Design for Manufacturing and Assembly

QUALITY

OMNEX 30 YEARS

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Omnex provides training, consulting and software solutions to the international market with offices in the USA, Canada, Mexico, China (PRC), Germany, India, the United Arab Emirates, and Thailand. Omnex offers over 400 standard and customized training courses in business, quality, environmental, food safety, laboratory and health & safety management systems worldwide.

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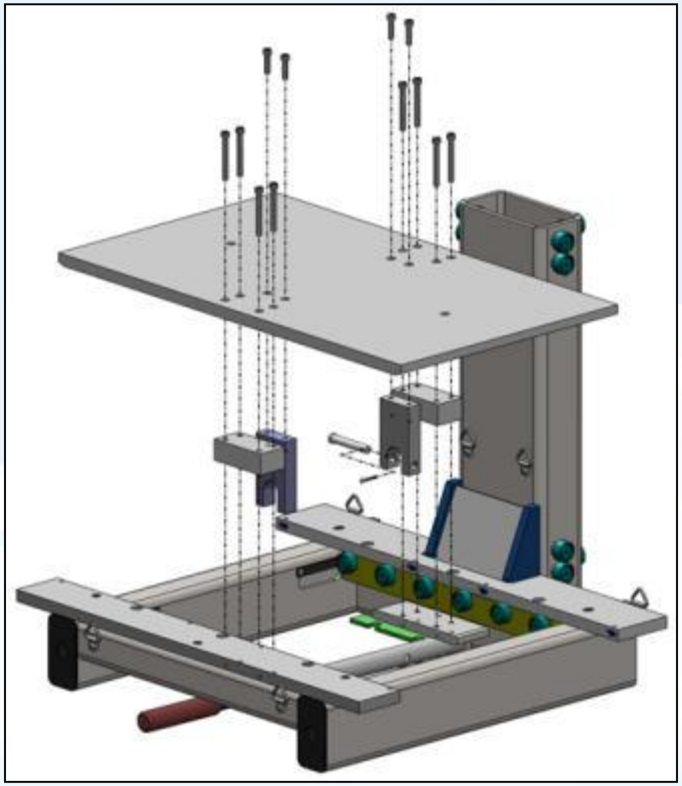
Design Philosophy

"The best design is the simplest one that works."

Albert Einstein

Welcome

To Design for Manufacturing and Assembly



Introduction of Participants

- **Name**
- **Role / Title**
- **Work Department or Location**
- **Length of Time at Company**
- **DFMA Experience**
- **Objective / Goals for Class**

Agenda

#	Topic	Time Frame
DAY 1		
1	Team Introduction & Context setting	30 Min
2	Pretest	30 Min
3	Introduction to Design for Manufacturing and Assembly: This section is focusing on aspects like why do Design for Manufacturing and Assembly (DFMA), brief outline on DFMA. Also providing a brief understanding on DFMA & differences between DFA and DFM including benefits of DFMA	60 Min + 30 Min
4	DFMA General Design Principles: This section helps in understanding how to interpret general design Principles and its related application. Also how to create and Use Design Rules to enable DFMA.	60 Min
5	Methods for Evaluating the Design for Assembly (DFA) This section is about enabling designers to analyze the design using Boothroyd-Dewhurst Technique for Minimizing number of parts. The scope of study includes use of DFA Analysis Worksheet & Evaluating design simplicity This section also includes case studies to apply the technique including a graded exercise.	90 Min + 60 Min

Agenda

#	Topic	Time Frame
DAY 1		
6	Design for Assembly Rules This section covers the 11 rules with examples & tools applicable to DFA which includes: • Minimizing Parts • Reducing Number of Operations • Precedence Diagrams • Allowing Failure Recovery • Ensure Product Standardization • Making Alignment Easy • Make Insertion Easy • Allow one direction of insertion • Allow Easy Stacking • Orienting Features • Fastener Design Rules Graded Exercises with presentations	60 Min + 60 Min

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Agenda

#	Topic	Time Frame
DAY 2		
7	Day 1 recap	30 Min
8	Optimizing Design for Assembly Method This section enables evaluation of Design using Hitachi Assembly Evaluation Methodology (AEM) & Lucas DFA Method. This section also extends the design efficiency and elaborates Boothroyd-Dewhurst DFA Method for selection of methods from Manual Assembly, High Speed automated assembly & Robotic Assembly. Graded Exercise’s with presentation	120 Min + 60 Min
9	Optimizing the Design for Production Readiness This section explores the steps involved which includes Selecting Manufacturing Process, Improving Design for Manufacturability & Analyze Cost.	60 Min + 30 Min

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Agenda

#	Topic	Time Frame
DAY 2		
10	Design Guidelines for DFM This section covers the application of DFM using design guidelines for following processes: Welding Coating & Plating Sheet Metal Forming Casting Machining This also includes additional selection criteria like Mistake proofing & Eliminating secondary operations.	60 Min + 60 Min
Day 3		
11	Day 1 & 2 Recap	30 Min
12	New product development Methodology This section describes the NPD methodology using project management approach. It elaborates on focus elements of realization process and their sequencing. Brief details about five phases of APQP and its linkage with DFMA.	120 Min
13	Product & Process robustness This section elaborates risk assessment using FMEA, verification and validation methodologies for product and process design.	120 Min
14	Putting it all together – Final Exercise	60 Min
15	Post Test	30 Min
16	Open Session for clarification and Journey forward	60 Min

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Participation

The key to successful training is participation

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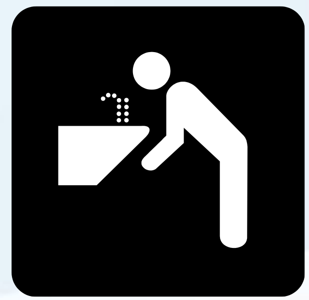
Facility Logistics

Making the most out of breaks!



Course Objectives

- **Participants will understand:**
  - Design for Manufacturing & Assembly influence on **Quality, Performance,** and **Cost**
  - **Differences** and **Similarities** between Design for Manufacturing and Design for Assembly
  - Basic Design Guidelines for **Design for Assembly**
  - Quantitative analysis of a **Design's efficiency**
  - Basic Design Guidelines for **Design for Manufacturing**
  - How to apply **DFMA** in Product Design

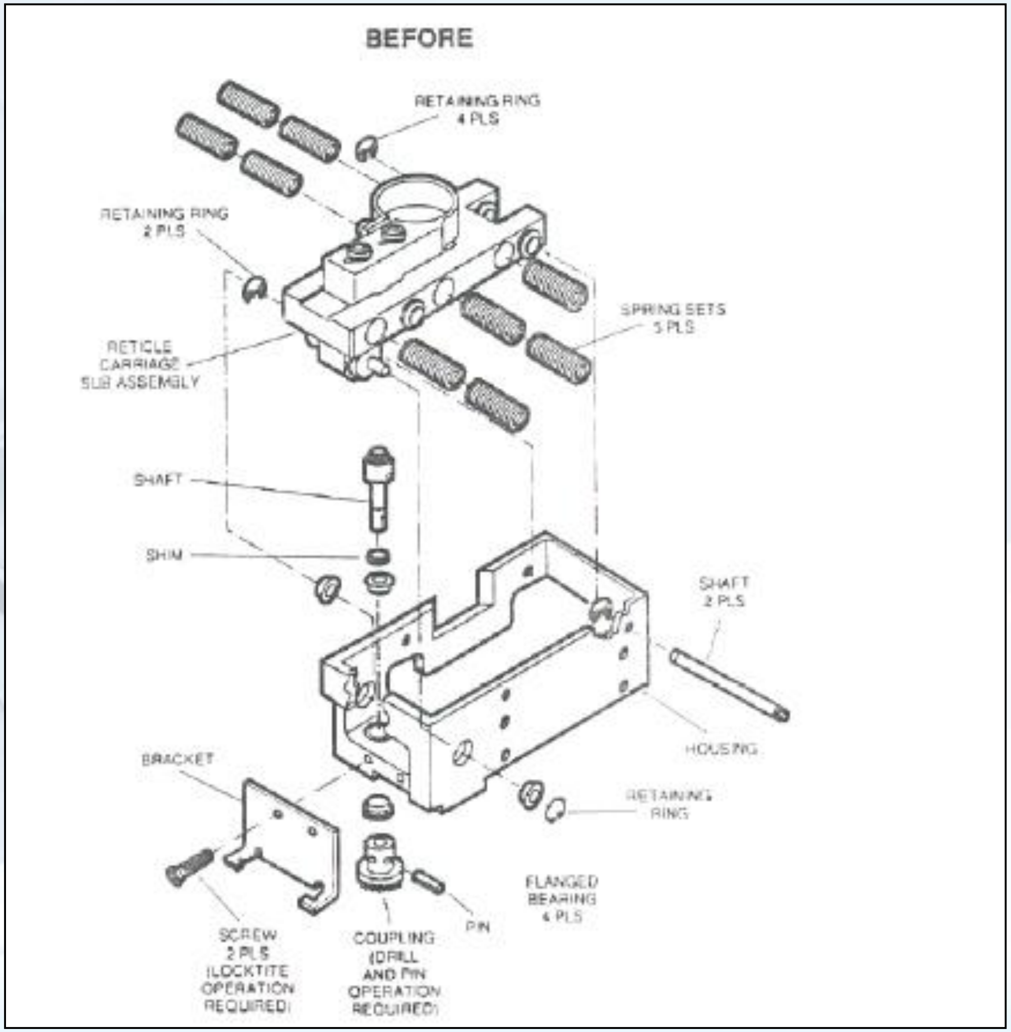
Chapter 1

Introduction to Design for Manufacturing and Assembly

Introduction to DFMA

- **Why do Design for Manufacturing and Assembly (DFMA)?**
- **What is DFMA?**
- **Understanding Design for Assembly (DFA)**
- **Understanding Design for Manufacturing (DFM)**
- **Understanding the differences between DFA and DFM**
- **Benefits of DFMA**
- **New Product Development and DFMA**

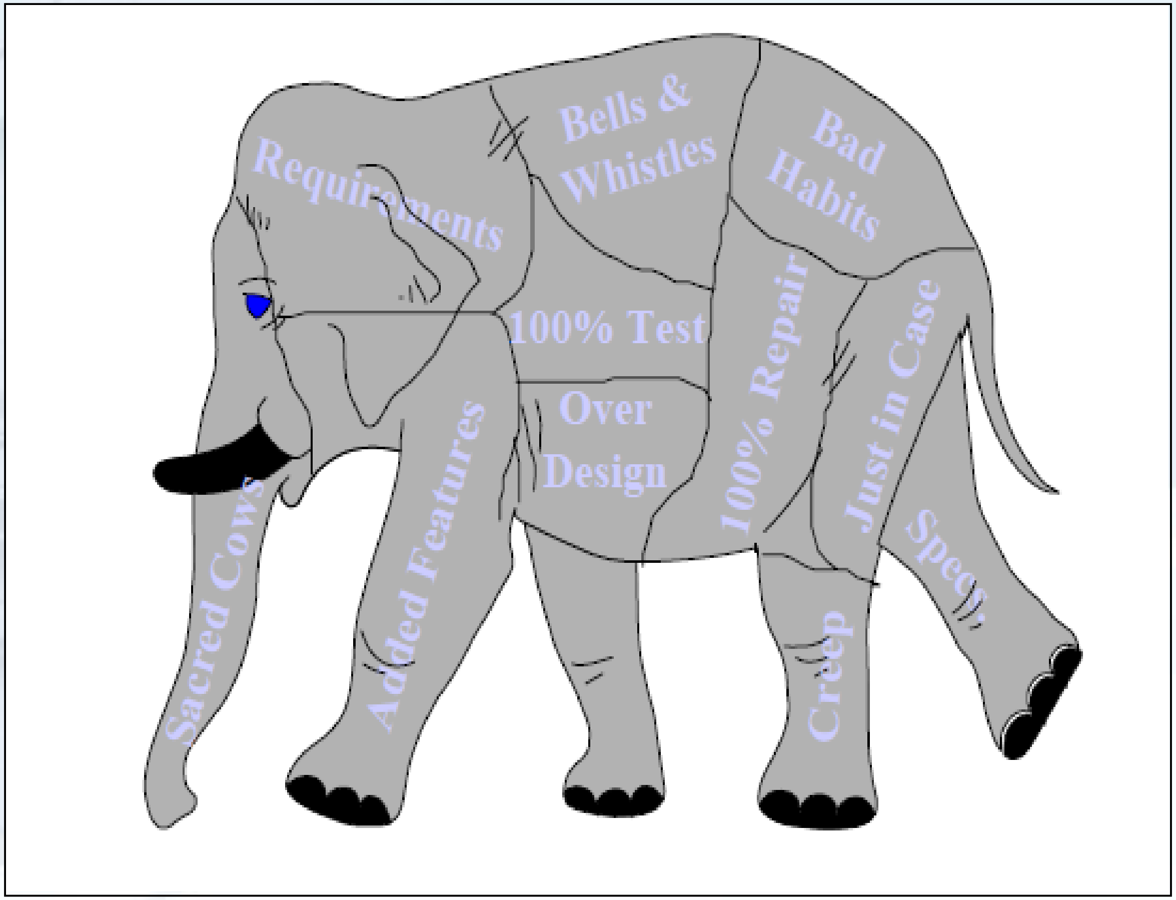
Why Do Design for Manufacturing and Assembly?



Good Design Right?

Can it be improved?

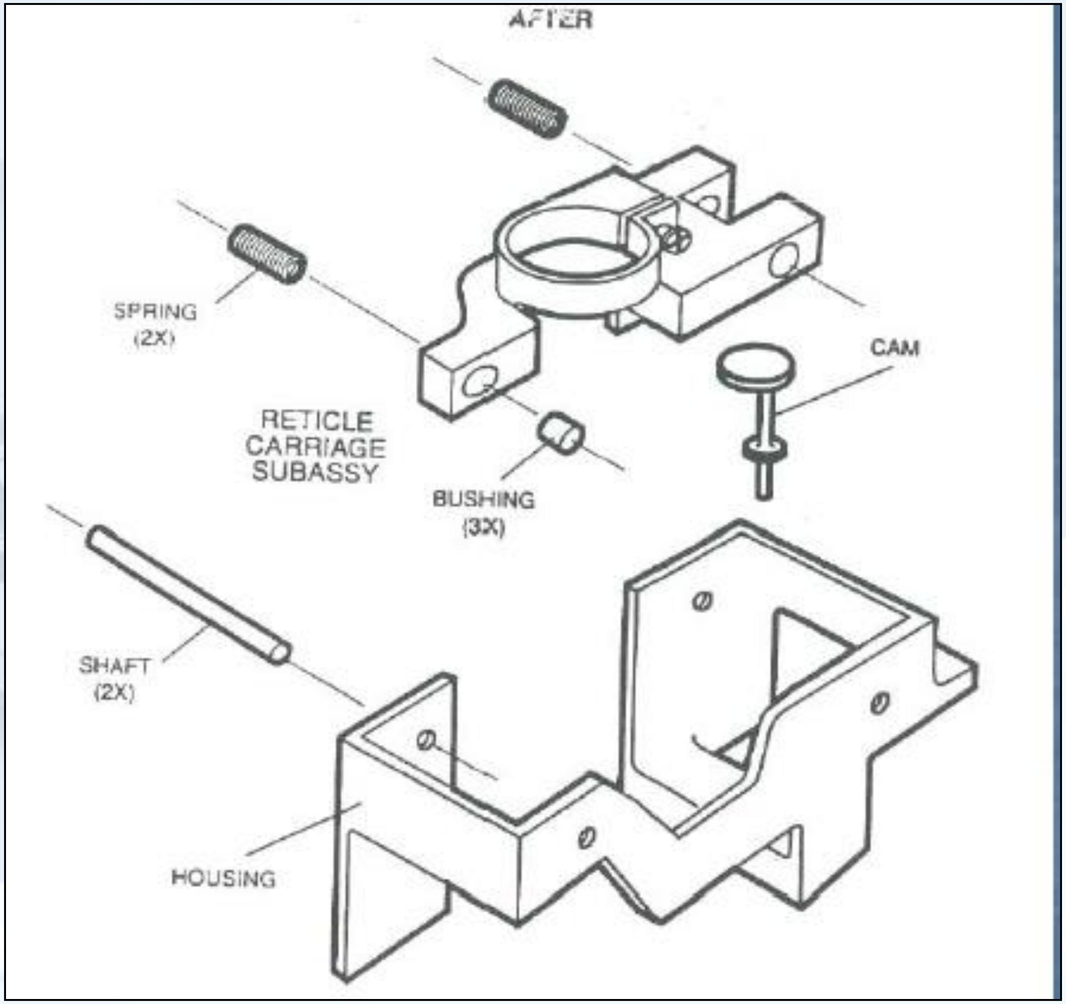
How to Attack Design Complexity



One Bite at a Time:

- Design Simplification Rules
- Challenge "Old" Beliefs
- Take a "New" look at Current Design
- Work as a Team

After DFMA



Design is Simplified

Is this a better design?

Why?

DFMA Advantages

- **Fewer parts, fewer assembly operations**
- **Less parts to manufacture**
- **Less materials usage**
- **Less energy usage**
- **Faster to manufacture, less expensive**
  - Fewer manufacturing steps
- **Faster to assembly, less expensive**
  - Fewer assembly steps
- **Less cost, more profit**

By the way, there are more opportunities in the previous design that a trained DFMA person would catch

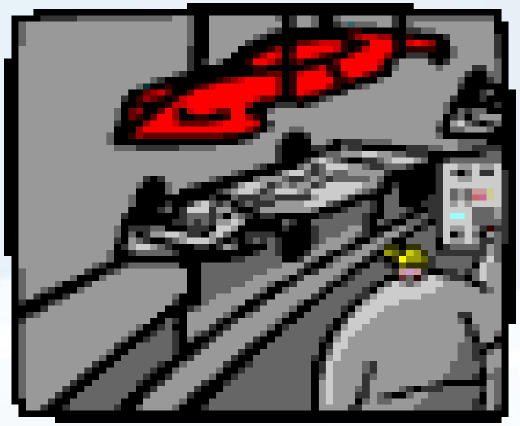
Design for Manufacturing & Assembly

- **DFMA is about reducing the cost of a product through simplification of it's design**

Design for Manufacturing

- **Design For Manufacturing (DFM) focuses on ensuring that product design help make the components and assembly easy to manufacture.** o.m.n.ex

'Optimization of the manufacturing process…'



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

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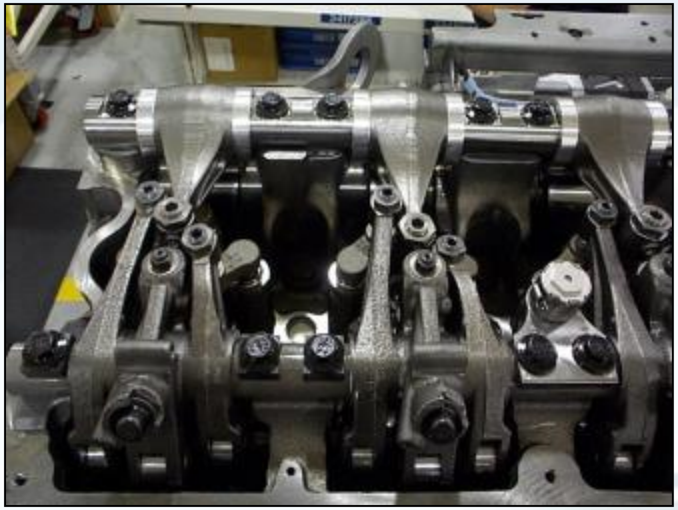
Design for Assembly

- **Design For Assembly (DFA) is a tool used to assist the design teams in the design of products that will transition to production at a minimum cost, focusing on the number of parts, handling and ease of assembly**

'…Optimization of the part/system assembly'



DFM and DFA (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**

DFM and DFA (Differences)

Design for Assembly (DFA)

- **concerned 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

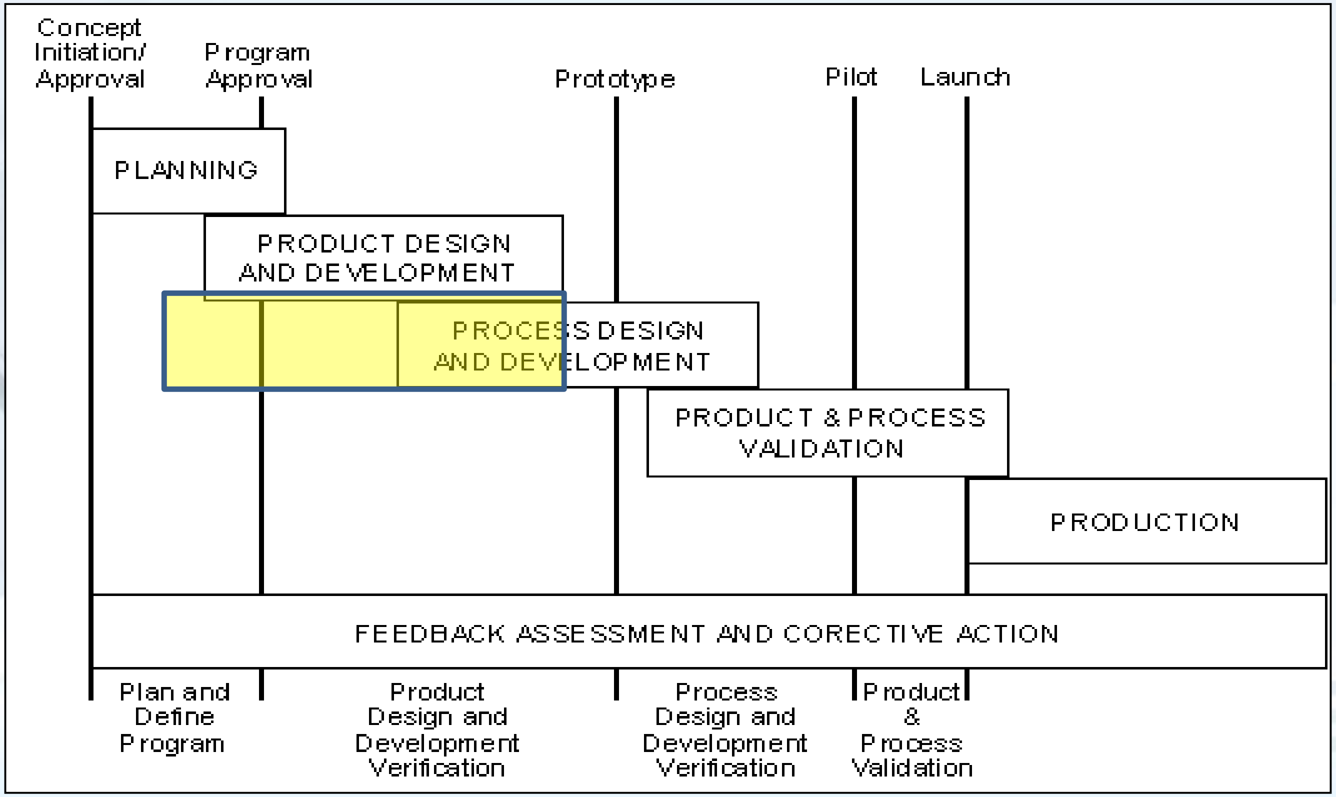
Today's Terminology

- **Design for Manufacturing (DFM) and Design for Assembly (DFA) are now commonly referred to as a single methodology, Design for Manufacturing and Assembly (DFMA)**

