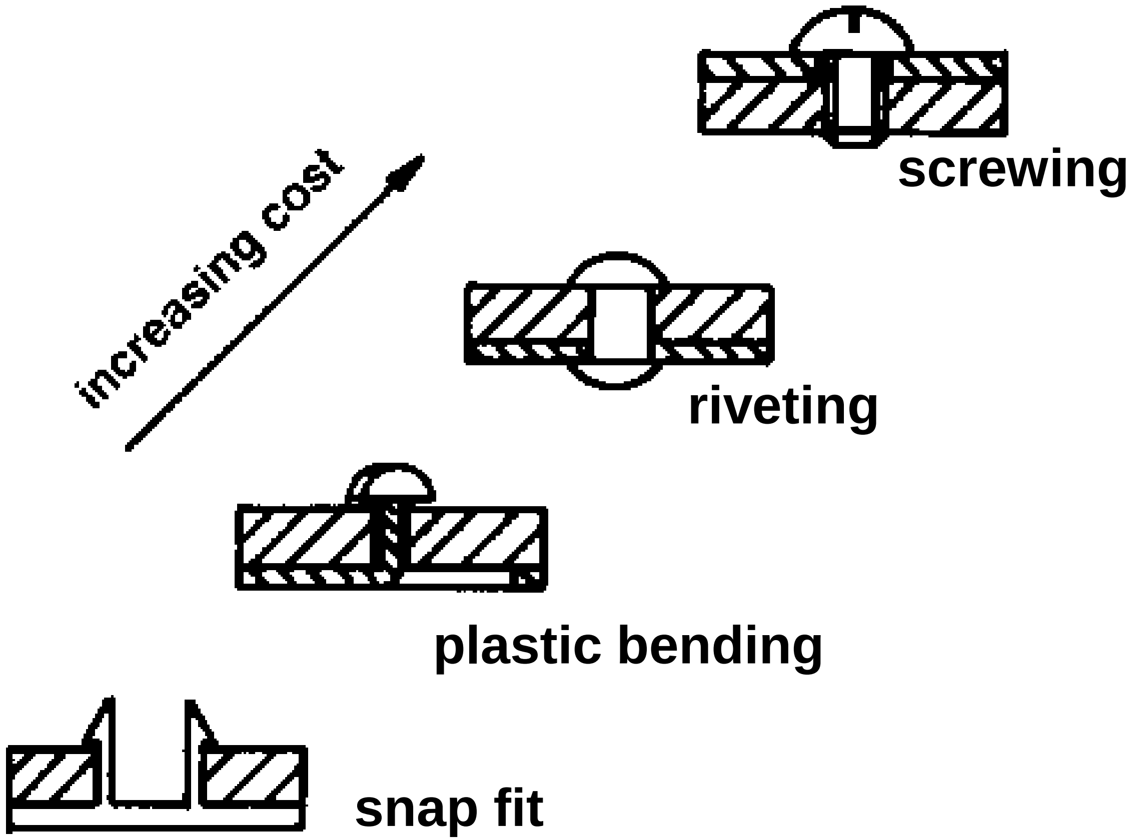
- Minimize extra sizes to both reduce inventory and eliminate confusion during assembly