DFA + DFM = DFMA

DFMA in the New Product Development Process

DFMA analysis occurs early in the product design and development phase as the product is being designed and manufacturing processes are being considered



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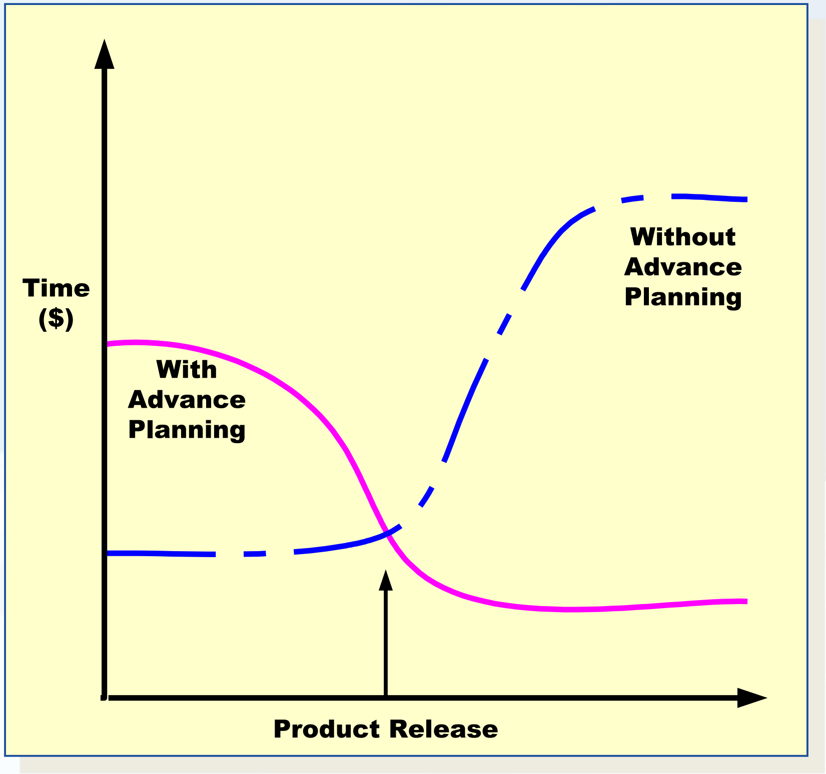
Concurrent Engineering

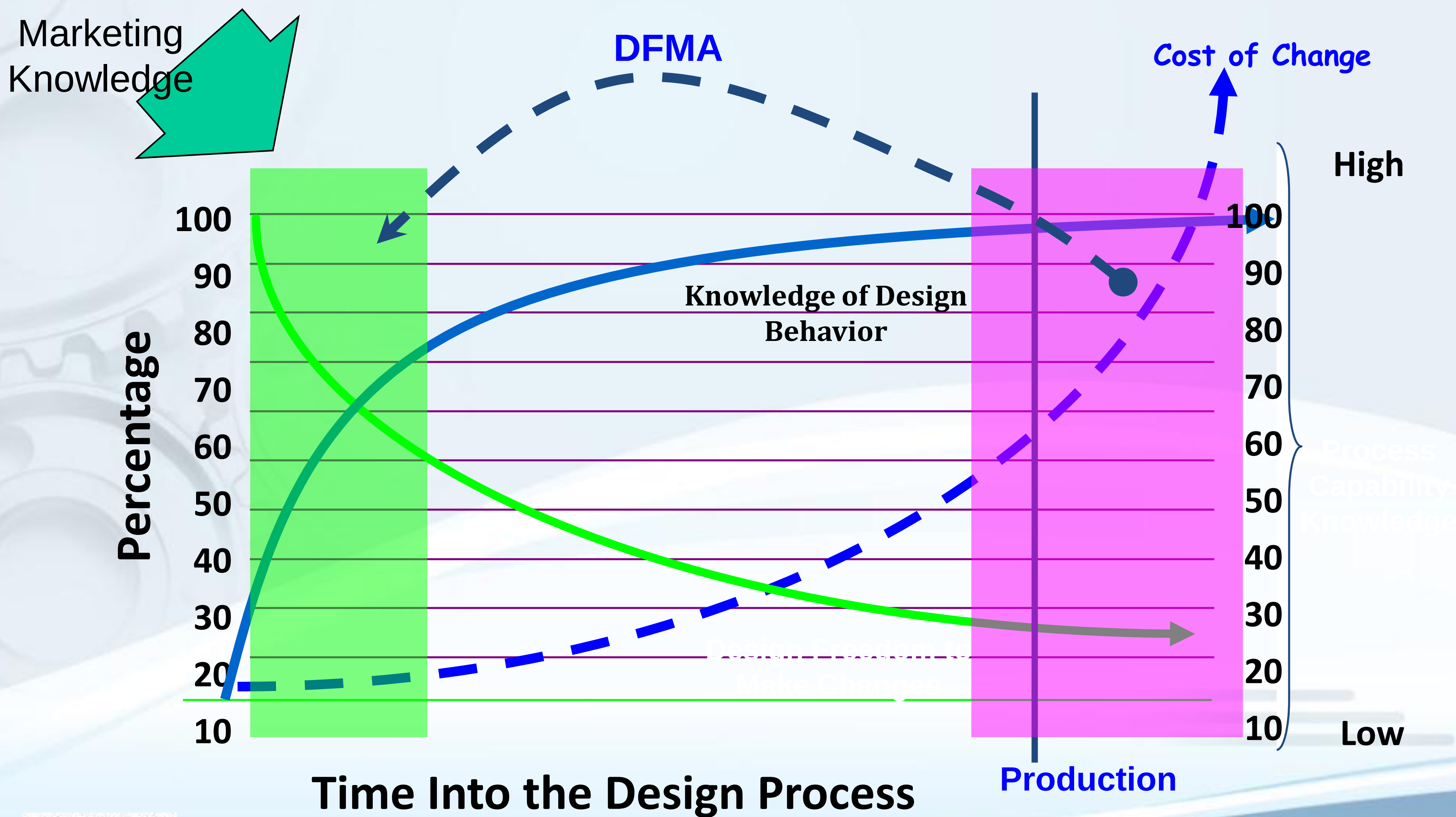
- It is concurrent engineering team approach that involves
- Engineering
- Manufacturing, and
- Suppliers

early in the design cycle to help minimize cost, improve quality, and performance

- Minimize # of components
- Reduce # manufacturing steps and operations
- Proven process capability
- Product provided on time at the lowest cost



Knowledge and Learning



DFMA Process Approach

- Formation of the multi-disciplinary design team
- The most basic approach to design for manufacturing and assembly (DFMA) is to apply design guidelines
- Use design guidelines with an understanding of design goals
- Make sure the application of a guideline improves the design concept on the goal

Formation of the Team
Typical Multi-discipline Team Members

- System Engineering
- Electrical Engineering
- Mechanical Engineering
- Material and Process Engineering
- Manufacturing Engineering
- Finance

- Supply Chain Management
- Key Suppliers
- Program Office
- Customer
- Quality
- Subject Matter Experts (outside the design team)

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Sequence of Analysis

Concept Design

Apply General Design Principles

Design for Assembly

Optimize Design for Part Count and Assembly

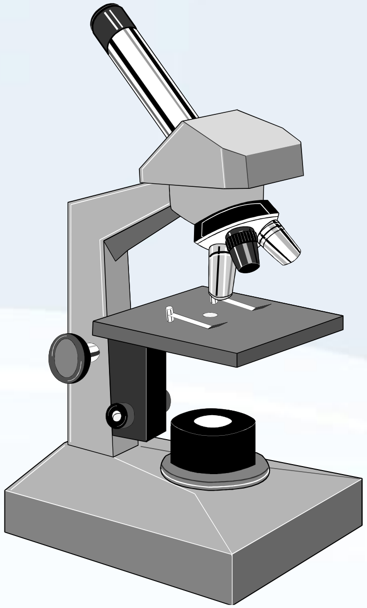
Apply DFA Design Rules

Design for Manufacturing

Design for Assembly and Choose Assembly Method

Detailed Design

Optimize Design for Production Process



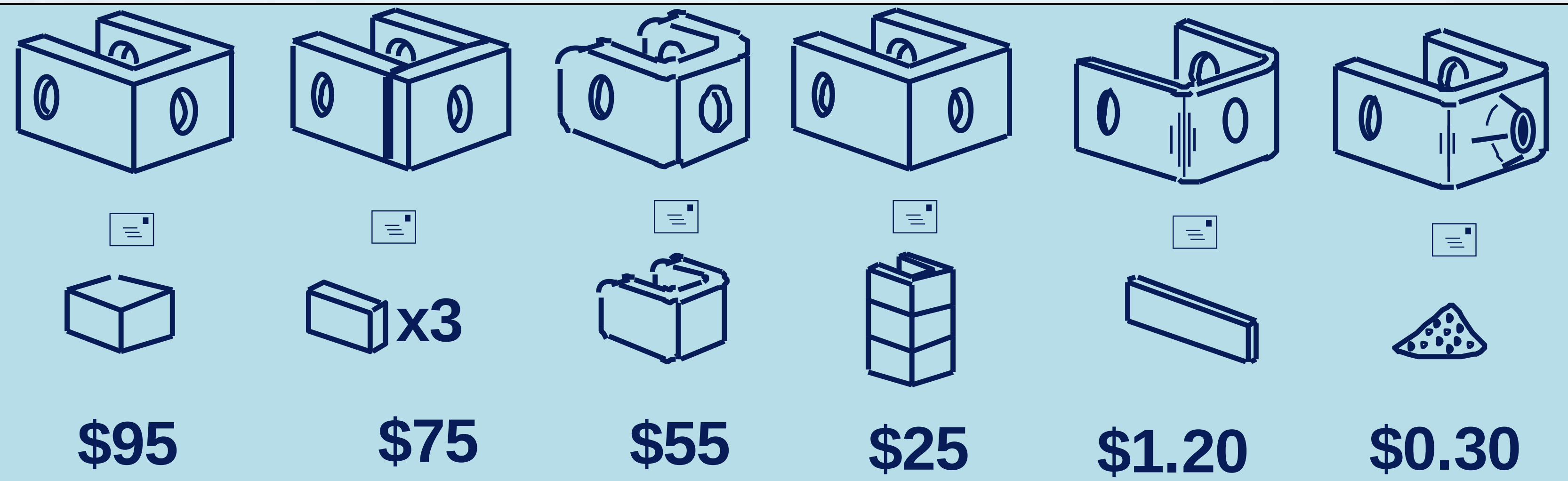
DFMA Benefits

- **Reduces part count, thereby reducing cost…**
  If a design is easier to produce and assemble; it can be done in less time and will be less expensive

- **Increases reliability…………….**
  If the production process is simplified, there is less opportunity for errors

- **Generally, increases the quality of the product…..**
  For the same reason that it increases the reliability

DFMA Benefits:
Investment/Cash Flow Decisions



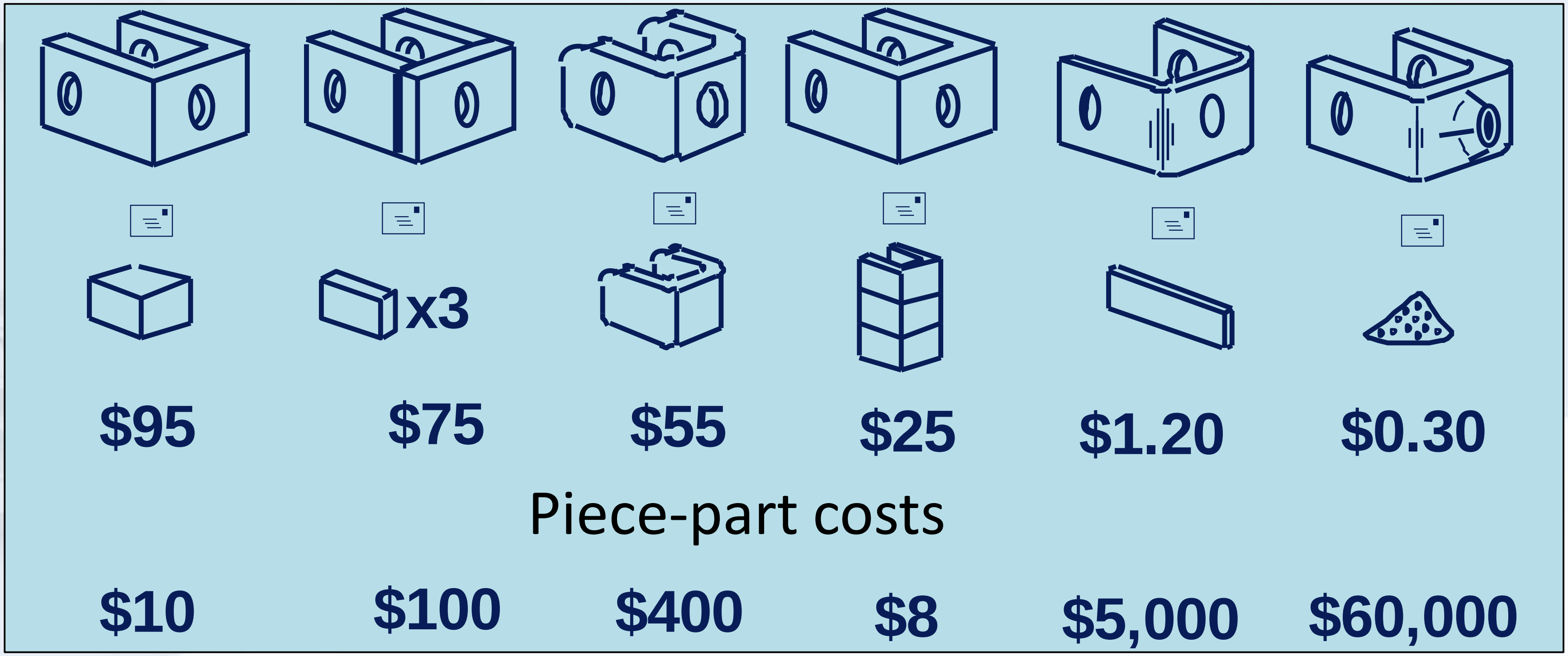
Trade off:

Recurring Costs versus Non-Recurring Costs

Example: $60,000 tooling investment = $0.30 per part

$5 tooling investment = $95 per part

DFMA Benefits: Investment/Cash Flow Decisions



Tooling costs

Chapter 2

DFMA General Design Principles

Content – General Design Principles

- **Understand General Design Principles and its application**
- **Creating and Using Design Rules**

Sequence of Analysis

Concept Design

↓

Design for Assembly

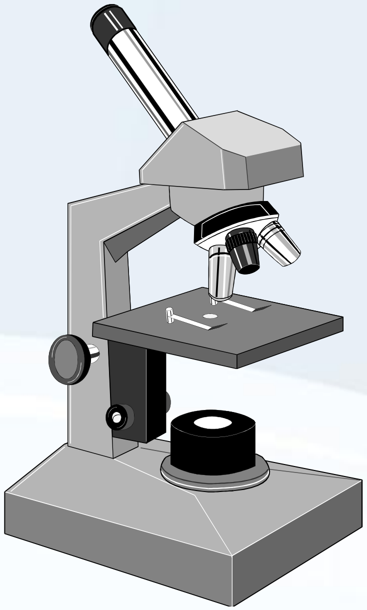
↓

Design for Manufacturing

↓

Detailed Design

- Apply General Design Principles
- Optimize Design for Part Count and Assembly
- Apply DFA Design Rules
- Design for Assembly and Choose Assembly Method
- Optimize Design for Production Process



General Design Principles

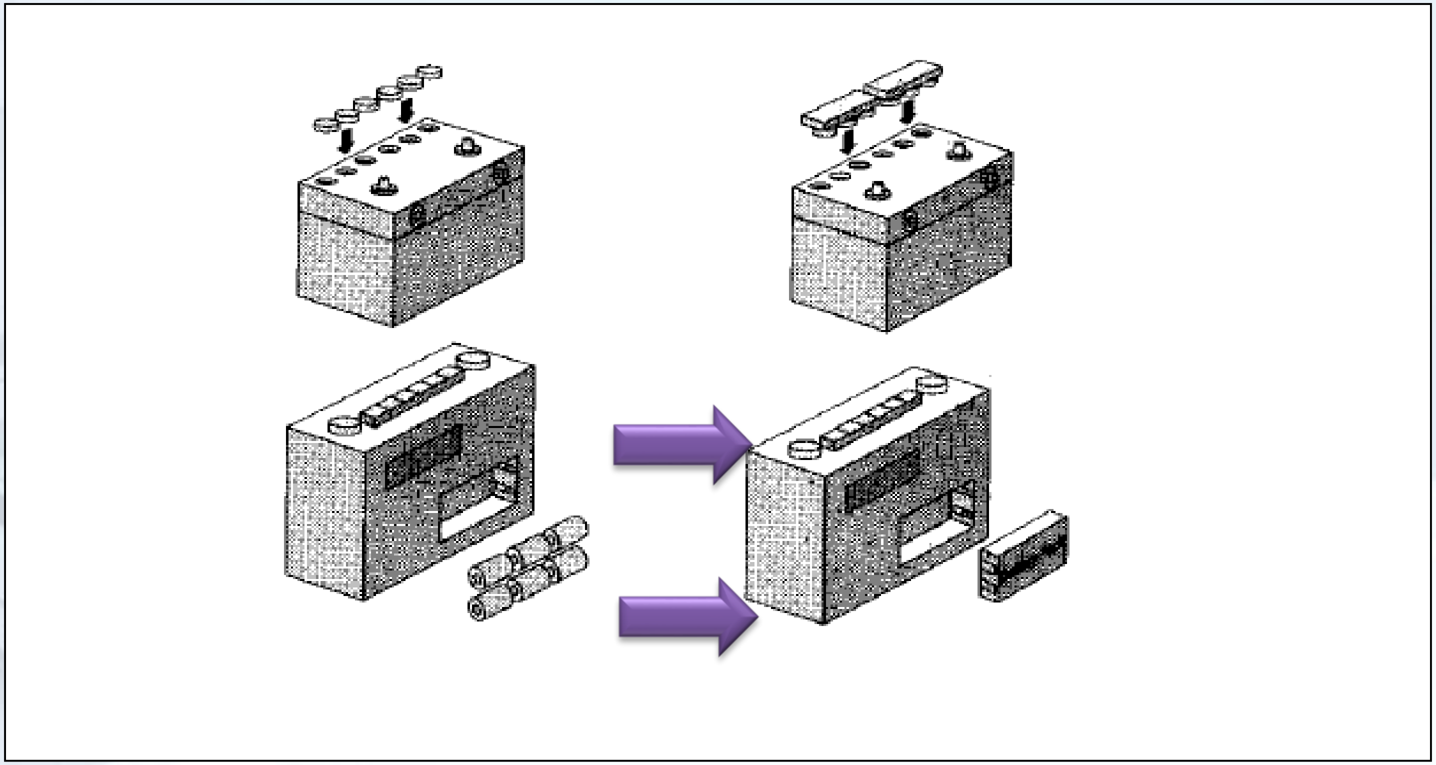
- **Design Rules are a checklist either enforced by design software or by design rules checklists.**
- **Design Rules are of three kinds for Design for Assembly (DFA)**
  - General Design Principles
  - Design for Assembly Principles
  - Design for Assembly principles for Assembly technique – Manual, Fixed/High Speed and Soft Automation/Robotic
- **Design rules for Design for Manufacturing is process-dependent and should be created**

Focus of this Chapter

Hint to Students

- The class is about DFMA techniques. The following list is Omnex recommended General Design Rules. As we do the lecture, start filling out your own personal DFMA Design Rules Checklist.
- See Breakout 1 for blank checklist

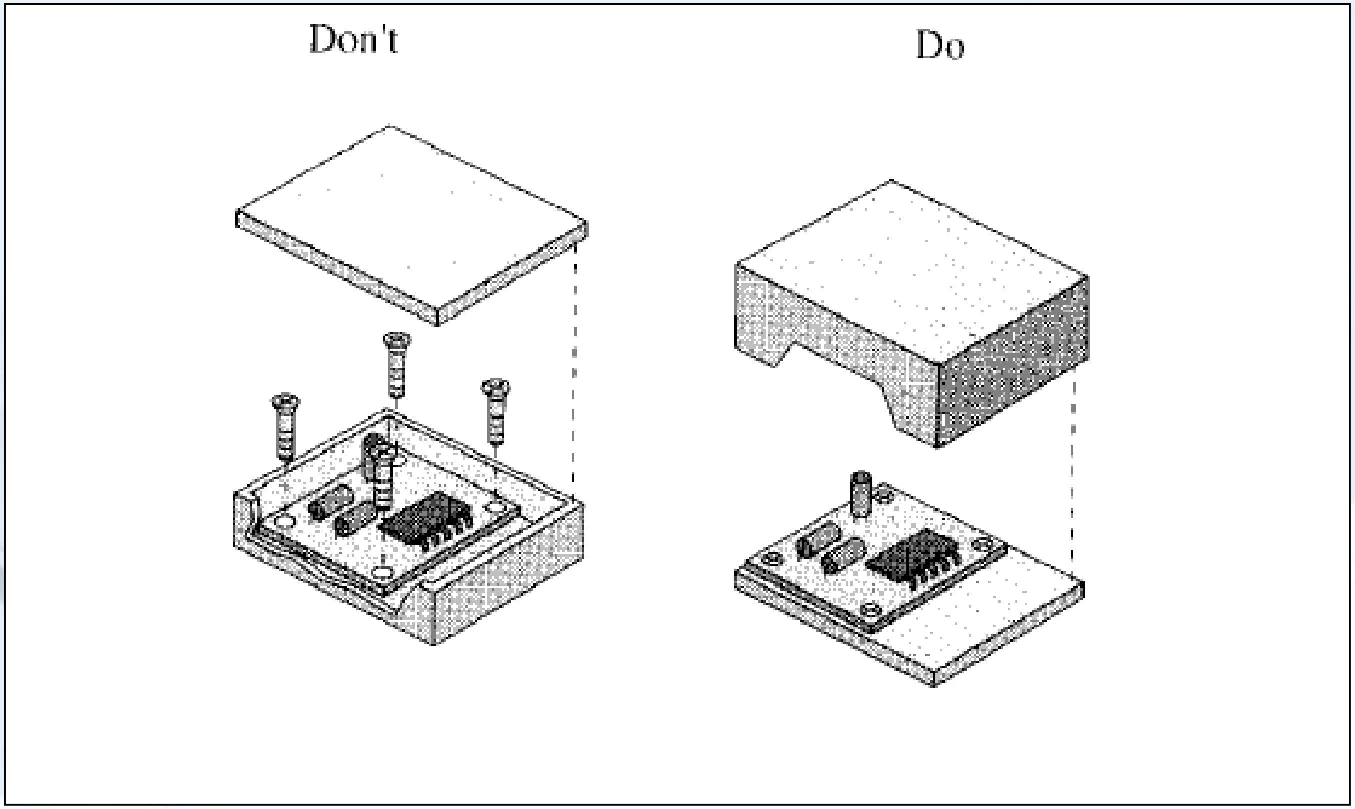
General Design Rules
Rule 1: Modularize Parts



Modularize parts into sub-assemblies

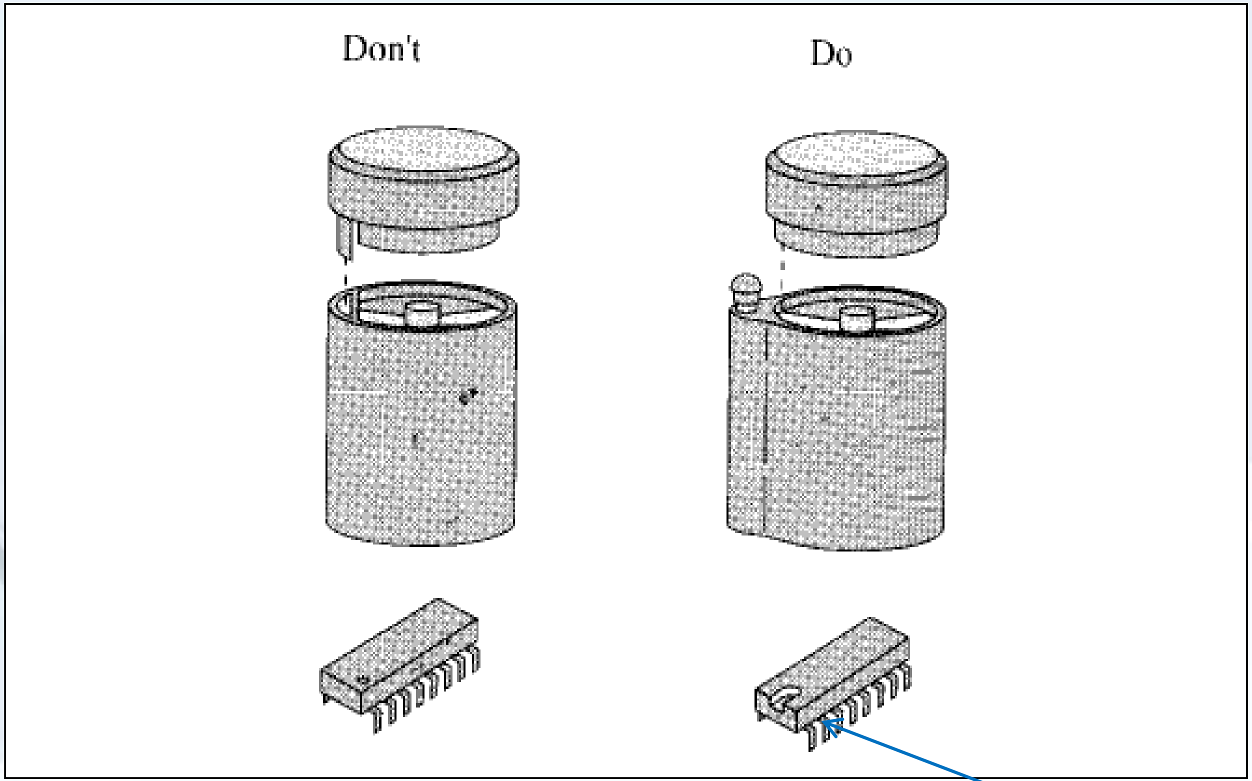
O-M-N-E-X

General Design Rules
Rule 2: Design for Open Spaces



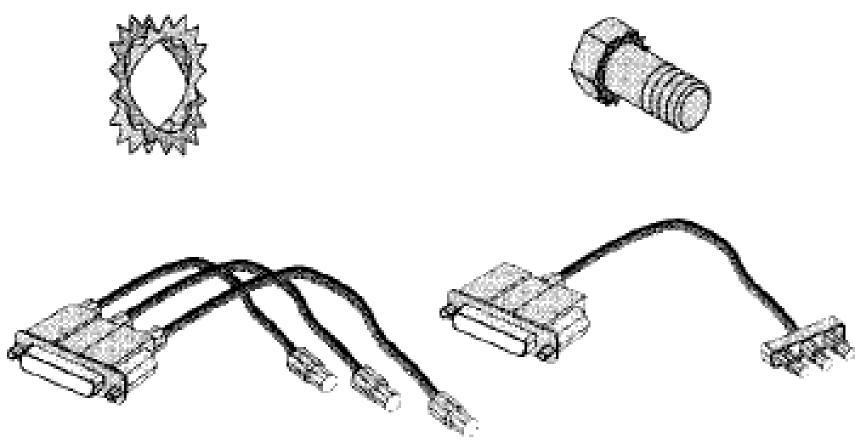
Ensure adequate access and unrestricted vision

General Design Rules
Rule 3: No Orientation and Self Locking

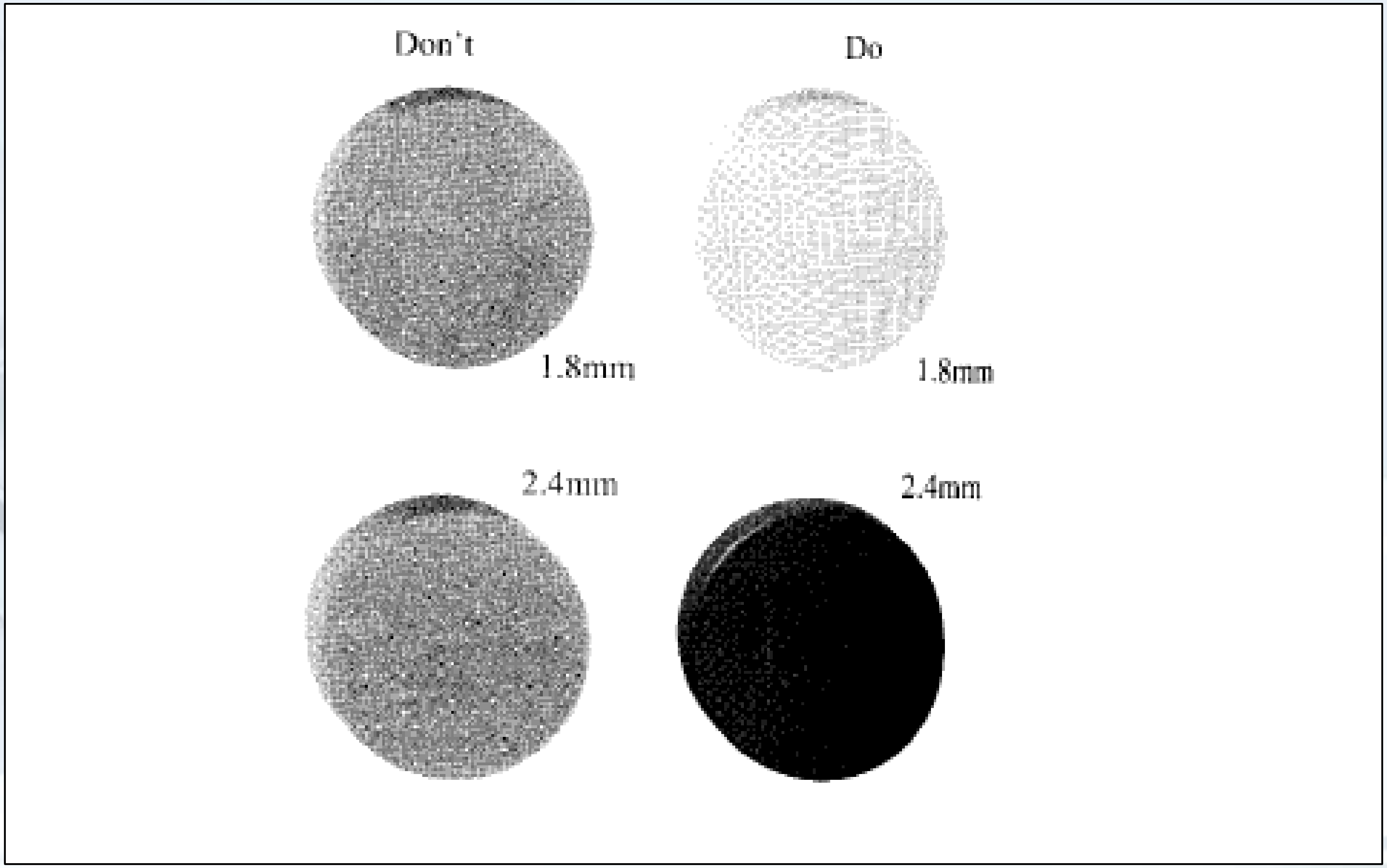


If there is an orientation, indicate it

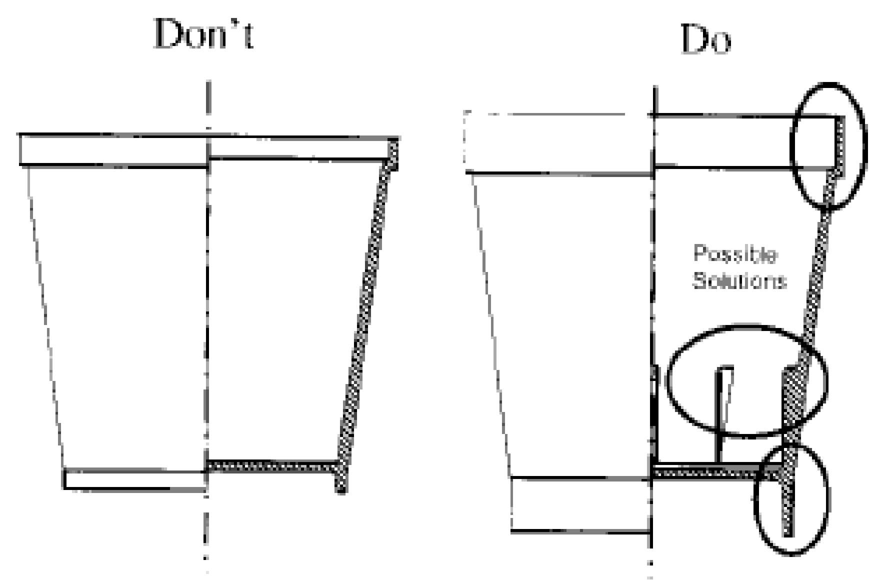
General Design Rules
Rule 4: Design Parts So they Do Not Tangle



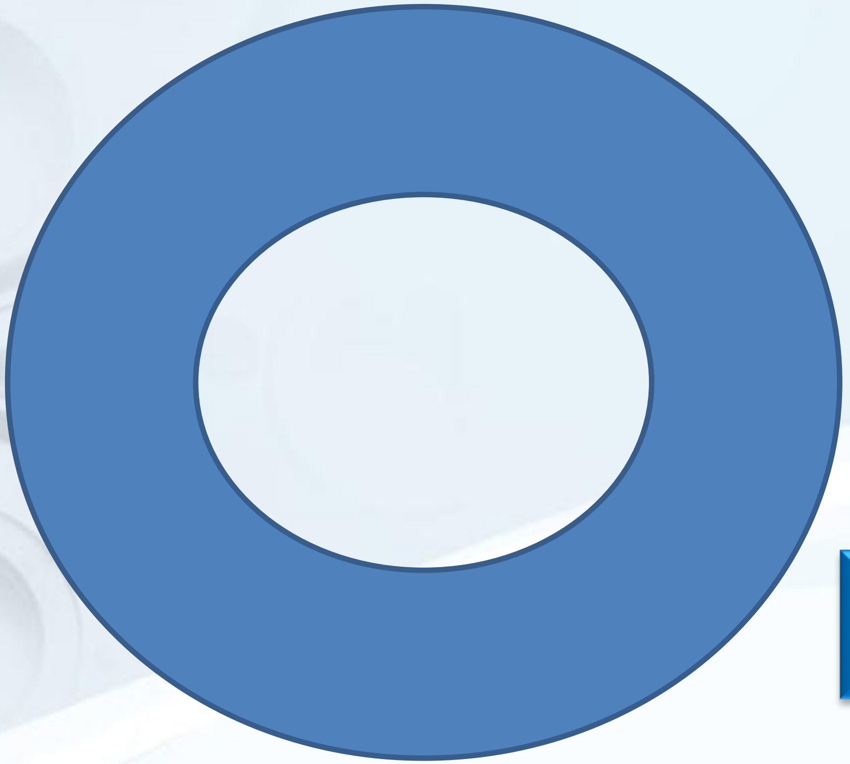
General Design Rules
Rule 5: Mistake Proof Similar Parts

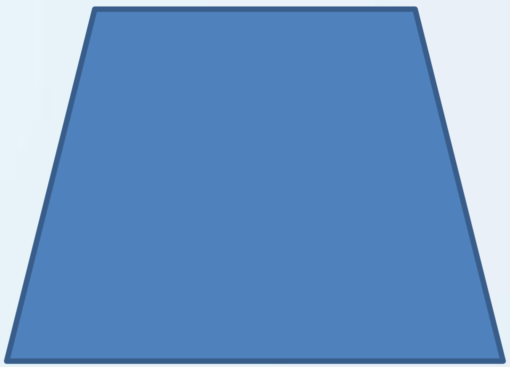


General Design Rules
Rule 6: Prevent Nesting



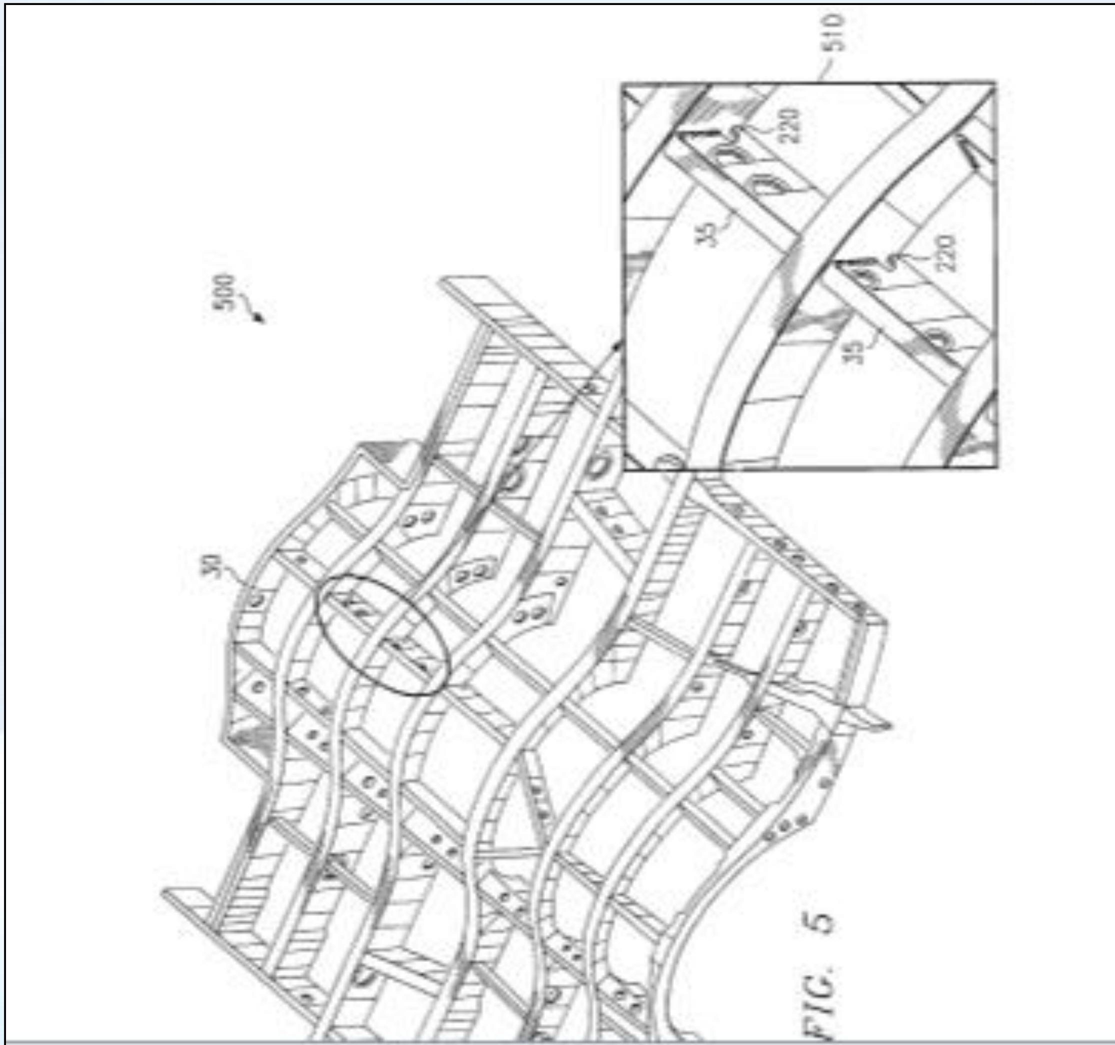
General Design Rules
Rule 7: Use Self-locating Features



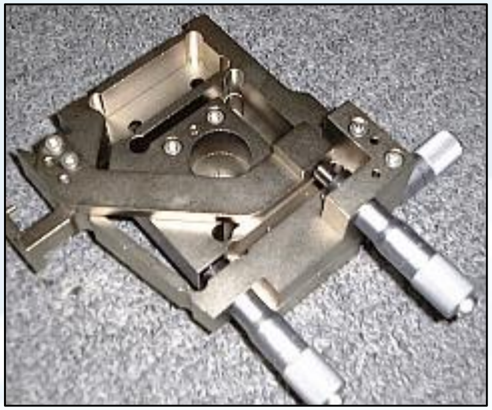


Mistake proof
Assembly failure modes

Self Locating Example
Aerospace Wing Assembly



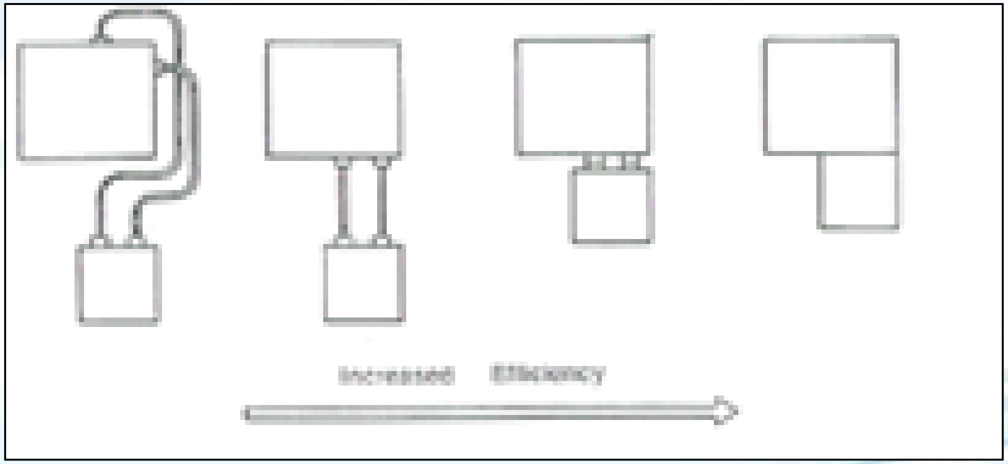
General Design Rules
Rule 7: Avoid Special Tooling/Test Equipment



"Special Tooling" means jigs, dies, fixtures, molds, patterns, taps, gauges, other equipment and assembly aids