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

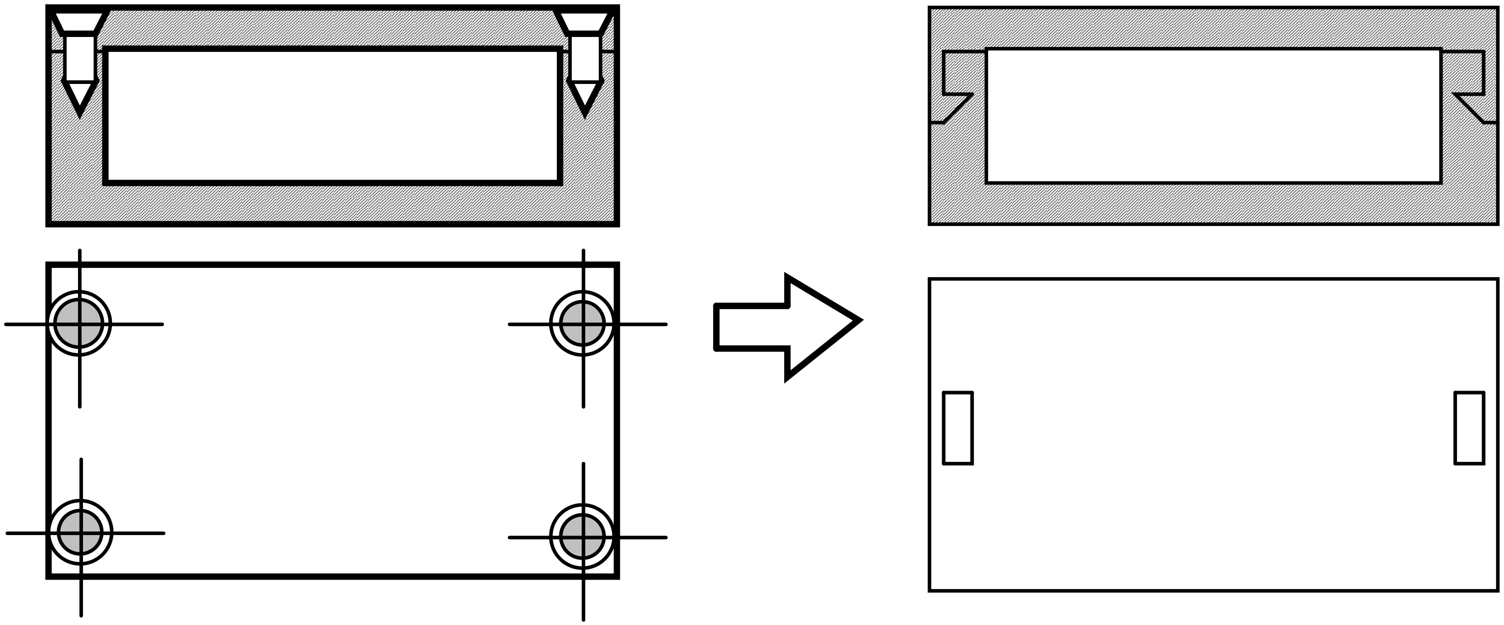
Fastener Cost

- Select the most inexpensive fastening method required



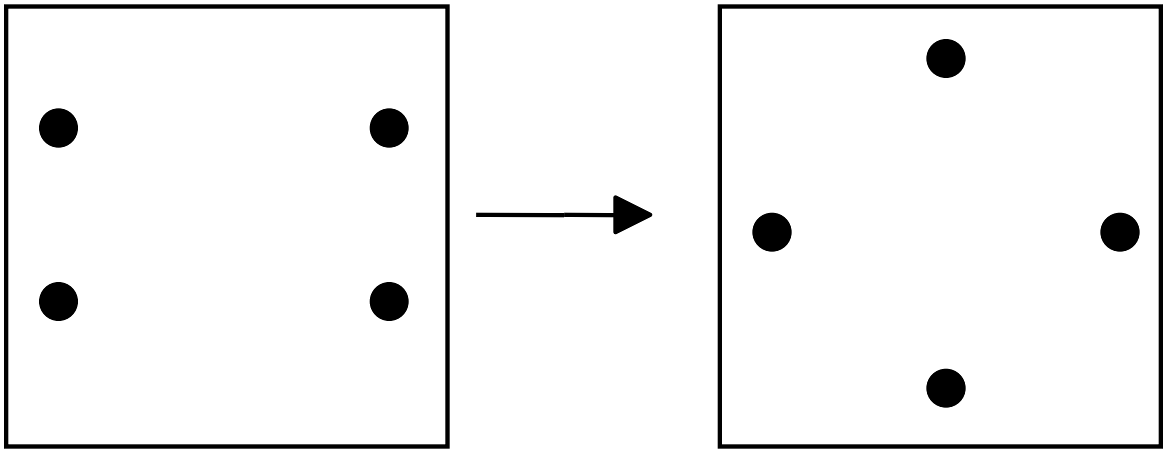
General Design Principles

Self-fastening features



General Design Principles

Symmetry eliminates reorientation

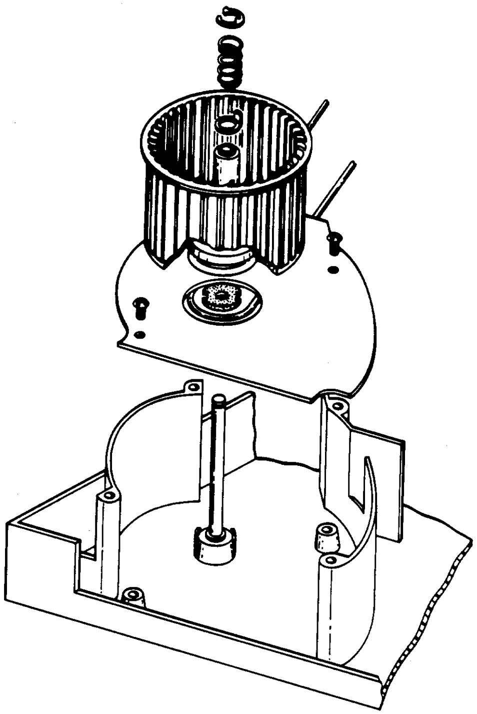


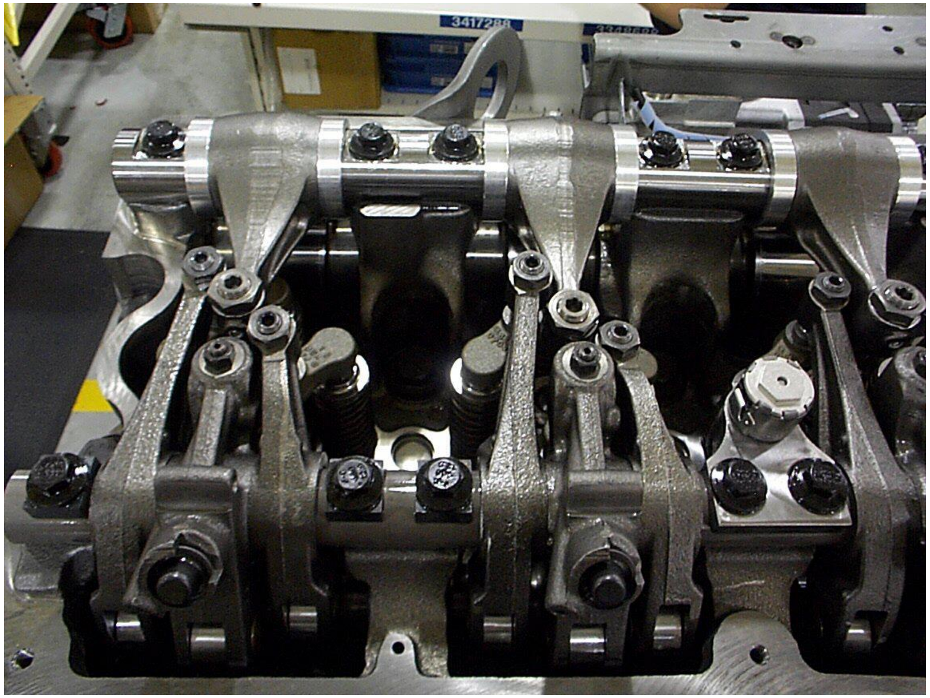
Asymmetric Part

Symmetry of a part makes assembly easier

General Design Principles

Top-Down Assembly

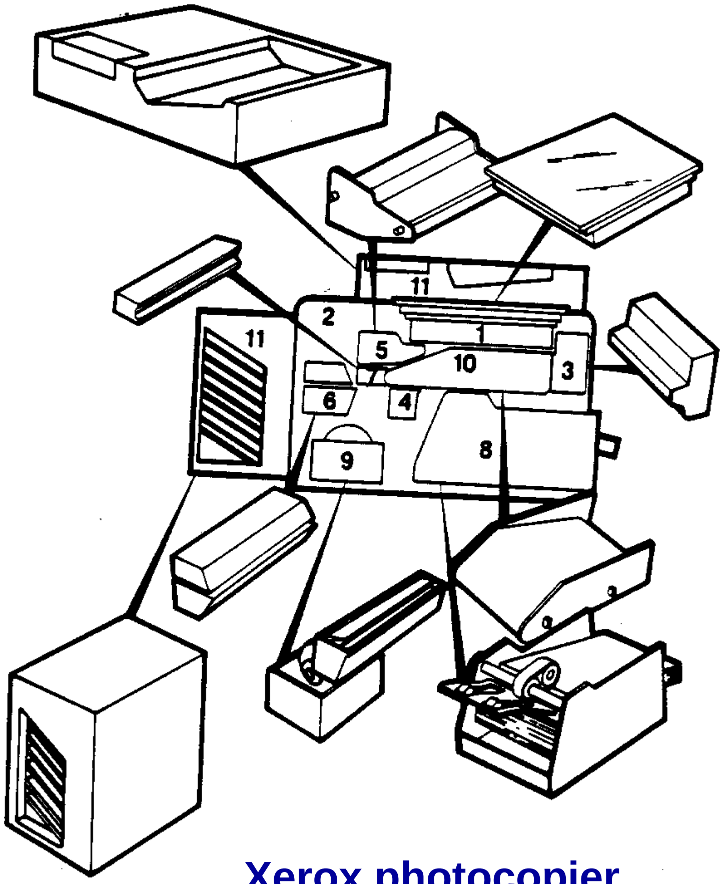




General Design Principles