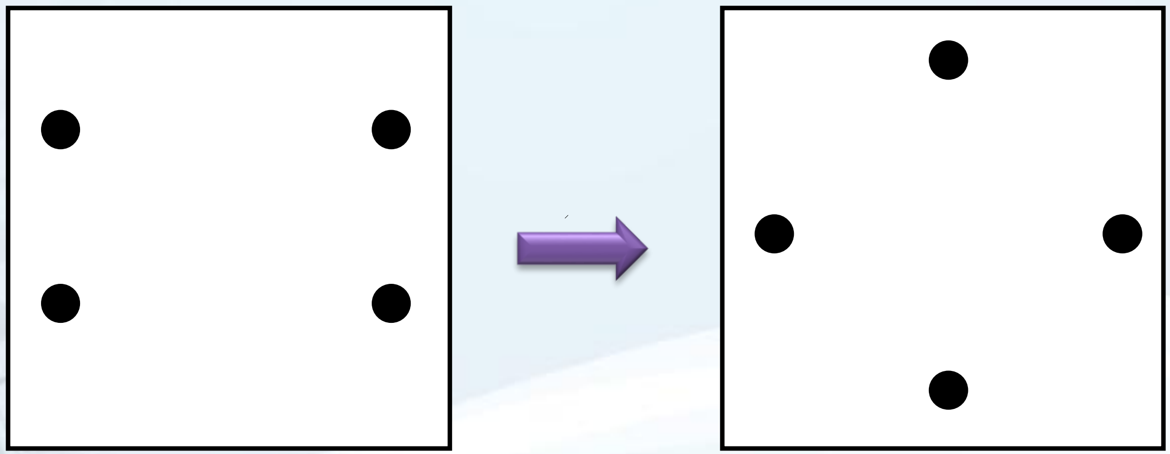
General Design Rules
Rule 8: Minimize Flexible Parts and Interconnections

- **Avoid flexible and flimsy parts such as belts, gaskets, tubing, cables and wire harnesses. Their flexibility makes material handling and assembly more difficult and these parts are more susceptible to damage.**
- **Use plug- in boards and backplanes to minimize wire harnesses. Where harnesses are used, consider fool-proofing electrical connectors by using unique connectors to avoid connectors being mis-connected. Interconnections such as wire harnesses, hydraulic lines, piping, etc. are expensive to fabricate, assemble and service. Partition the product to minimize interconnections between modules and co-locate related modules to minimize routing of interconnections.**



General Design Rules
Rule 9: Design in Symmetry

Symmetry eliminates reorientation



Asymmetric Part

Symmetry of a part makes assembly easier

Benefits of Design Rules Checklists

- **Captures lessons learned**
- **Ensures key past mistakes are not repeated**
- **Opportunity to use DFMA rules during product and process design concurrently**
  - Before Pilot design, product release, and process/tooling design
- **Can be customized by product and process families**

Breakout Exercise 1:
Design Rules Checklist

- As a group, list the DFA rules that need to be applied by the designer on the flip chart
- Use the following format:

Design Rules – General Principles	Checked	Comments

Chapter 3

Methods for Evaluating the Design for Assembly (DFA)

Content – Evaluating DFA

- **Minimize number of parts using Boothroyd-Dewhurst Technique**
  - DFA Analysis Worksheet
  - Evaluating design simplicity
- **Conduct case studies to apply the technique**

Sequence of Analysis

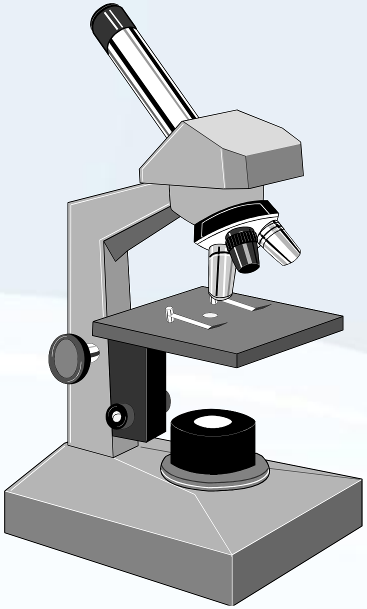
Concept Design → Apply General Design Principles

Design for Assembly → Optimize Design for Part Count and Assembly

Apply DFA Design Rules

Design for Manufacturing → Design for Assembly and Choose Assembly Method

Detailed Design → Optimize Design for Production Process



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Minimizing the Number of Parts Questions to Ask

- To determine whether it is possible to combine neighboring parts, ask yourself the following questions:
- Must the parts move relative to each other?
- Must the parts be electrically or thermally insulated?
- Must the parts be made of different material?
- Does combining the parts interfere with assembly of other parts?
- Will servicing be adversely affected?
- If the answer to all questions is “NO”, you should find a way to combine the parts

Minimizing the Number of Parts
Boothroyd-Dewhurst Technique

Established in 1983 by Geoffrey Boothroyd and Peter Dewhurst, the concept of theoretical minimum number of parts.

- **Obtain Product Information**
- **Decompose (disassemble) design to assess each part**
- **Predicts assembly time and assembly cost**
- **Evaluate for design Simplicity**
- **Compare design to its' idea (future) state**

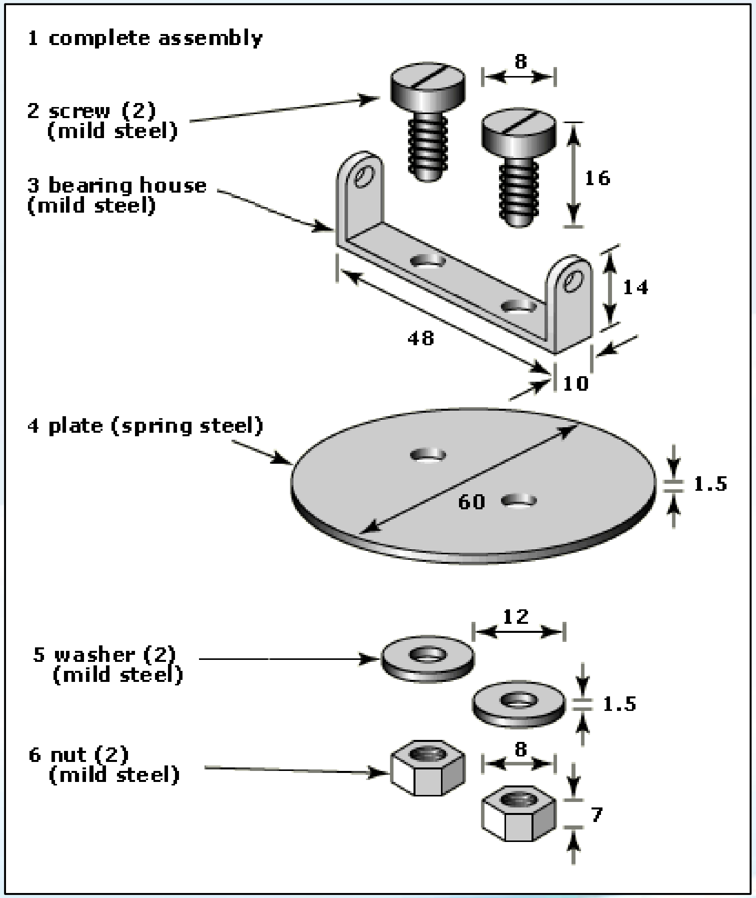
Step 1: Obtain product Information

- **Figure in next slide shows a simple sub-assembly used in the construction of a gas-flow meter. The objective is to analyse the design using the Boothroyd-Dewhurst method with the intention of using the information obtained to create a new, easier-to-assemble, less expensive sub-assembly.**

- **In this analysis only manual assembly will be considered. For the redesign of an existing product, it will be assumed that the functional parts must have the same dimensions and be made of the same materials.**

Step 2: Decompose (disassemble) design to assess each part

- **Obtain the best information about the product or assembly**
  - Useful items are: Engineering drawing or 3-D views
  - Surrogate product or prototype



Step 3: Predict Assembly Time & Cost

Take it apart in the reverse order it was assembled

part no	number repeats	total assembly time	manual assembly cost	min number parts	remarks
6	>2	6	1.2		nut
5	2	6	1.2		washer
4	1	4	0.8		plate
3	1	3	0.6		bearing housing
2	2	20	4		screw
1	–	–	–		complete assembly
		39	7.8		

Step 4 : Evaluate for Design Simplicity

- **Determine the theoretical minimum number of parts for the assembly**
- **If a part is justified by the handling and insertions question on the previous page, it receives a 1 in the worksheet.**
- **If the justification is not possible, then the part is non-essential and receives a 0 in the worksheet. Note: non-essential parts should be designed out or combined with another essential part.**

part no	number repeats	total assembly time	manual assembly cost	min number parts	remarks
6	>2	6	1.2	0	nut
5	2	6	1.2	0	washer
4	1	4	0.8	1	plate
3	1	3	0.6	0	bearing housing
2	2	20	4	0	screw
1	–	–	–	–	complete assembly
		39	7.8	1	
design efficiency = 3 × min parts / assembly time = 3 × 1 / 39 = 0.077					

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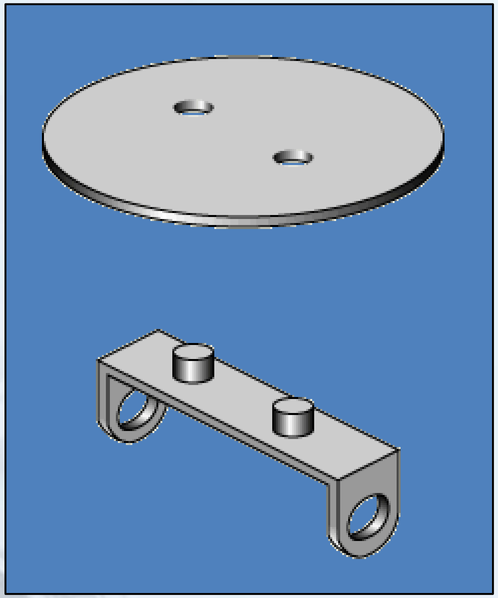
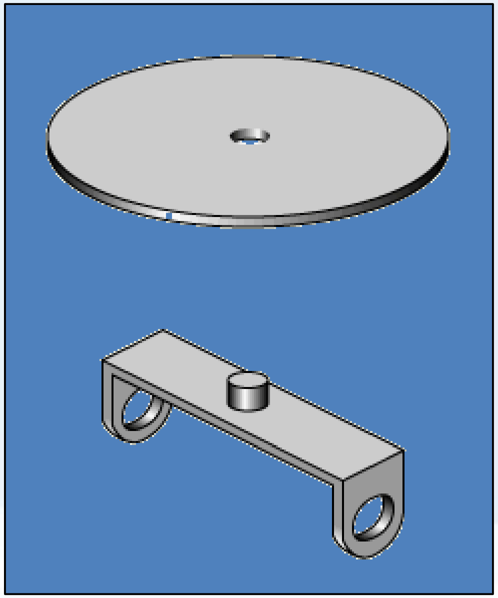
Compare Ideas





part no	number repeats	total assembly time	manual assembly cost	min number parts	remarks
3	1	3	0.6	1	bearing housing
2	1	4	0.8	0	plate
1	–	–	–	–	complete assembly
		7	1.4	1	
design efficiency = 3 * min parts / assembly time = 3 * 1 / 7 = 0.428					

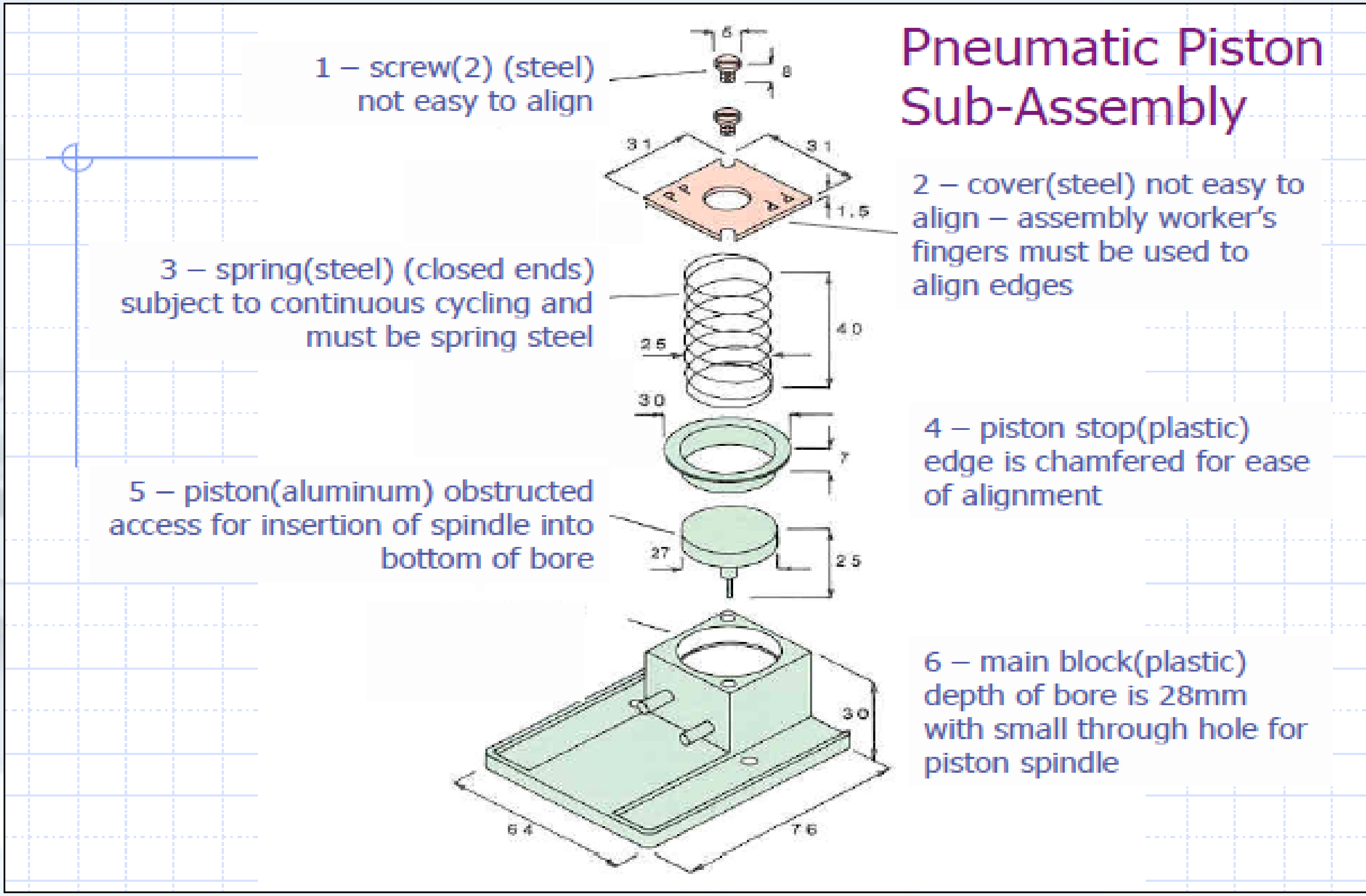
part no	number repeats	total assembly time	manual assembly cost	min number parts	remarks
3	1	3	0.6	1	bearing housing
2	1	4	0.8	0	plate
1	–	–	–	–	complete assembly
		7	1.4	1	
design efficiency = 3 * min parts / assembly time = 3 * 1 / 7 = 0.428					

Your Turn

- **Exercise: Analyze the Pnuematic Piston design to identify those features resulting in high assembly cost and then calculate the design efficiency.**

1. Obtain the product information
2. Use the exploded view to identify and count each part
3. Predict the assembly time & cost.
4. Re-assemble the product to evaluate for design simplicity

Exploded View to Identify and Count Parts



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B-D Manual Handling Chart

MANUAL HANDLING—ESTIMATED TIMES (seconds)

Key: ONE HAND

		parts are easy to grasp and manipulate					parts present handling difficulties (1)				
		thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
		size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm	size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm
parts can be grasped and manipulated by one hand without the aid of grasping tools		0	1	2	3	4	5	6	7	8	9
$(\alpha+\beta) < 360°$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
$360° \leq (\alpha+\beta) < 540°$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
$540° \leq (\alpha+\beta) < 720°$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
$(\alpha+\beta) = 720°$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

piston

screws

cover

spring

B-D Insertion Chart A

MANUAL INSERTION—ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED

			after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
			easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
			no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
			0	1	2	3	6	7	8	9
addition of any part (1) where neither the part itself nor any other part is finally secured immediately	part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
	part and associated tool (including hands) cannot easily reach the desired location — due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
	part and associated tool (including hands) cannot easily reach the desired location — due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

spring

piston

cover

B-D Manual Insertion Chart B

PART SECURED IMMEDIATELY

addition of any part (1) where the part itself and/or other parts are being finally secured immediately		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
				plastic bending or torsion			rivetting or similar operation				
		easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	not easy to align or position during assembly: no resistance to insertion	not easy to align or position during assembly: resistance to insertion (5)	easy to align and position during assembly (4)	not easy to align or position during assembly: no resistance to insertion	not easy to align or position during assembly: resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
		0	1	2	3	4	5	6	7	8	9
part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

screws

Pneumatic Piston Exercise

Debrief

- Is there opportunity to reduce the number of parts? *Hint: Areas for part count reduction are easy to locate using row 9*
- What parts might possibly be reduced?
- Are there areas for improvement of handling and assembly? *Hint: Improvements can be seen by reviewing the figures in row 4 & 6.*

Pneumatic Piston (re-design)

- The method for re-designing the product is as follows:
- Examine row (9) on the worksheet. When the number is < row (2), there might be scope for eliminating.

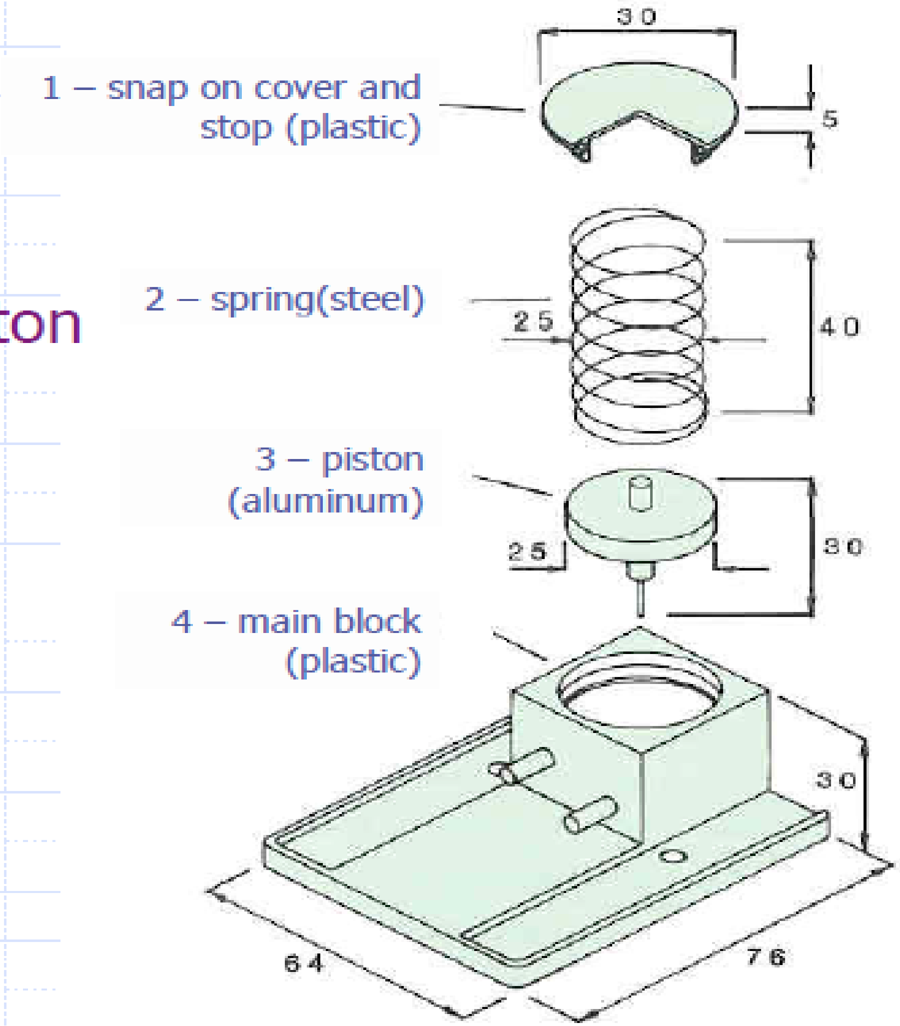
(R9) 4 < 7 (R2)

- Examine rows (4) and (6). The figures indicate potential for assembly time reduction; the > the time, the > the potential saving.