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

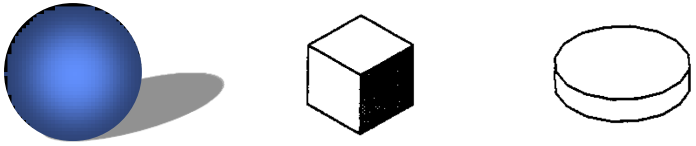
Eliminated Parts are NEVER...

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

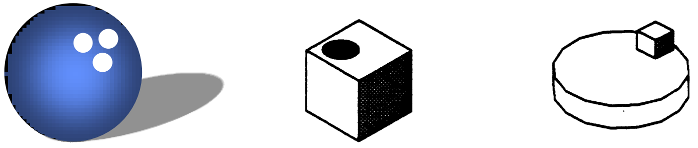
- Identify **quality** (mistake proofing) opportunities

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

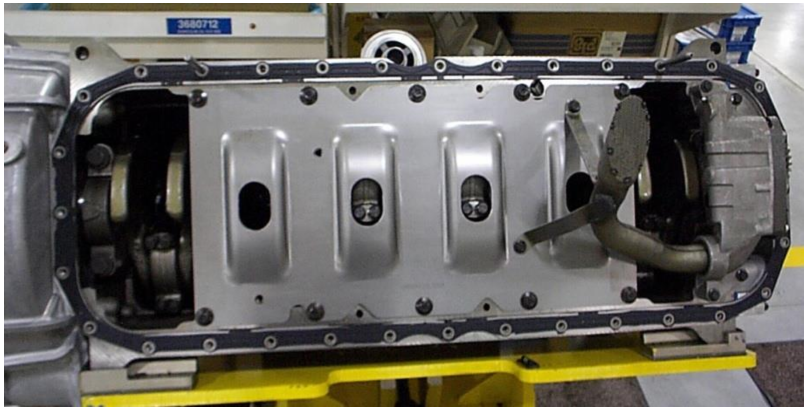
CDC - Rocky Mount, NC

Step Four

- Identify handling (grasp & orientation) opportunities

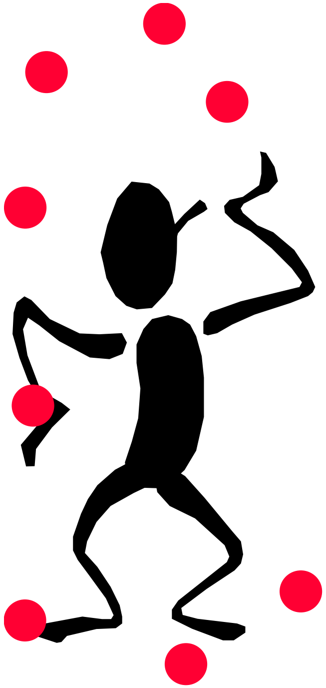
Quantitative criteria

- **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?

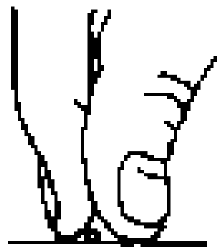


Handling Difficulty

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

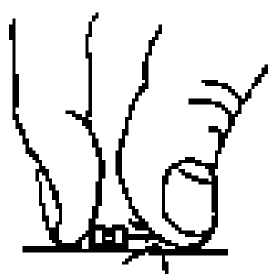


Handling Difficulty

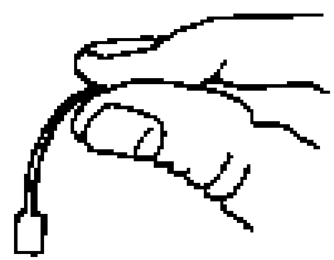


size

slipperiness

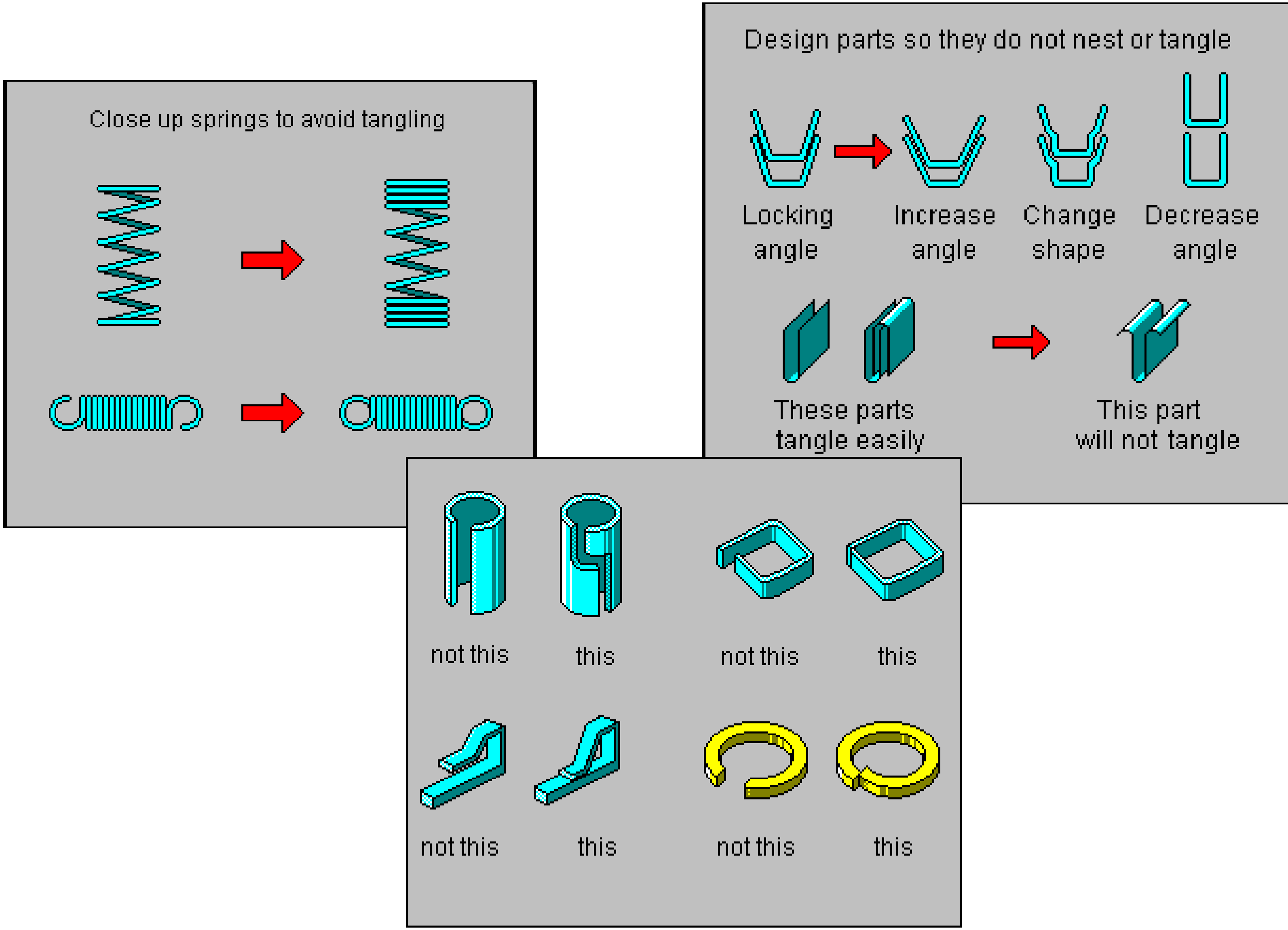


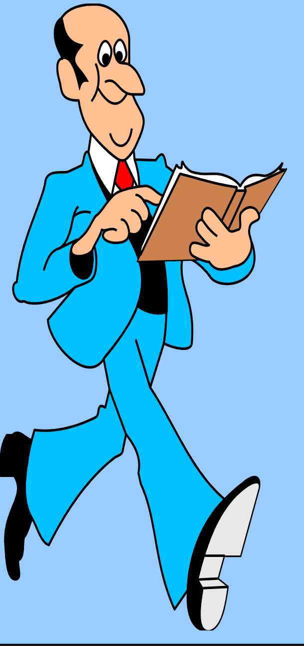
sharpness



flexibility