Cover time = 2.36 handling and 6.5 insertion

Reduced Parts with Re-design

Redesign: Pneumatic Piston Sub-Assembly



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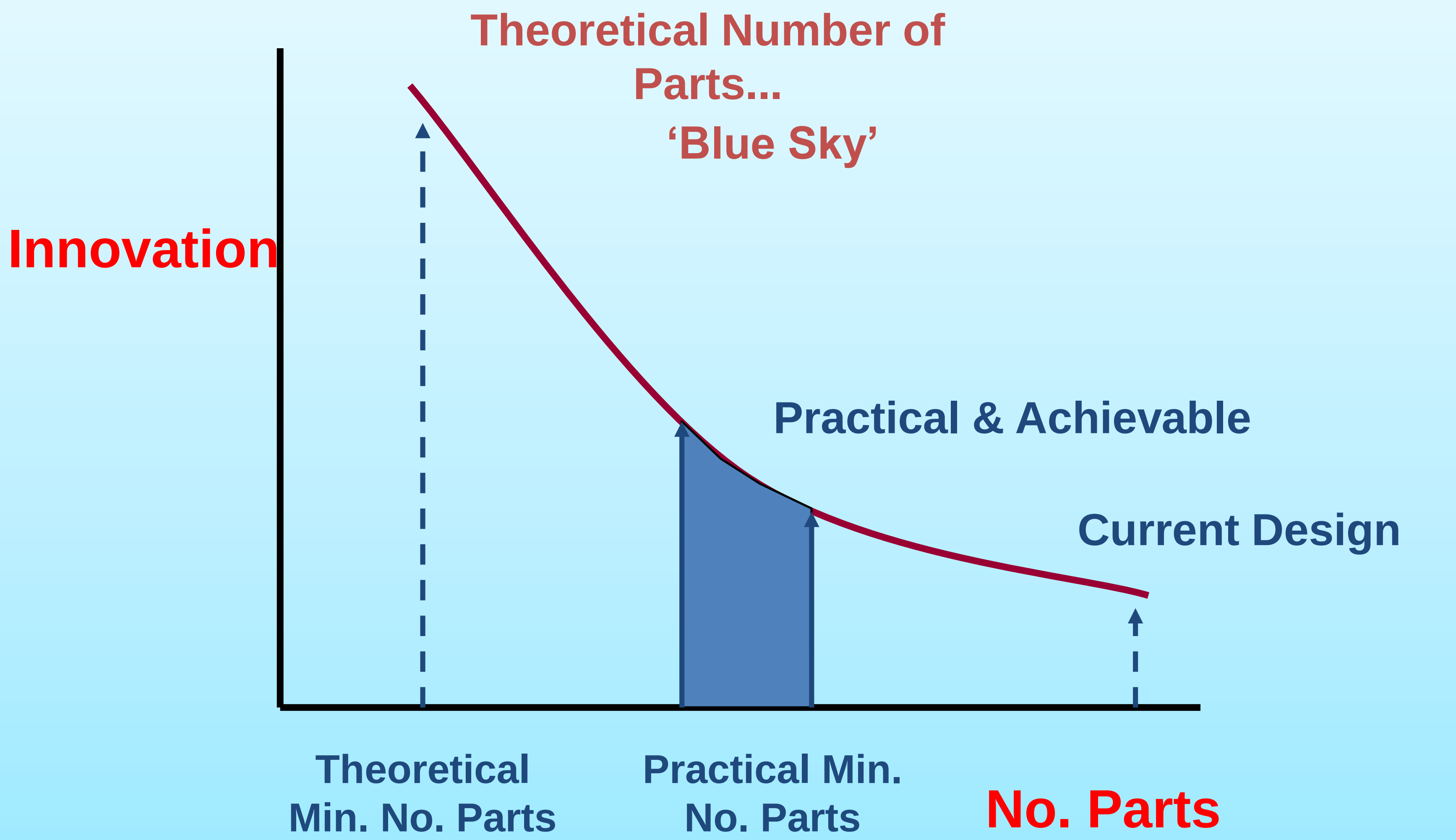
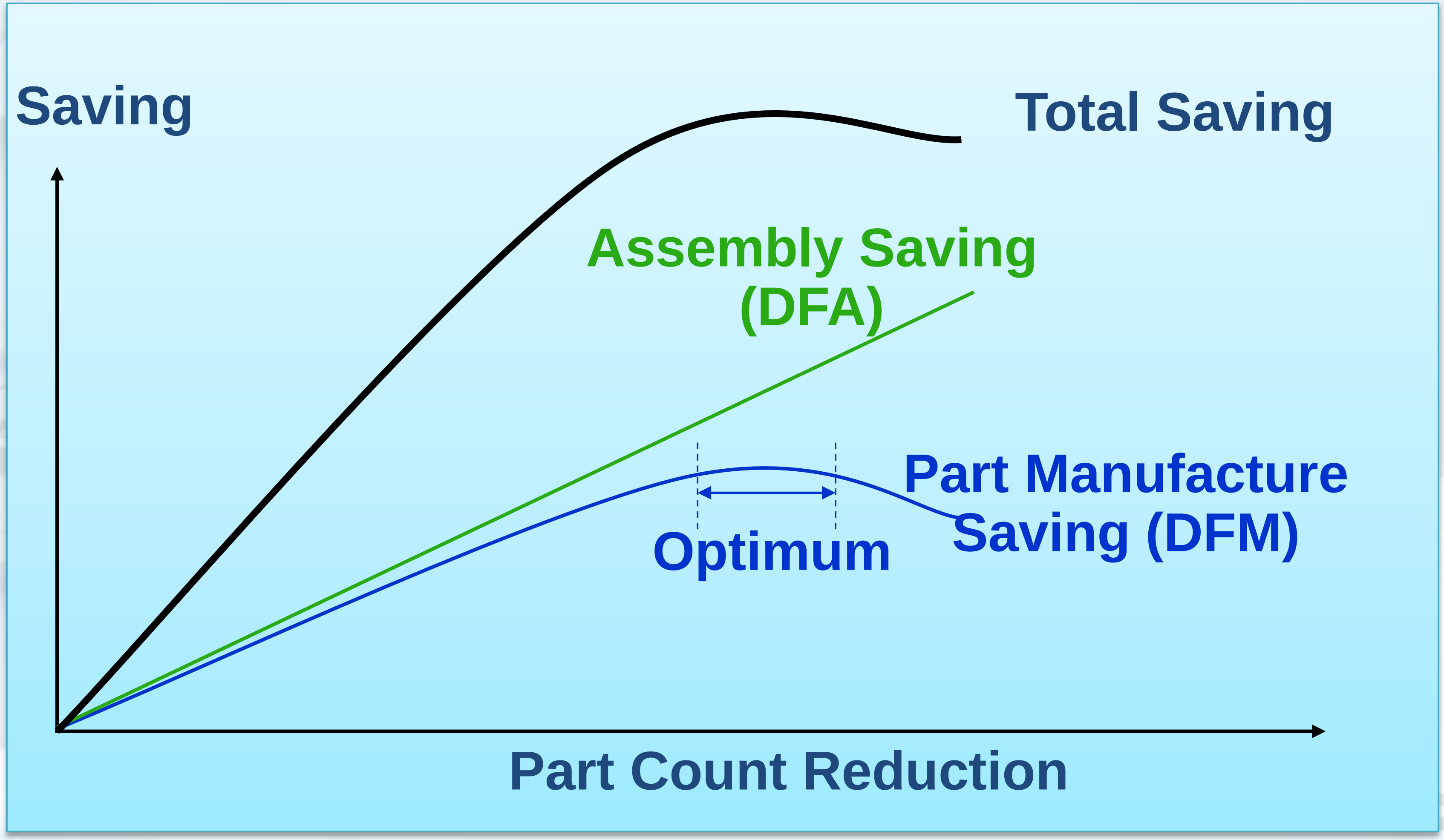
Analysis Worksheet for Re-design

1	2	3	4	5	6	7	8	9	Name of Assembly
Part I.D. No.	number of times the operation is carried out consecutively	two-digit manual handling code	manual handling time per part	two-digit manual insertion code	manual insertion time per part	operation time, seconds (2)*[(4)+(6)]	operation cost, cents 0.4*(7)	figures for estimation of theoretical minimum parts	PNEUMATIC PISTON (re-design)
4	1	30	1.95	00	1.50	3.45	1.38	1	MAIN BLOCK
3	1	10	1.50	00	1.50	3.00	1.20	1	PISTON
1	1	05	1.84	00	1.50	3.34	1.34	1	SPRING
2	1	10	1.50	30	2.00	3.50	1.40	1	COVER & STOP
						13.29	5.32	4	design efficiency = (3*NM)/TM: 0.90
						TM	CM	NM	

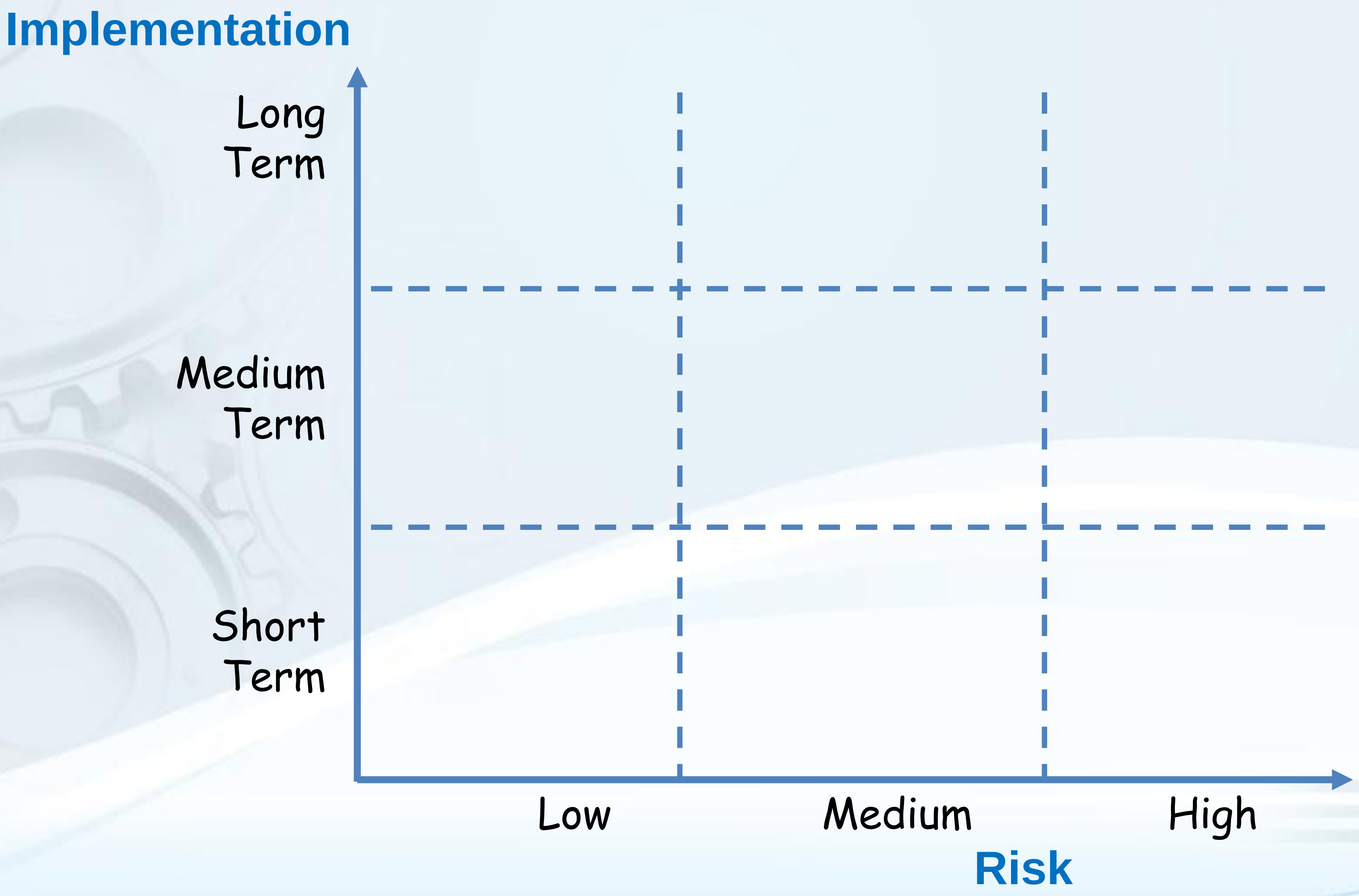
Creativity & Innovation



Cost of Assembly vs. Cost of Part Manufacture



Idea Classification



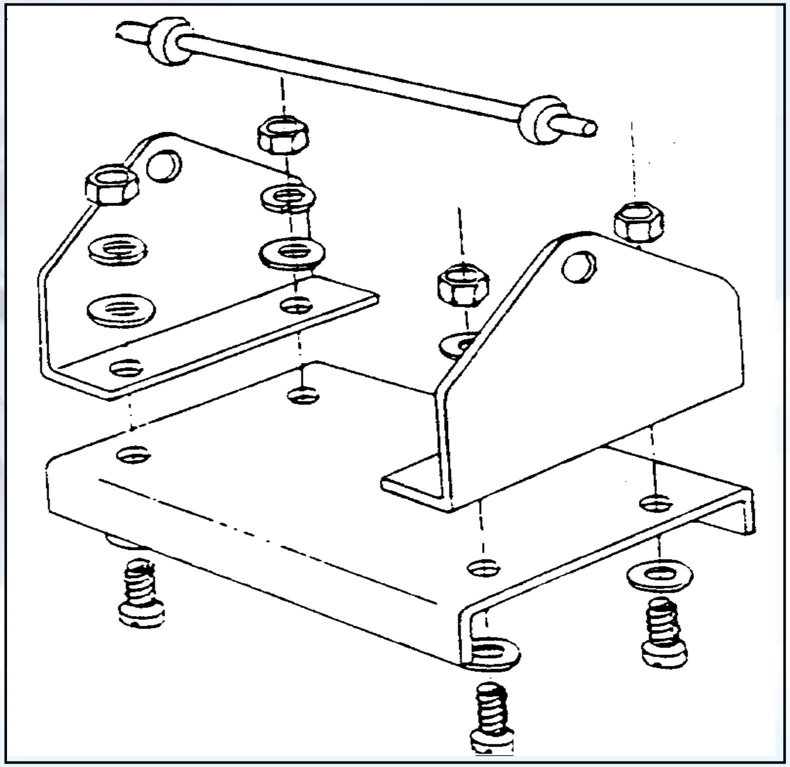
Don't Constrain Yourself to Incremental Improvement Unless You Have To!

This style doesn't tear paper like the claw style and is much cheaper to produce!

Breakout Exercise 2: Simplify the Design

- **Using the DFA guidelines discussed in this chapter, identify opportunities to simplify the Roll Bar Assembly**

Hint: If more than 1/3 of the parts are fasteners, the assembly logic should be questioned.



Existing Roll Bar Design consist of:

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

Chapter 4

Design for Assembly Rules

Content – Design for Assembly Rules

- Minimizing Parts
- Reducing Number of Operations
- Precedence Diagrams
- Allowing Failure Recovery
- Ensure Product Standardization
- Making Alignment Easy
- Make Insertion Easy
- Allow one direction of insertion
- Allow Easy Stacking
- Orienting Features
- Fastener Design Rules

Applying Design Rules

Sequence of Analysis

Concept Design

Design for Assembly

Design for Manufacturing

Detailed Design

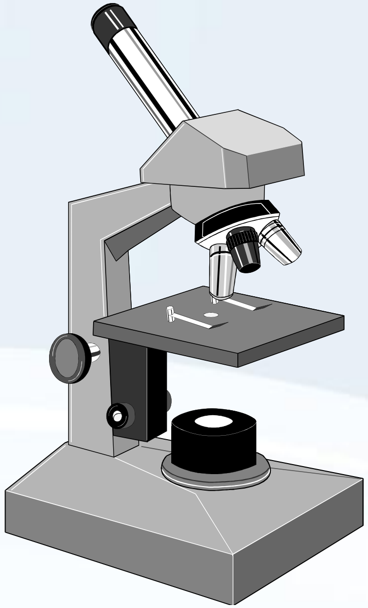
Apply General Design Principles

Optimize Design for Part Count and Assembly

Apply DFA Design Rules

Design for Assembly and Choose Assembly Method

Optimize Design for Production Process



General Design Principles

- **Design Rules are a checklist either enforced by design software or by design rules checklists.**
- **Design Rules are of three kinds for Design for Assembly (DFA)**
  - General Design Principles
  - Design for Assembly Principles
  - Design for Assembly principles for Assembly technique – Manual, Fixed/High Speed and Soft Automation/Robotic
- **Design rules for Design for Manufacturing is process-dependent and should be created**

Focus of this Chapter

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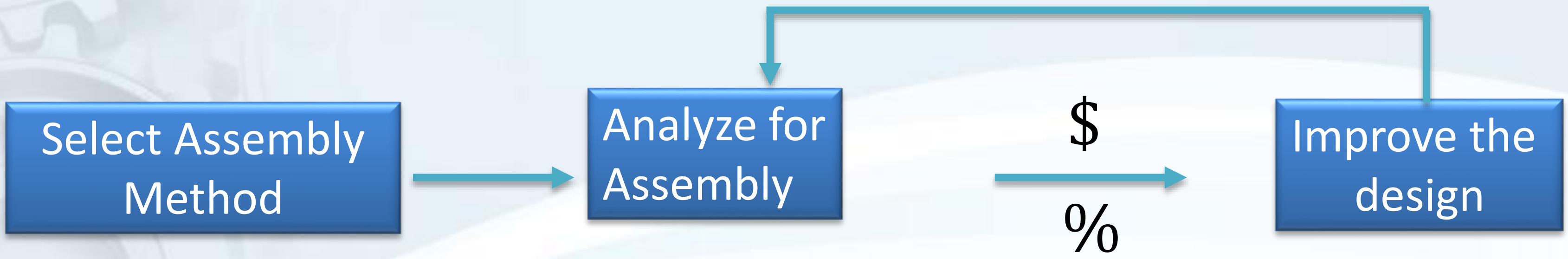
Design For Assembly (DFA)

- **DFA addresses product structure simplification, since the total number of parts in a product is a key indicator of product assembly quality.**
- **Assembly typically occupies between 40% and 60% of the total production period.**



- Manual
- Robotic
- Special purpose

- DFA principles
- BDI handbook
- Software (BDI,
- Sapphire, AEM)

- Combine
- Eliminate
- Simplify

Hint to Students

- **Continue to add to your DFMA Checklists (add to your own personal DFMA Checklist)**
- **Continue with checklist from Breakout 1**

DFA Principles

- **'Product' Design for Assembly**
  - The design of the entire product with a view to overall ease of assembly
- **'Component' Design for Assembly**
  - The design of each component for ease of assembly to its neighbors

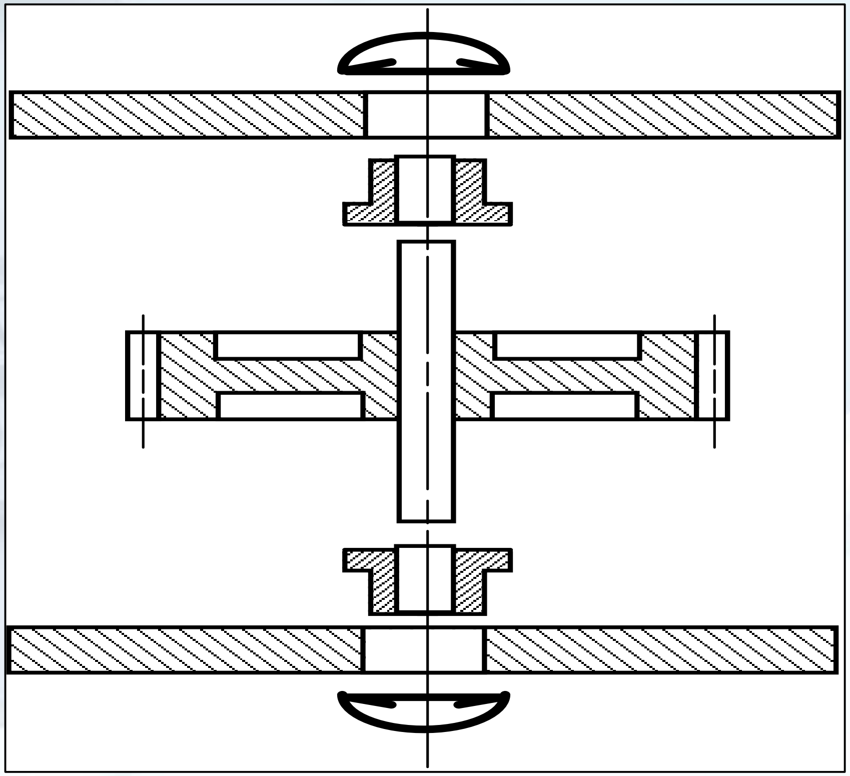
Principle 1-A: Minimizing Parts – More Profit

- **Less parts to design, document, revise**
- **Less Bill of Material (BOM) cost, parts to receive, inspect, store, handle**
- **Less labor and energy to build product**
- **Higher quality**
- **Higher profit margin**
- **More competitive in the marketplace**

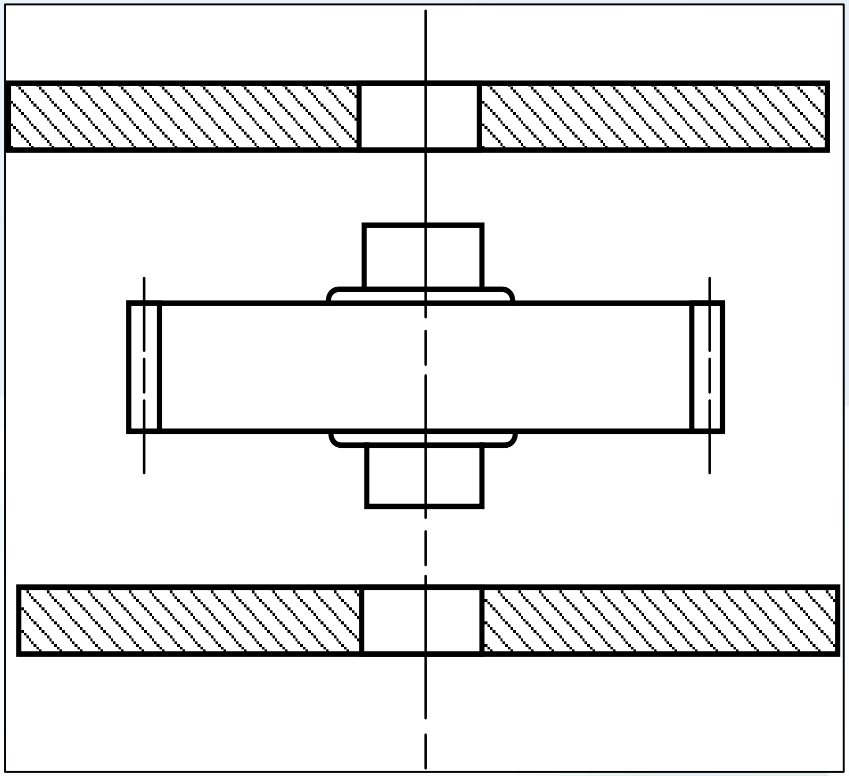
Let us make sure this is Rule 1 in the DFA Rule Book