Eliminate Tangling/Nesting





Step Five

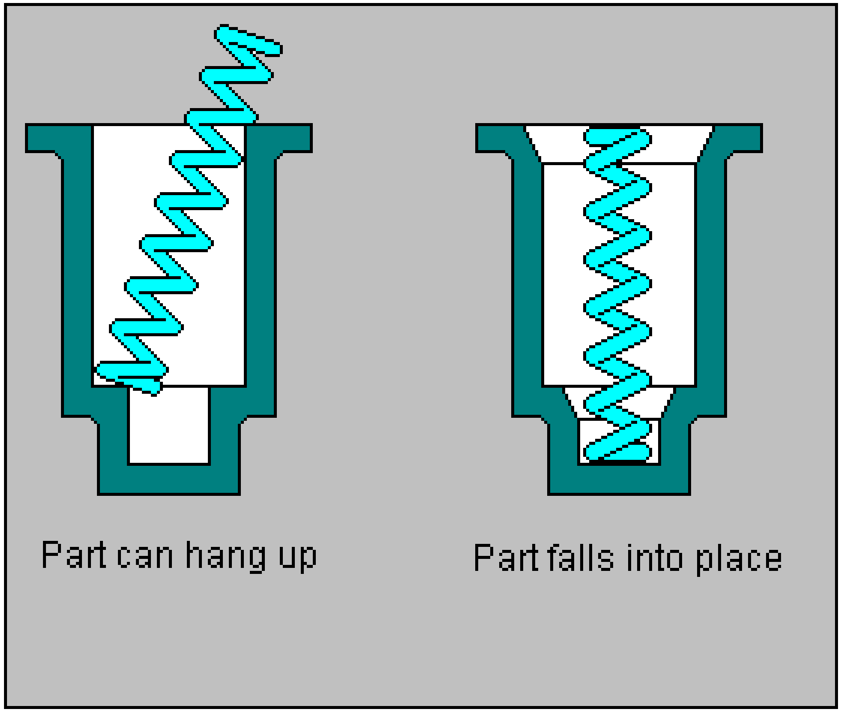
- Identify insertion (locate & secure) opportunities

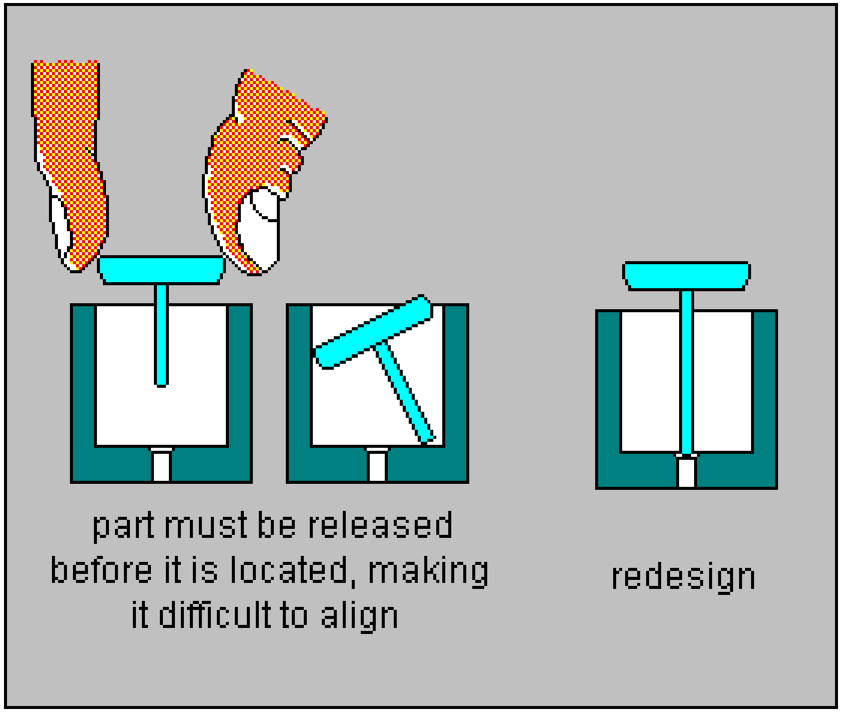
Quantitative criteria

- **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

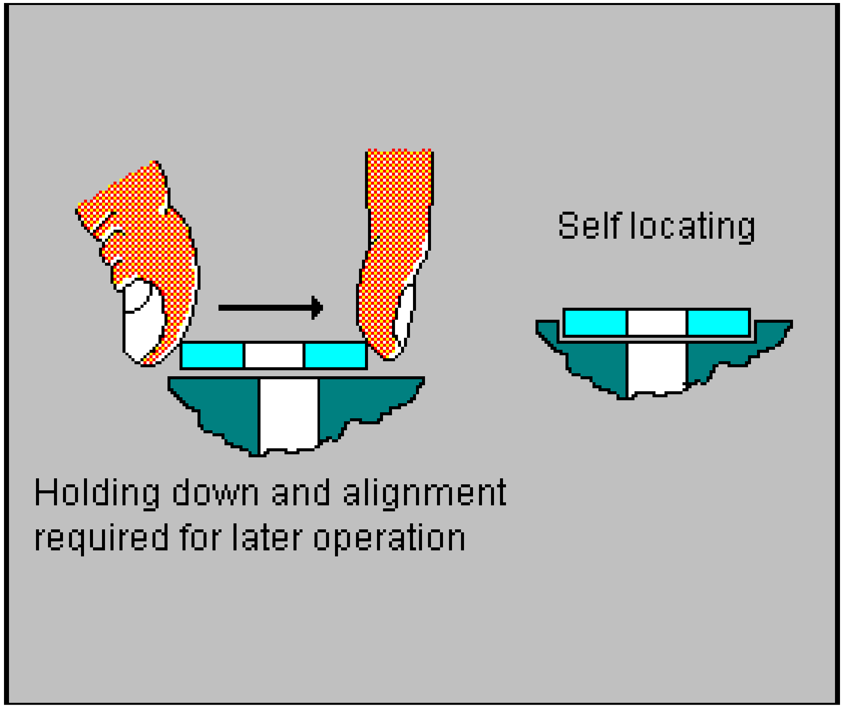
- Provide self-aligning & self locating parts

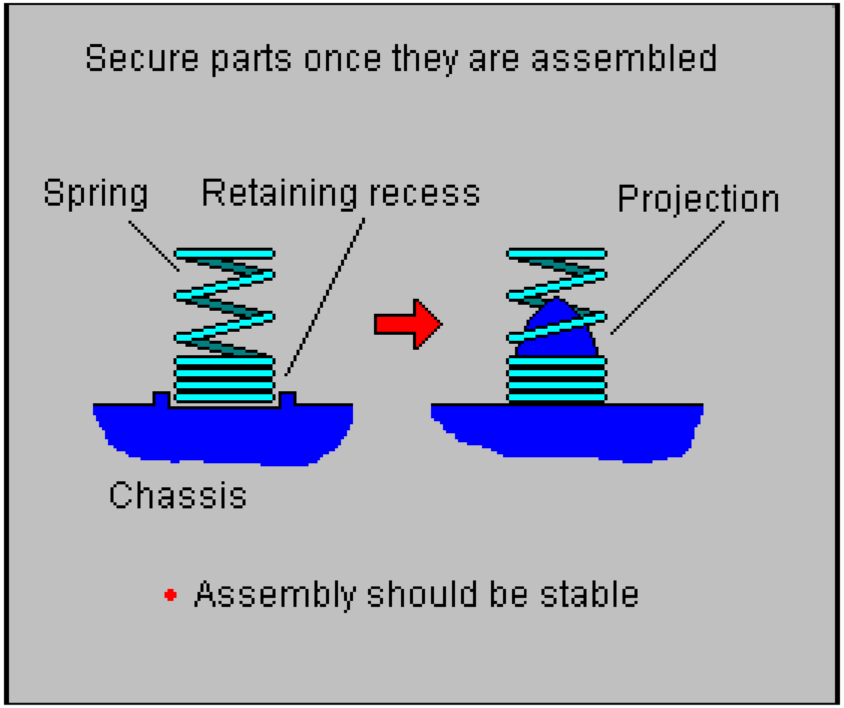




Insertion Issues

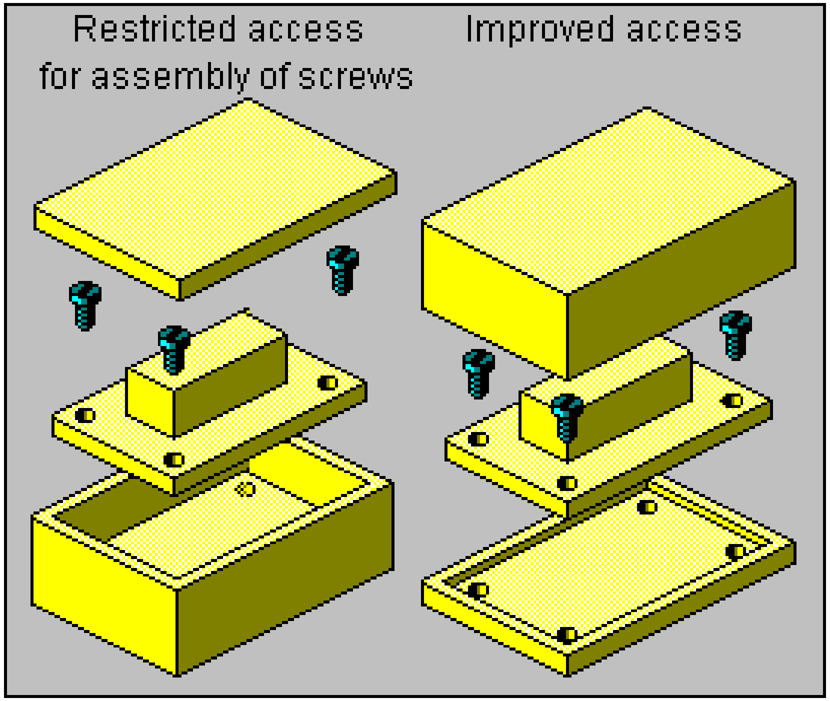
- Ensure parts do not need to be held in position