Ex. Application of Principle #1

Old design= 8 parts

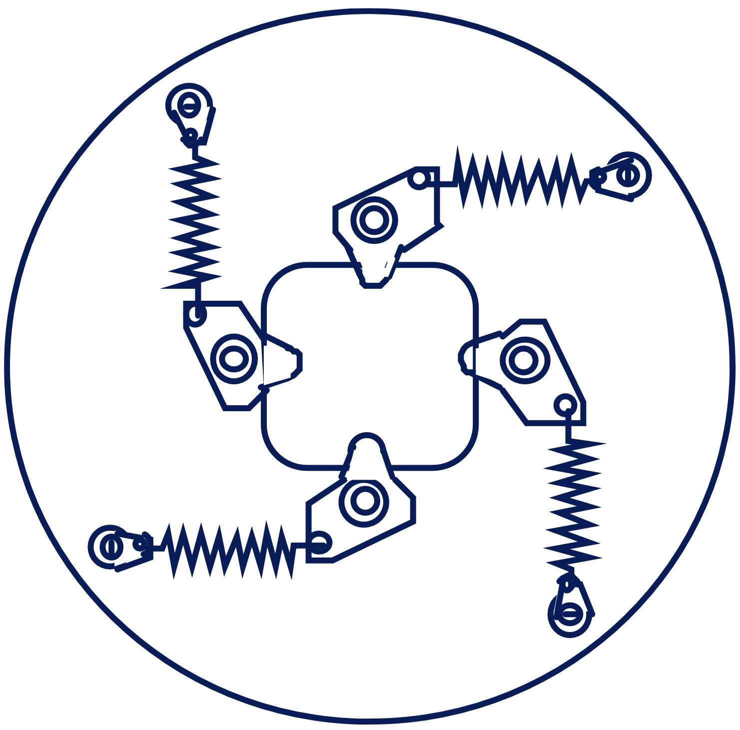


New design= 3 parts

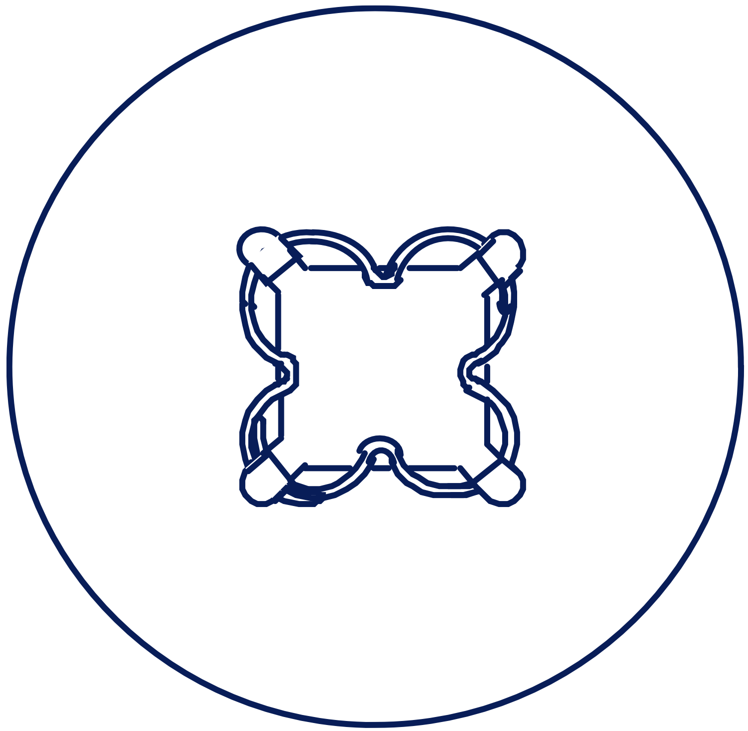


Ex. Application of Principle #1

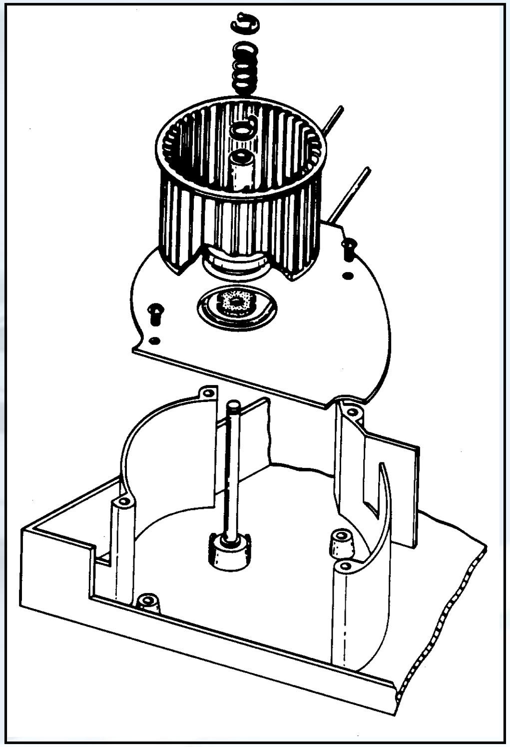
Old Design = 25 parts

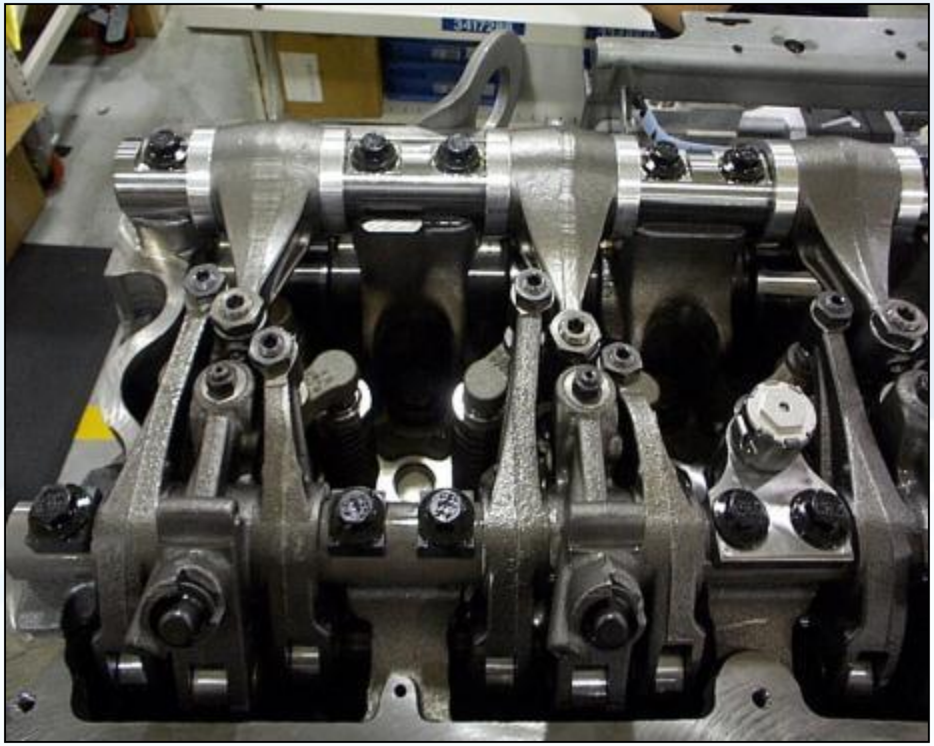


New Design = 2 parts



Top-Down Assembly





Good or Bad ?

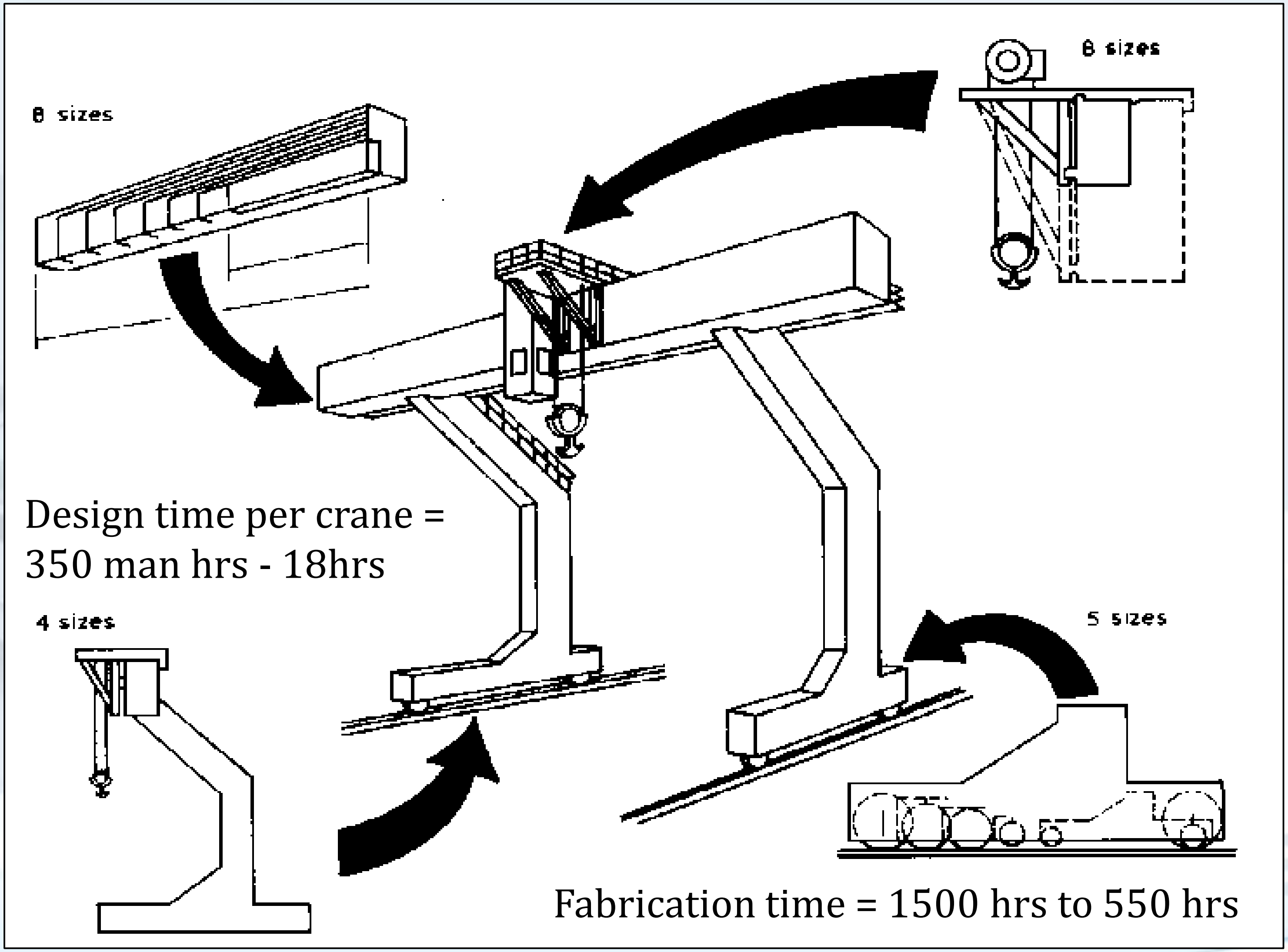
Principle A-2:
Avoid the Need to Turn the Assembly Over

- **If previously placed components have not been fastened, they may move out of position**
- **Datum and location points change, and complicate the assembly process, which leads to jamming and assembly failure**

Principle A-3:
Adopt a Modular Design Philosophy For the Product Group

- **Allows model variations to be accomplished at a sub-system level; subassembly volumes increase, total parts decrease**
- **Modular sub-assemblies may be built and tested by specialist teams (higher quality)**

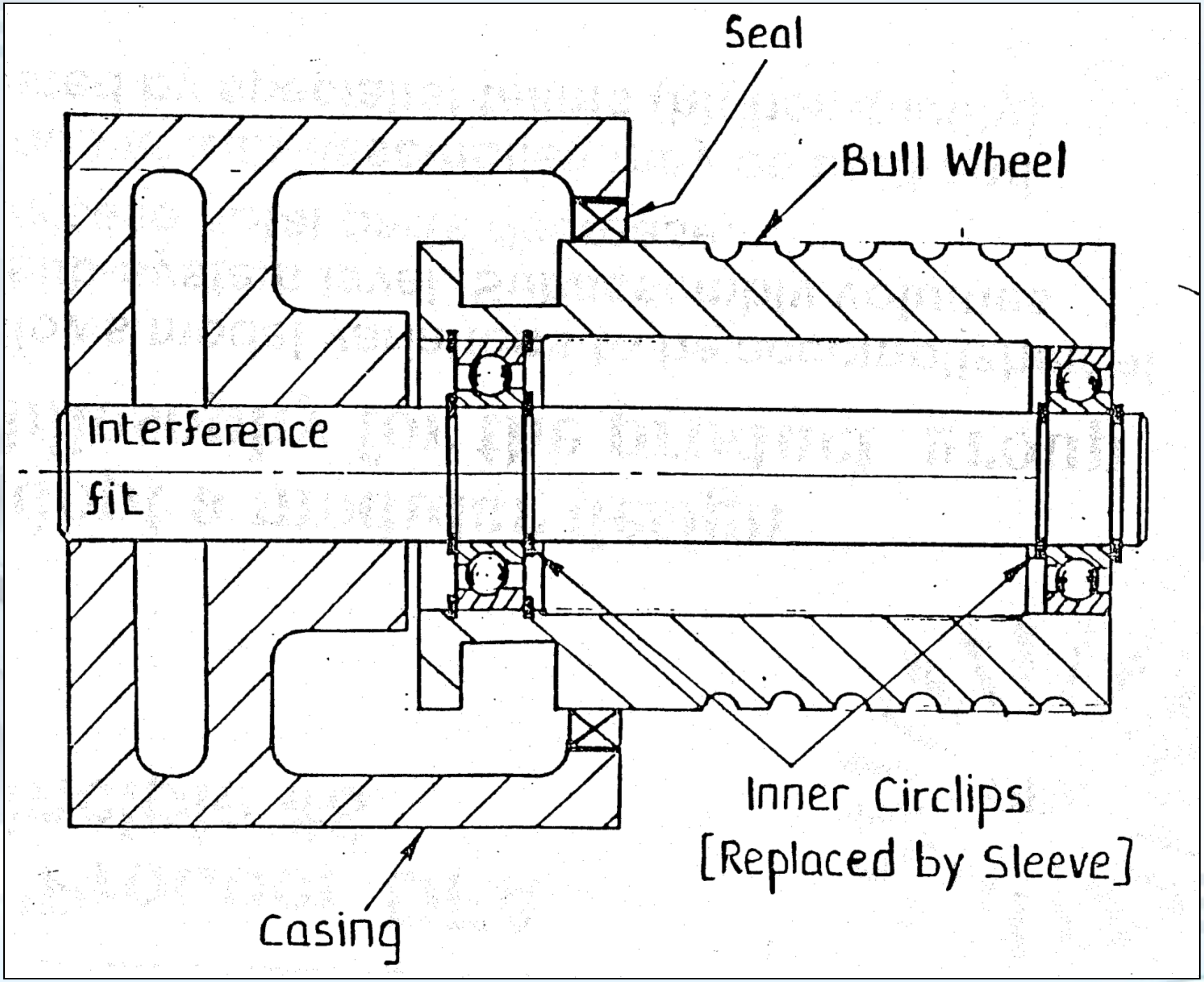
Modular Design Assembly time reduced from 540 hrs to 180 hrs



Principle A-4: Consider Ease of Disassembly For Maintenance, Service, Repair, & Recycling

- **Integral snap fits, press fits, and retaining clips allow compact designs, but if care is not taken, can result in impossible disassembly**

- **Disassembly is frequently necessary due to incorrect assembly, the need to service/repair, and now the requirement to recycle**


Seal
Bull Wheel
Interference
fit
Inner Circlips
[Replaced by Sleeve]
Casing

Allow Failure Recovery

- **Ensure that the component, subassembly or highest failure item can easily be repaired or reworked**
- **Ask:**
  - Will the entire assembly have to disassembled?
  - Where in the assembly is it?
  - Can I remove and replace it as a module
  - Can I test it offline before assembly
  - Is the failure caused in the system?

Collect this data from warranty, assembly or customer data from similar designs.
Also, identify risk from SFMEA or DFMEA

Failure Recovery In Action

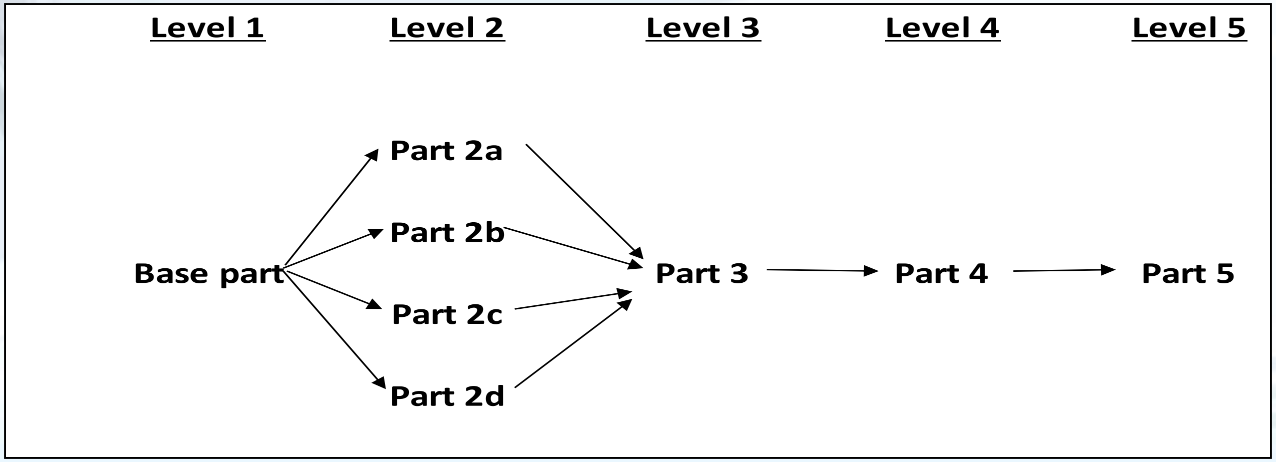
Operation	Station		Risk	In Line Testing
10	Assembly	Insert 1 , 3	High	
20	Assembly	Insert 2, 5	Low	
30	Insert Module	Insert Sub Assy	High	Test in Line
40	Assembly	Insert 4	Low	
50	Dyno Test			
55	Final Inspect			

Product is assembled vertically

Principle A-5: Select the Assembly Sequence

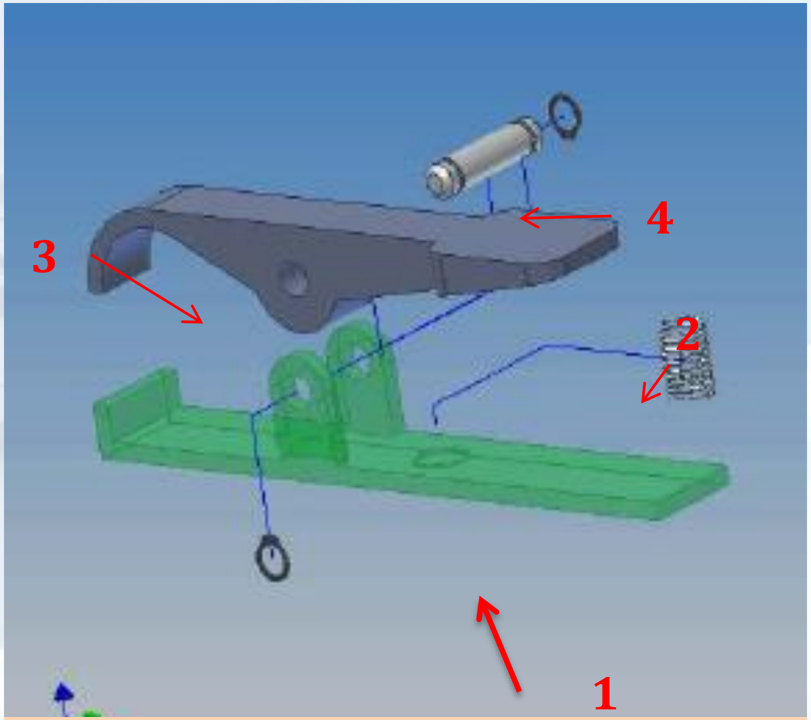
Precedence Diagram

- **One of the most useful tools available for selecting the assembly sequence of a product to maximize the performance for a particular assembly method.**
- **The Precedence Diagram examines how the product may be assembled part (operation) by part (operation)**

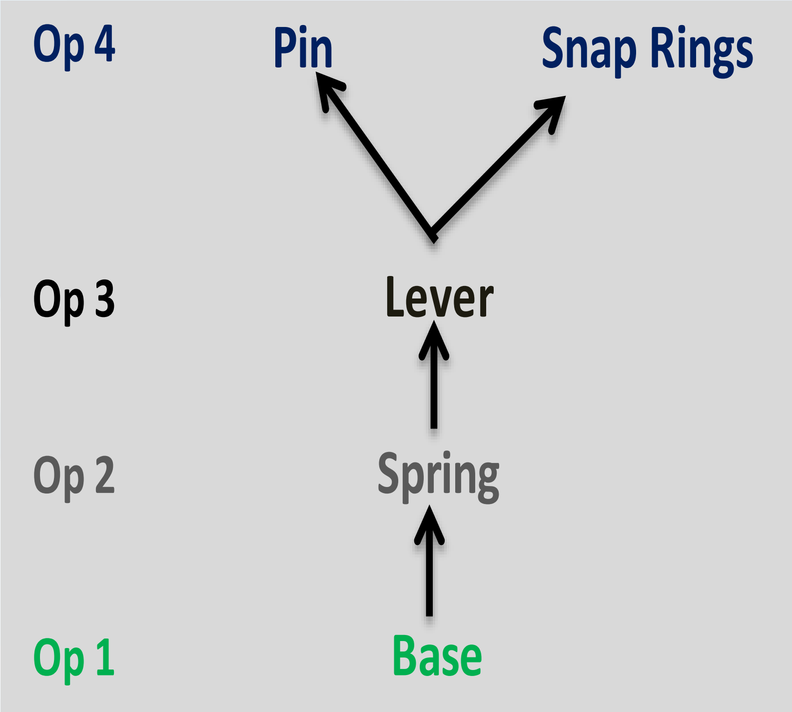


Precedent Diagram Example: Spring Loaded Clamp

- **This product can be divided into 4 sub-assembly operations: Base, Spring, Lever, and Pin & 2 snap rings**
- **Next, what is the first part to be assembled?**