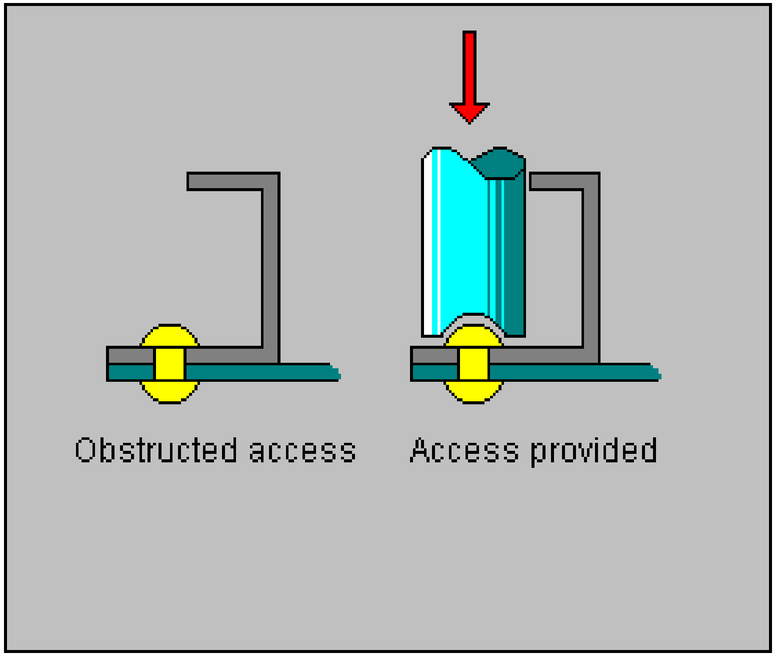
Insertion Issues

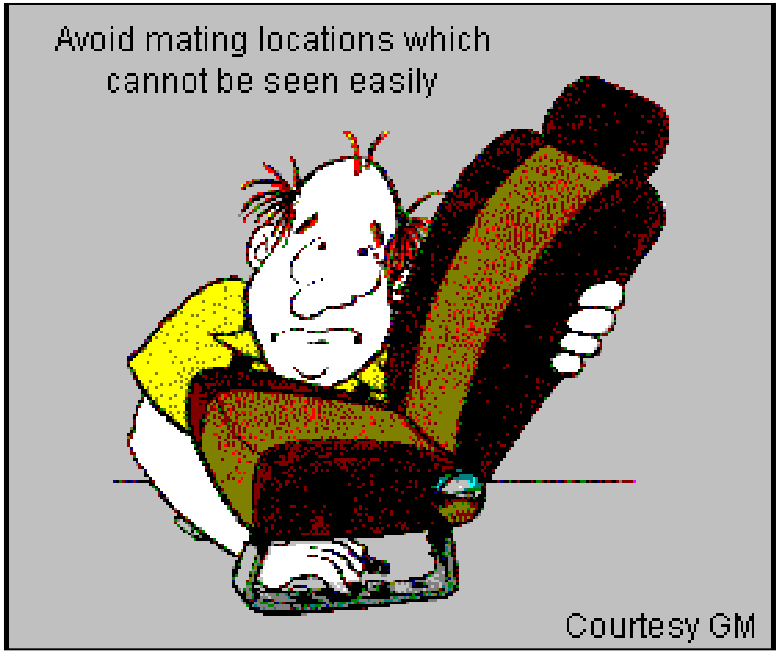
- Parts are easy to insert.
- Provide adequate access & visibility



Insertion Issues

- Provide adequate access and visibility



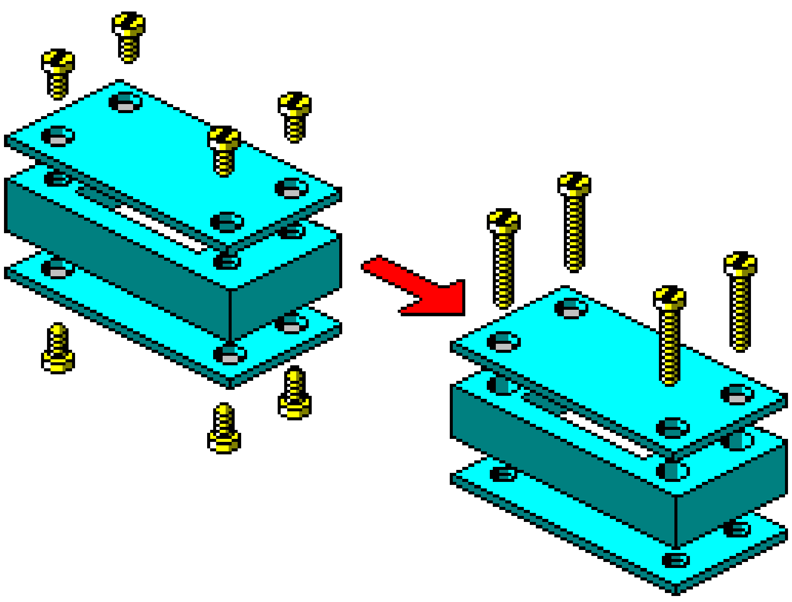


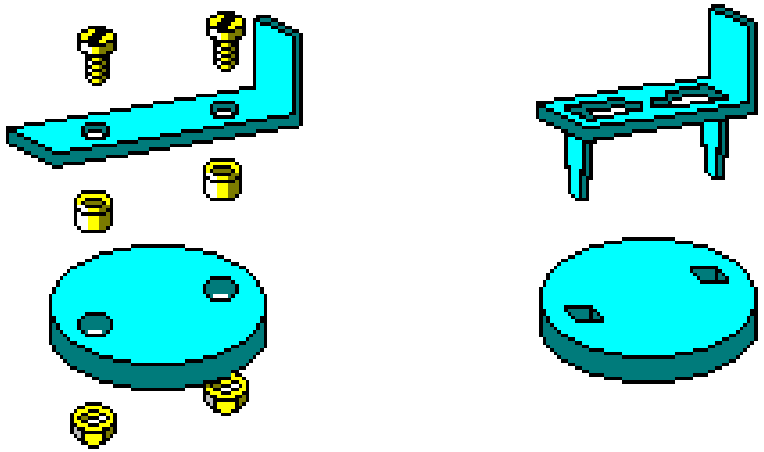
Step Six

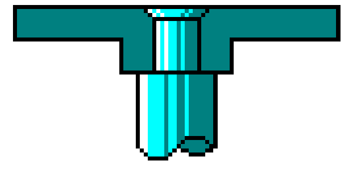
- Identify opportunities to reduce secondary operations

Eliminate Secondary Operations

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



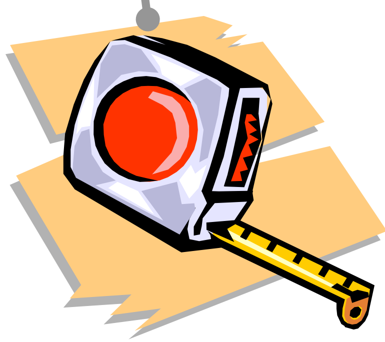


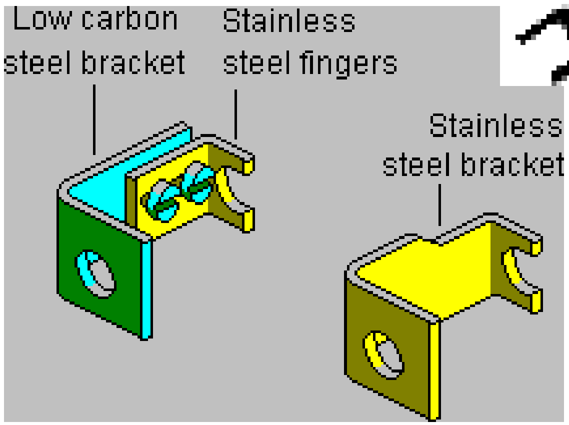


Rivet

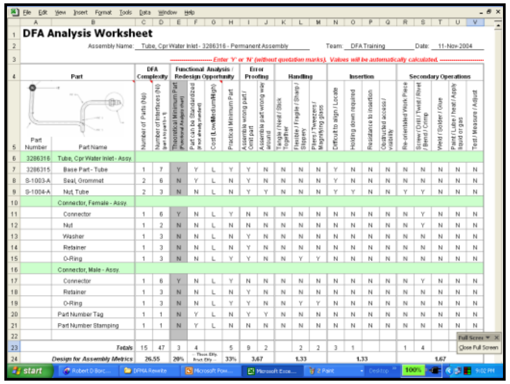
Eliminate Secondary Operations

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





Assembly Metrics



Error Proofing = Sum all Y's in Error Columns / Theoretical Min. No. Parts

Handling Index = Sum all Y's in Handling Columns / Theoretical Min. No. Parts

Insertion Index = Sum all Y's in Insertion Columns / Theoretical Min. No. Parts

2nd Op. Index = Sum all Y's in 2nd Op. Columns / 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

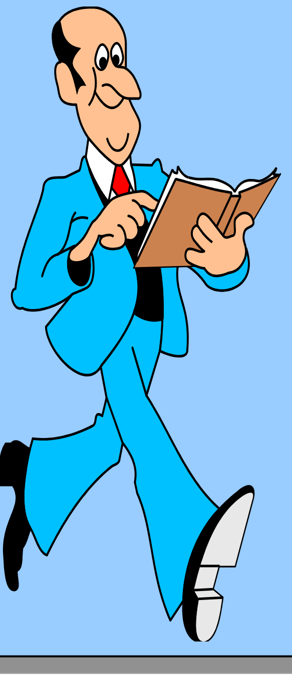
Set Target Values for These Measures

Your Turn...

Steps
Two - Six

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:

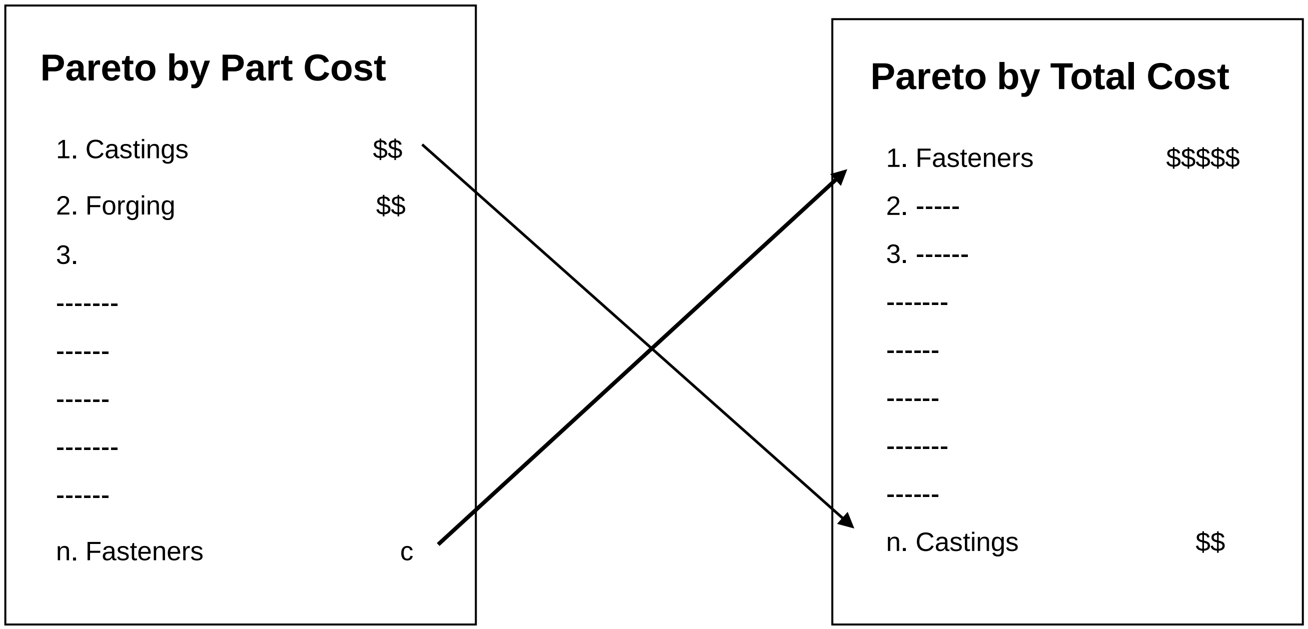
- Reduce part count & types
- Ensure parts cannot be installed incorrectly
- Strive to eliminate adjustments
- Ensure parts self-align & self-locate
- Ensure adequate access & unrestricted vision
- Ensure parts are easily handled from bulk
- Minimize reorientation (assemble in Z axis) & secondary operations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

Understanding Product Costs

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

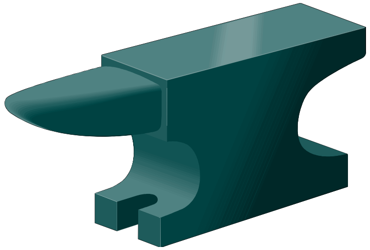
Typical Costing

Total Cost



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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