Exploded View of Spring Load Clamp



Precedent Diagram of Spring Load Clamp

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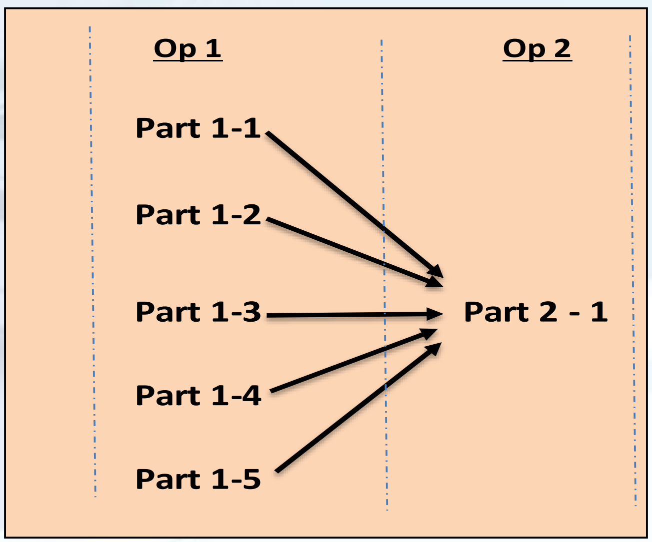
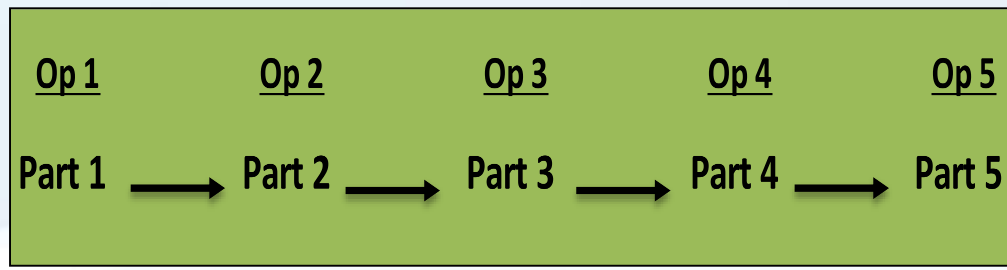
Increase Flexibility using a Precedence Diagrams

- **A Precedence Diagram helps to determine the order in which a product is assembled**
- **Using a precedent diagram, all the possible sequences of assembly can determined and considered**



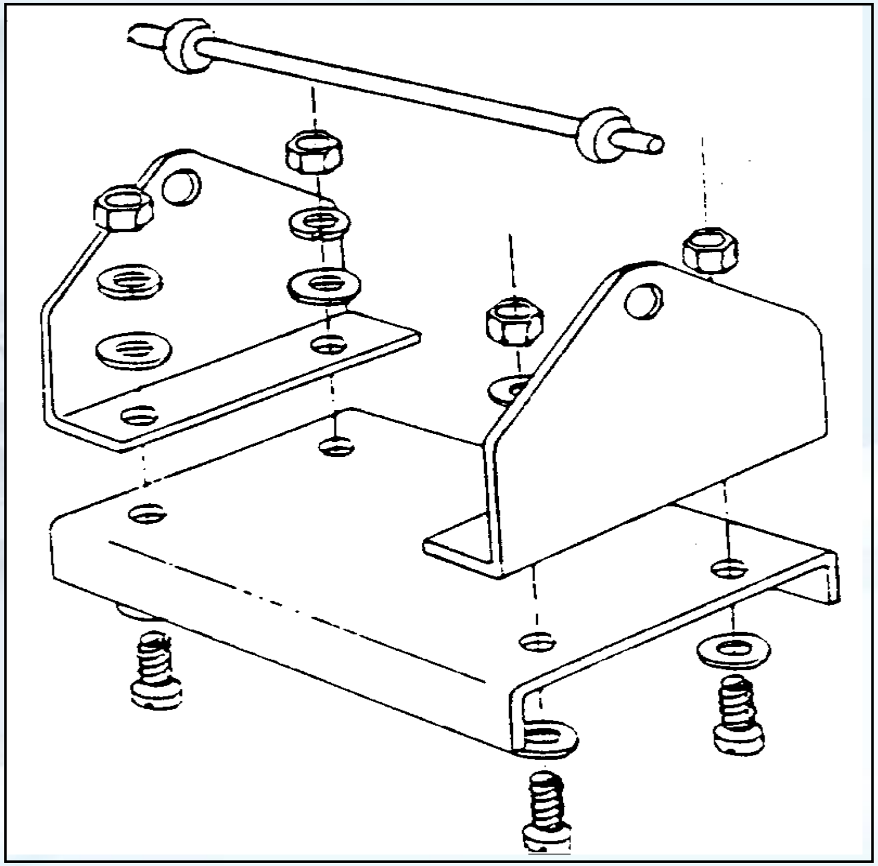


Worst Possible Precedence: Stacking assembly with no re-orientation of the sub-assemblies or operations.

Perfect Precedence: Parts can be assembled at any point in the sequence

Breakout Exercise 3: Precedence Diagram

Using the carrying case from Breakout Exercise 2, draw a Precedence Diagram for the assembly



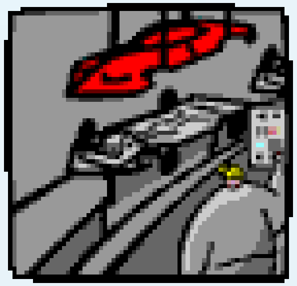
Page 31,figure 3.1

Hint:

1. Divide the product into sub-assemblies or operations.
2. Determine the first part of the product to be assembled
3. Are there any parts that have to be covered, flipped, or turned to assemble?
4. Best case allows for multiple points for assembly

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**

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

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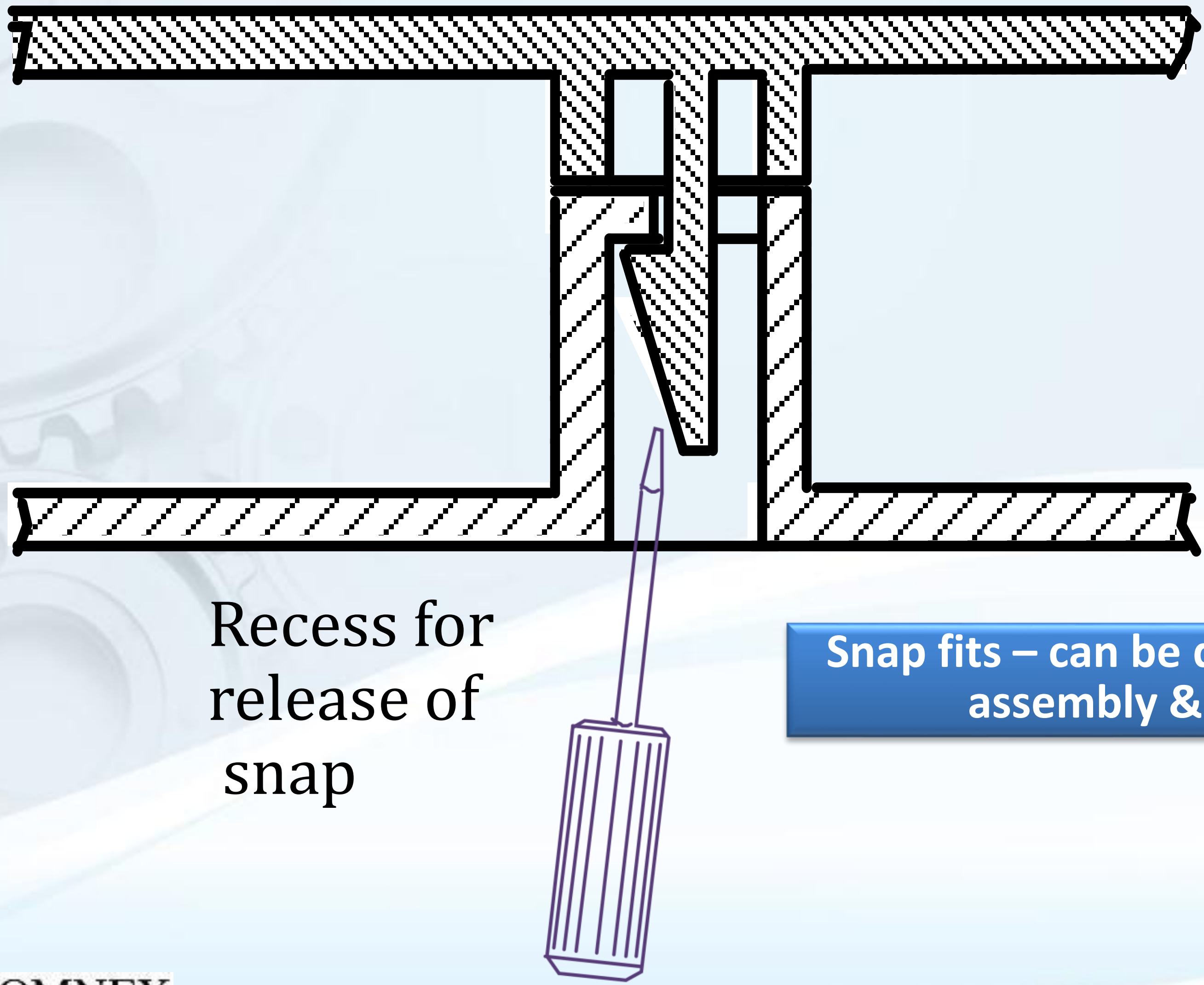
Principle A-6: Minimize the Number of Fasteners

- **Minimize number of fasteners and their components**
  - Use snap fits where possible
  - Use press fits where disassembly is not required
  - Consider molded hinges, straps, or hook-unders
  - Rationalize fasteners – types, lengths, etc.
  - Use one piece fasteners with lead in pilots
  - Design geometry for automatic alignment

Ex. Applications of Principle A-6

Hook-under design to minimize number of fasteners

Ex. Applications of Principle A-6

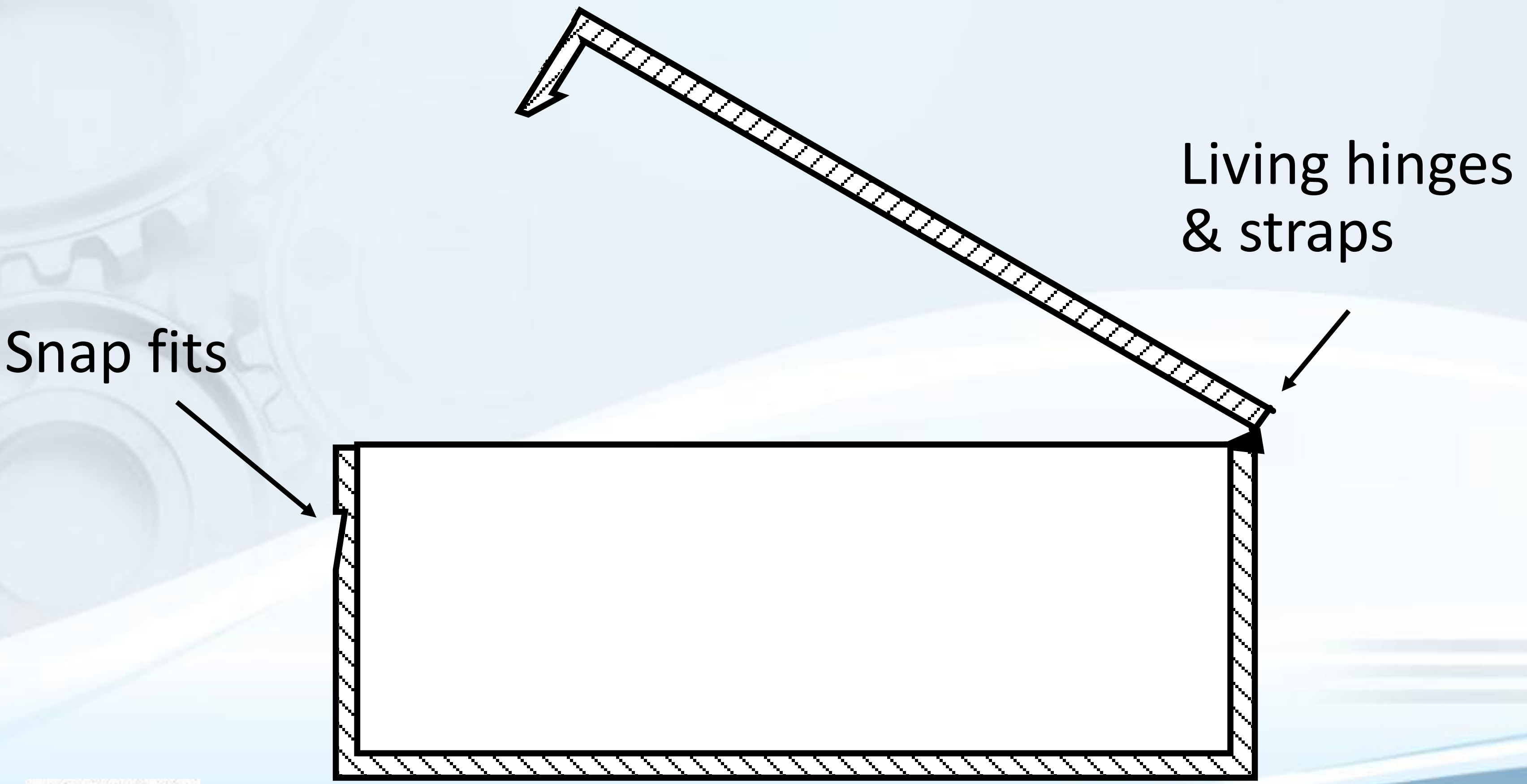


Recess for release of snap

Snap fits – can be designed for ease of assembly & disassembly

Ex. Applications of Principle A-6

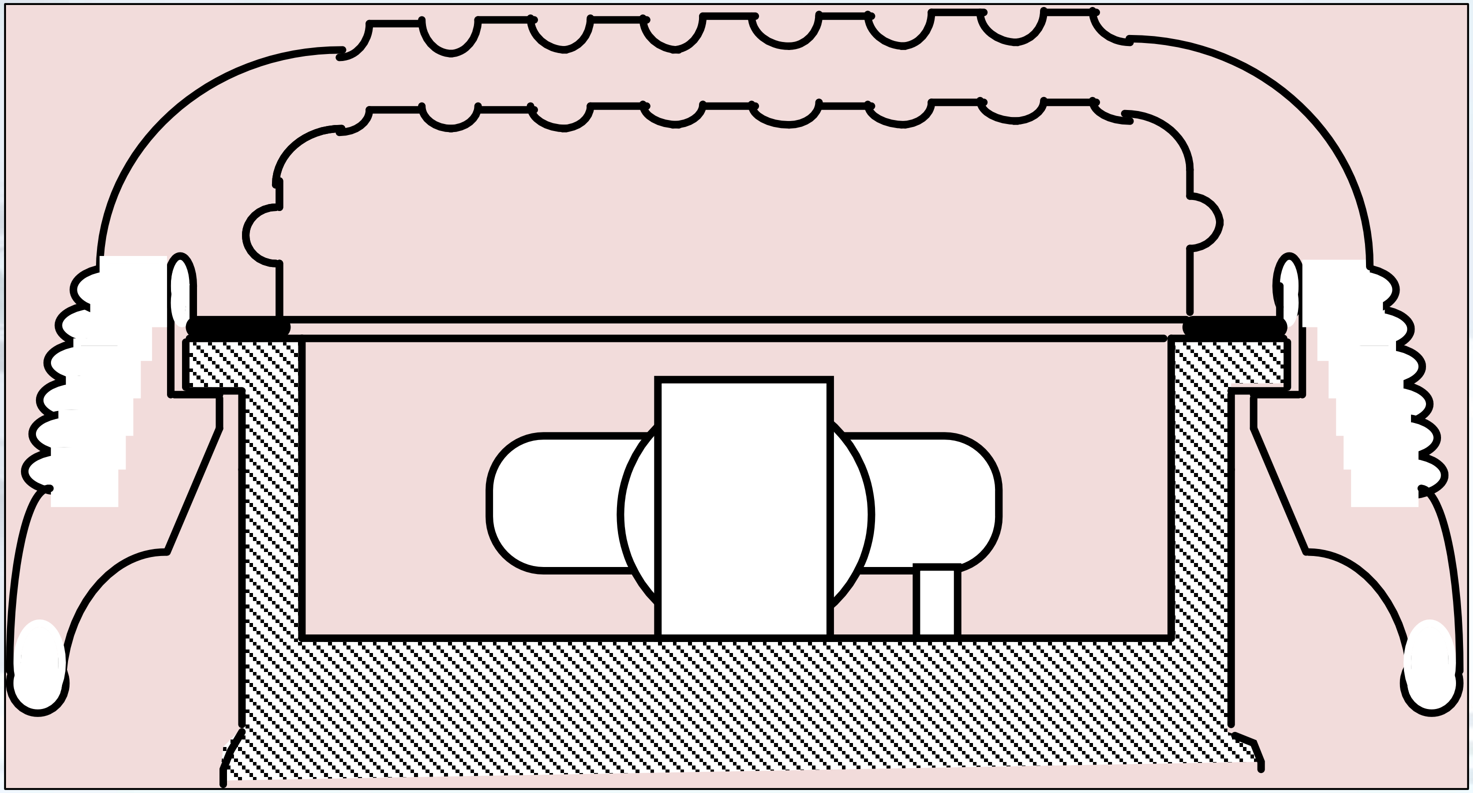
Hinges, straps
and/or snap fits:



Ex. Applications of Principle A-6

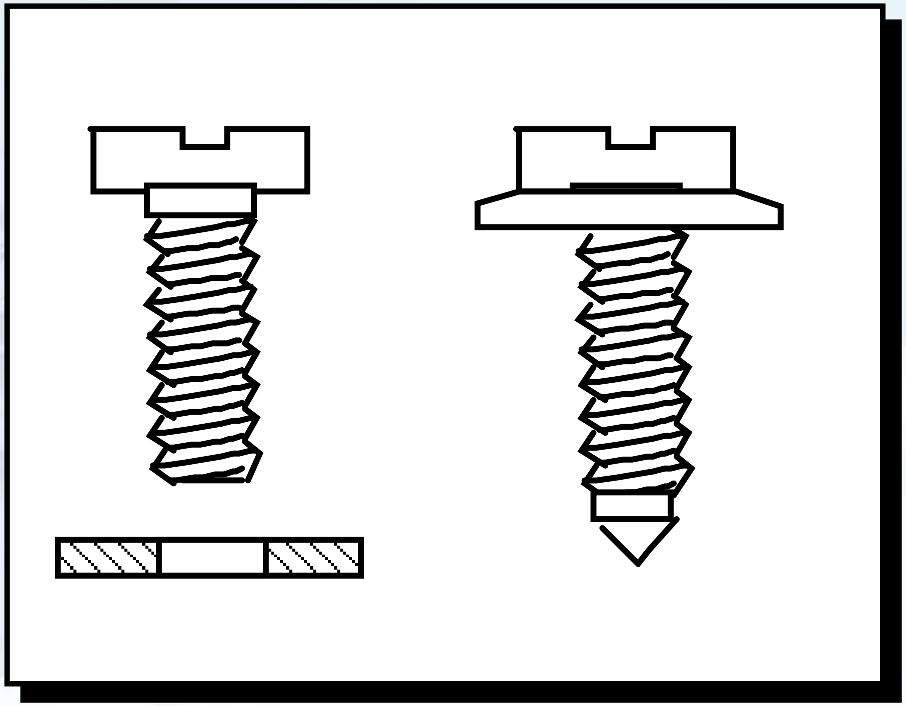
Rocker-box example:

Good ergonomics / style

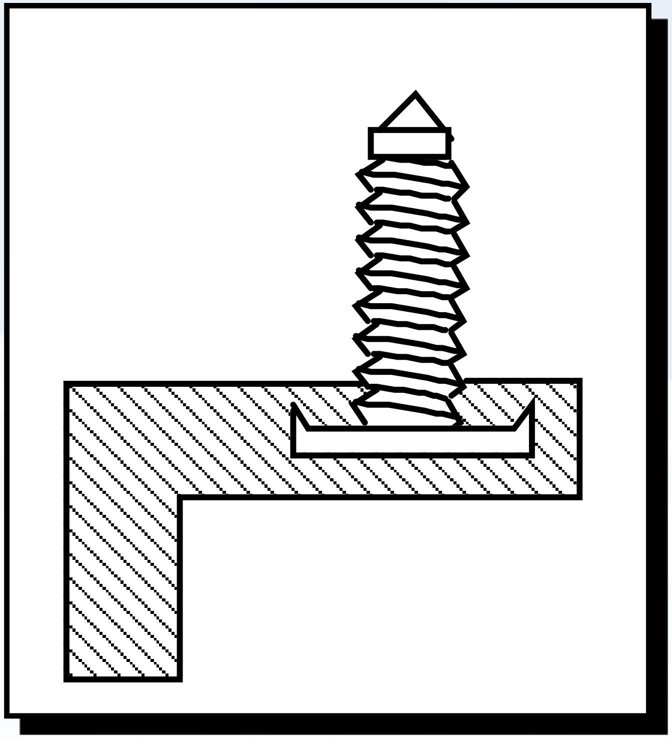


Ex. Applications of Principle A-6

Use single-piece fasteners, with guide pilots

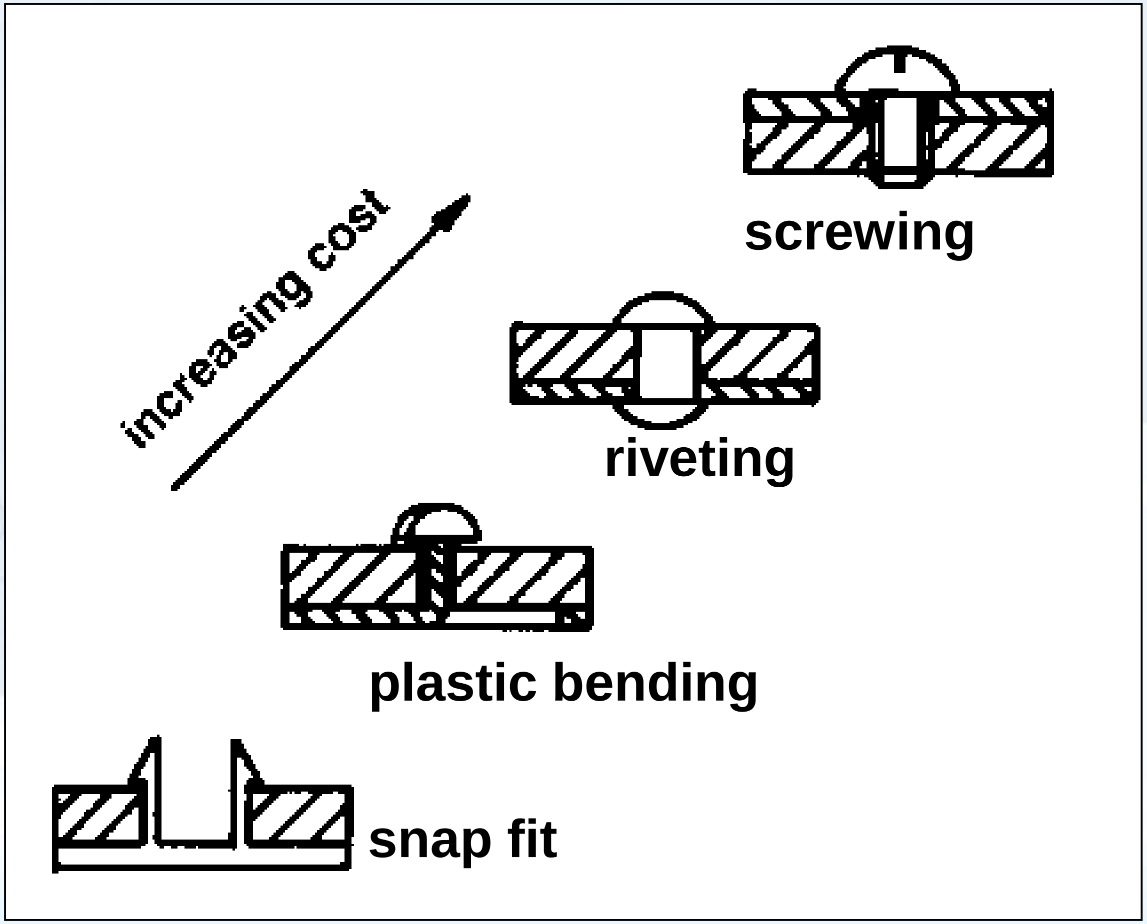


or inserts

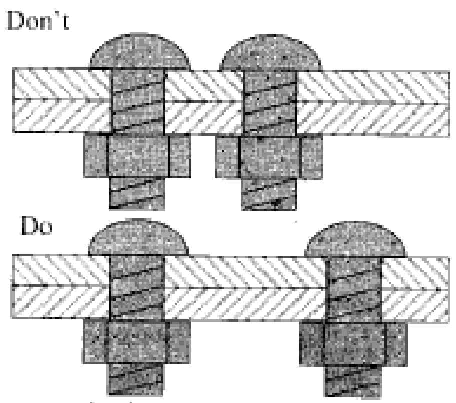


Fastener Cost

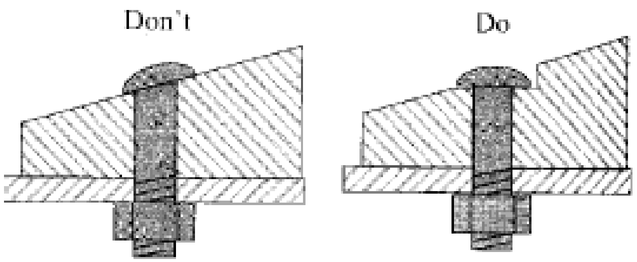
- **Select the most inexpensive fastening method required**



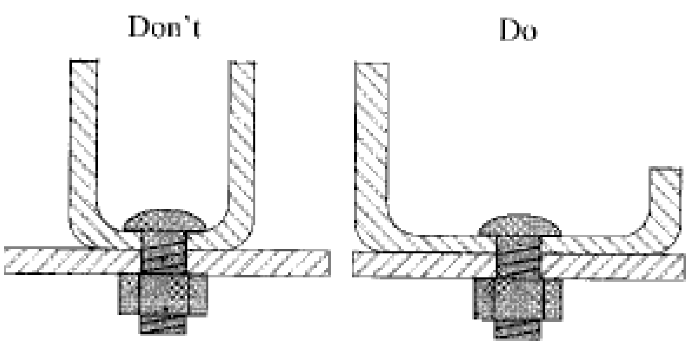
Develop Fastener Design Rules



Proper spacing insures allowance for a fastening tool.



Providing flats for uniform fastening and fastening ease.



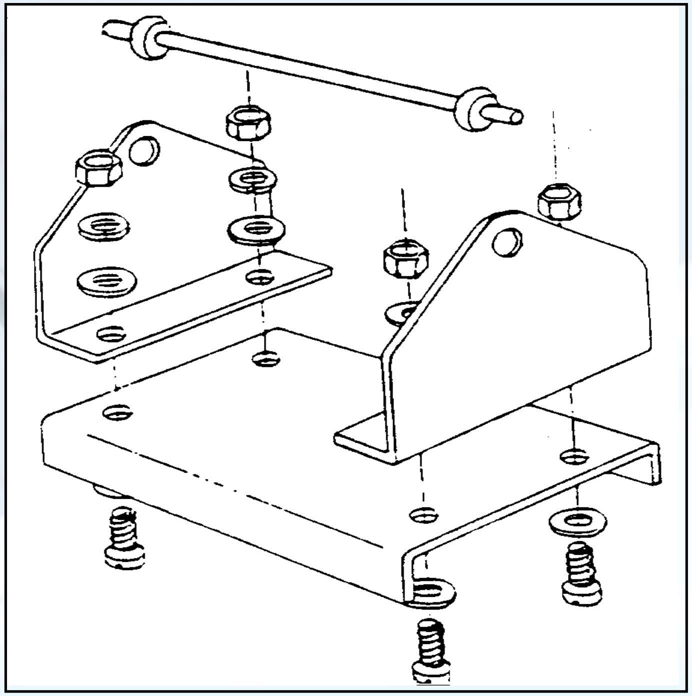
Deep channels should be sufficently wide to provide access to fastening tools. No channel is best.

More Fastener Design Rules

- **Deep channels should be sufficiently wide to provide access to fastening tools; eliminate channels if possible**
- **Provide flats for uniform fastening and fastening ease**
- **Ensure sufficient space between fasteners and other features for a fastening tool**

Breakout Exercise 4: Simplify the Design

- **Using the Design Rules discussed in this chapter, identify opportunities to simplify the Pneumatic Piston Assembly. Draw a precedence diagram and apply the techniques discussed to the assembly. Use the simplified design from the previous breakout.**



Existing Roll Bar Design consist of:

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

Hint: If more than 1/3 of the parts are fasteners, the assembly logic should be questioned.

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Apply All The DFA Rules

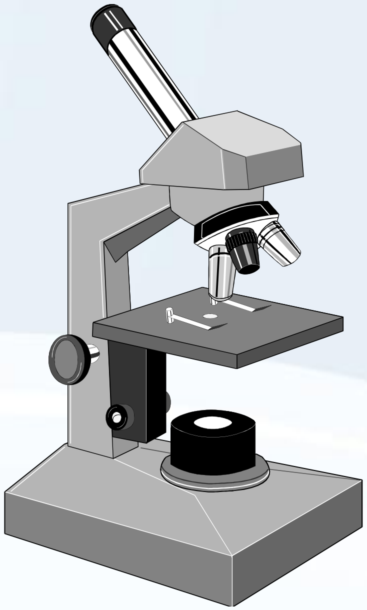
- Minimizing Parts – Use the BD Technique
- Reducing Number of Operations
- Precedence Diagrams
- Allowing Failure Recovery
- Ensure Product Standardization
- Making Alignment Easy
- Make Insertion Easy
- Allow One Direction of Insertion
- Allow Easy Stacking
- Orienting Features
- Parts Handling
- Fastener Design Rules

Chapter 5

Optimizing Design for Assembly Method

Sequence of Analysis

Concept Design	Apply General Design Principles
↓	
Design for Assembly	Optimize Design for Part Count and Assembly
↓	Apply DFA Design Rules
Design for Manufacturing	Design for Assembly and Choose Assembly Method
↓	
Detailed Design	Optimize Design for Production Process



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Focus of this Chapter

- **Design rules for Design for Manufacturing is process-dependent and should be created**

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Content

- **Conduct analysis of the assembly flow using an analytic method – Hitachi AEM**
- **Study different types of assembly methods including the design rules for each type of method**
- **Understand how to select which type of Assembly method**
- **Principles as per assembly methods.**

Intro to Design for Assembly Method

- **When planning to optimize the design of the product, it is important to have a measure of how efficient the design is in terms of assembly**

Hitachi AEM allows a DFMA team to evaluate motion, fixturing, and joining factors of an Assembly Flow

Methods for Evaluating and Improving Product DFA

- **There are a number of different methodologies for evaluating and improving product DFA**
- **The methods are based on measuring the ease or difficulty of handling parts and assembling into a given product**
- **Analytical procedures are followed where design problems are detected and quantitatively assessed**
- **DFA Most Common Evaluation Methods:**
  - Hitachi Assembly Evaluation Method (AEM)
  - Lucas DFA Evaluation Method
  - Boothroyd – Dewhurst DFA Method (preferred)

Hitachi Assembly Evaluation Method (AEM)

- **Originally, employed to refine the design of tape recorder mechanism in order to develop an automatic assembly system**
- **The method does not distinguish between manual and automatic assembly. The Hitachi AEM approach is based on assessing the assembly of the design based on two indices:**
  - The assembly evaluation score € is used to assess design quality or difficulty of the assembly operations.
  - The estimated assembly cost ratio (K) is an indication of the assembly improvements.

Hitachi AEM Scoring

Direction of Motion

The Hitachi method uses symbols to represent operations

O*M*N*E*X*

Penalty score is determine for each part to give the assembly evaluation score for that part

Symbol	Penalty Point	Description of Operation
↓	0	Straight Downward
↑	30	Straight Upward
← →	20	Move Horizontally
↗ ↙	30	Move diagonally up/down
∩ C	30	Turn like a screw
R	40	Turn or lift the whole assembly to insert a part

Hitachi AEM – Fixturing and Joining

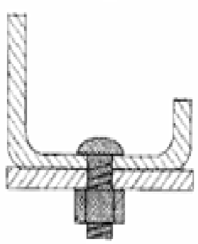
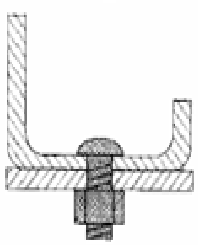
Symbol	Penalty Point	Description of Operation
f	20	Hold a part for next one operation
F	40	Hold a part for more than next one operation
G	40	Deform a soft/flexible part (O-ring/gasket)
P	20	Bend or cut (wire,..)

E values for all parts are then combined to produce an assembly evaluation score for the whole assembly

Symbol	Penalty Point	Description of Operation
B	20	Bond with adhesive or heat or lubricate a part
W	20	Weld

Hitachi AEM

- **K is the ratio between the assembly cost of the new (modified) design divided by the assembly cost of the initial and/or standard design**

Step / Examples	Product Structure and assembly operations			E, Part assemblability evaluation score	E, Assemblability evaluation score	K, Assembly cost ratio	Part to be improved
Structure 1		C ↓	Set Chassis A	100	73	1	B
		B ↓	Bring down block B and hold it to maintain its orientation	50			
		A ↓	Fasten screw C	65			
Structure 2		C ↓	Set Chassis A	100	88	approx. 0.8	C
		B ↓	Bring down block B orientation is maintained by spot-facing	100			
		A ↓	Fasten screw C	65			

- **Any savings in the assembly cost can be achieved by reducing the parts count in a product and/or simplifying the assembly operations**

Lucas DFA Method

- **Unlike AEM, the Lucas DFA evaluation is not based on monetary costs, but three indices to give a relative measure of assembling difficulty**

- **Analysis is carried out in three sequential stage:**
  1) Functional Analysis
  2) Feeding (or handling) Analysis
  3) Fitting Analysis

Lucas DFA Methods (cont'd)

Functional Analysis:

- **Components are divided into two groups**
  - Components perform primary function = A
  - Component perform secondary functions = B
- **Design Efficiency (D.E.) is given by: D.E. = 100 * A / (A + B)**
- **If D.E. is low, Design is improved by eliminate part B**

Feeding Analysis:

- **Feeding / Handling index is calculated based on size, weight, handling difficulties, and orientation of part.**
- **Feeding/Handling ratio is calculated as:**
  - Feeding/Handling ratio = Feeding/handling index / Number of component A

Lucas DFA Methods (cont'd)

Fitting Analysis

- **An index is given to each part based on its fixturing requirement resistance to insertion.**
- **The fitting index is manipulated to yield the fitting ratio as:**

Fitting ratio = fitting Index/ number of essential components

Example:

- **If a component has rotational symmetry and concealed end-to-end asymmetry and mass not at geometric center and parts envelope is a long cylinder then possible method**
- **Orientate using swing tooling**
- **Efficiency 0.5**
- **Tooling time 15 hours**

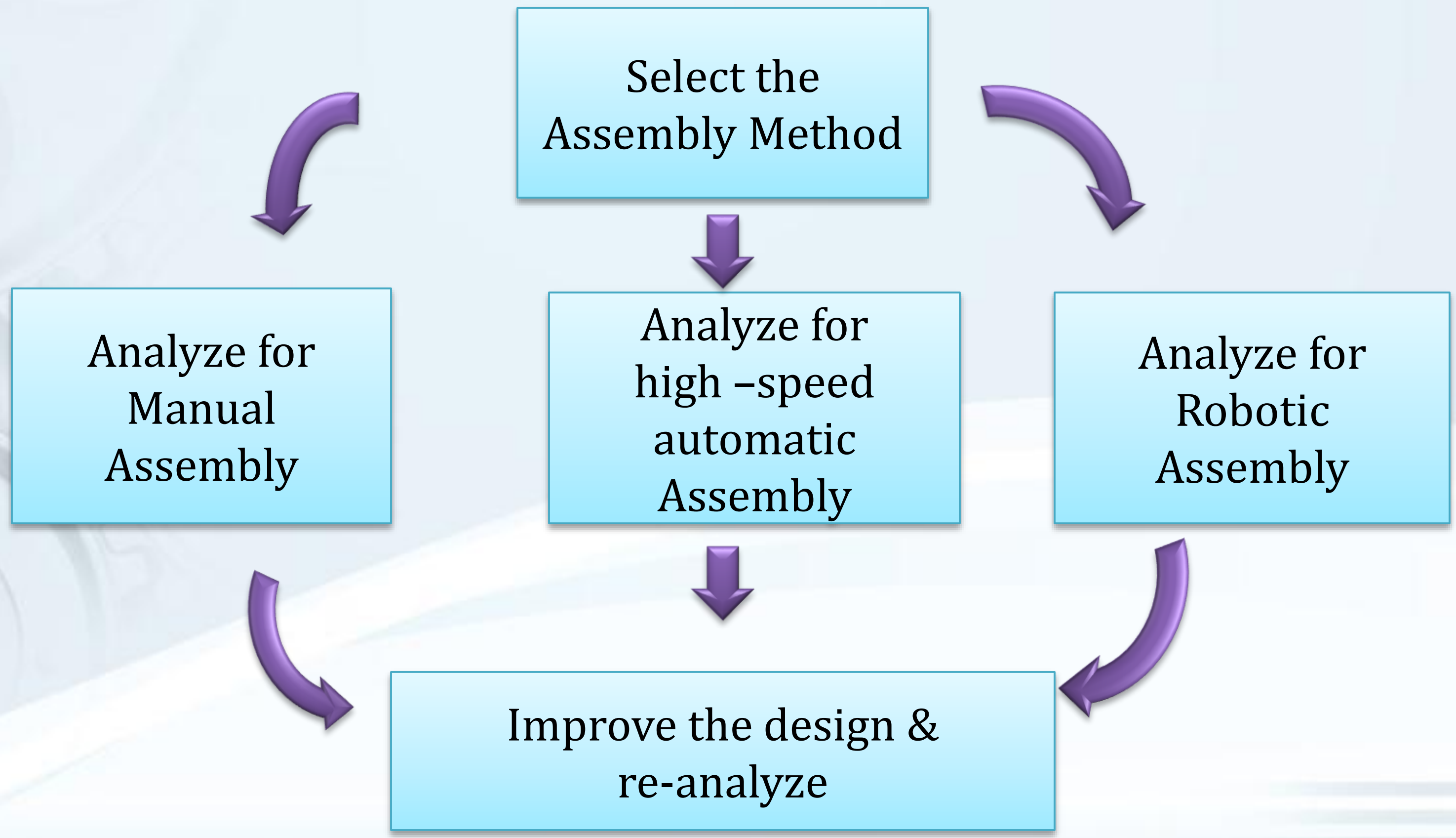
Lucas DFA Method – Example

The feeding (or handling) analysis consist of questions about each component, the answers which are used to determine a feeding index. An example taken from the knowledge base is given below:

- **Substrate cover – If component is a flat regular prism and can maintain a stable orientation on track and has only slight asymmetry or has features too small for mechanical tooling then possible method**
  - Orient with remote (optical, laser) tooling
  - Cost index 3
  - Design advice: consult FRP file.

Boothroyd-Dewhurst DFA Method

The first stage in Boothroyd-Dewhurst DFA Method is to select the assembly method



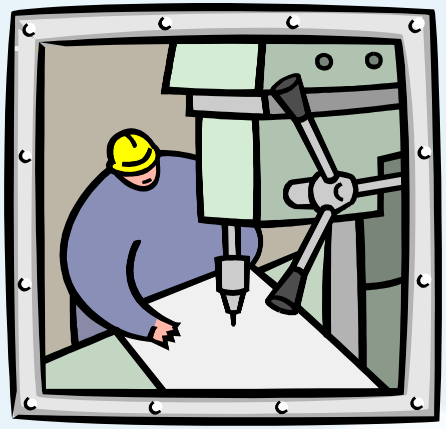
The method to calculate the design efficiency was discussed in chapter 3

Design for Assembly

- **There are 3 major design group methods:**

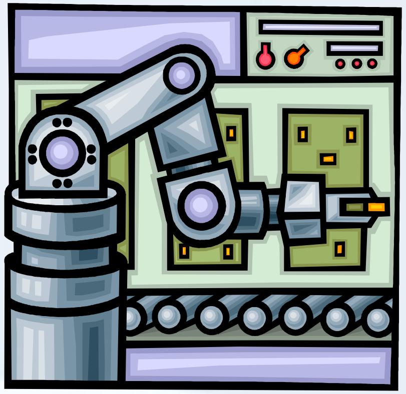
Manual Assembly

- Human assembly
- Single tool
- Bench or transfer line



Fixed or High-speed Automation

- Machine assembly
- Transfer device



Soft Automation or Robotic Assembly

- Robot arm operated
- Single station or multi-station free-transfer machine

Design Rules for Manual Assembly

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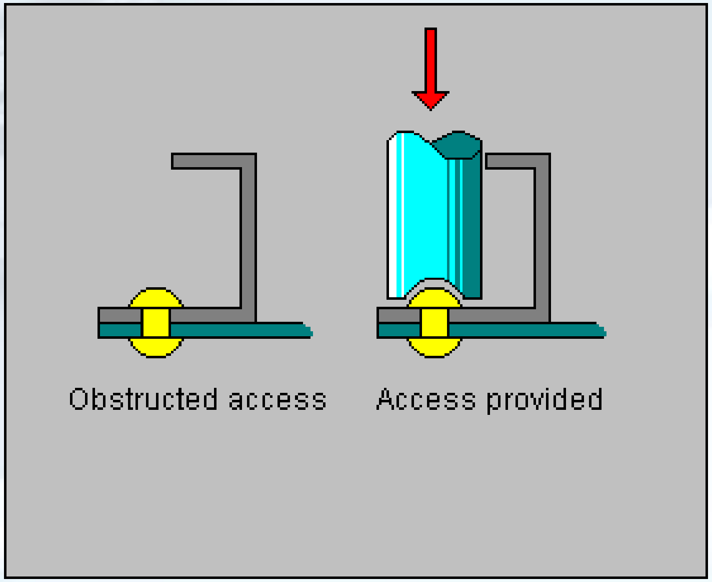
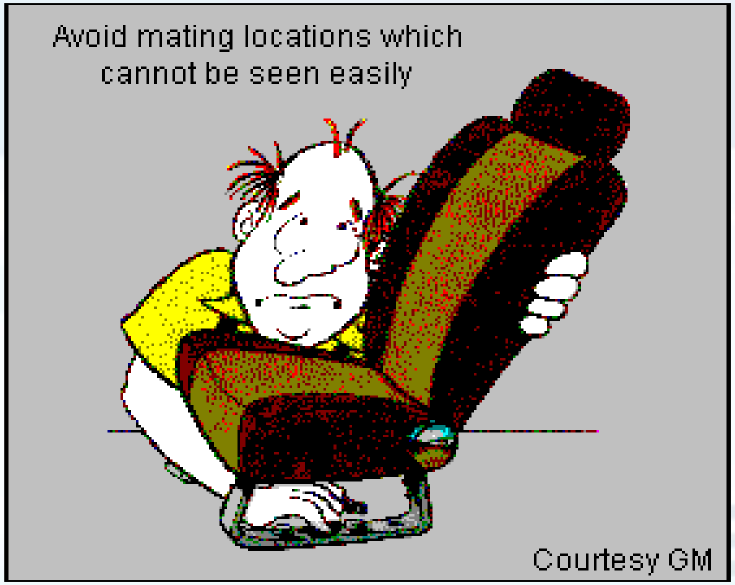
Manual Assembly – Advantages

- Tools employed are simple and inexpensive
- Cost remains relative constant and independent of production volume
- Great flexibility and adaptability

Manual Assembly Rule 1: Design for Accessibility & Visibility

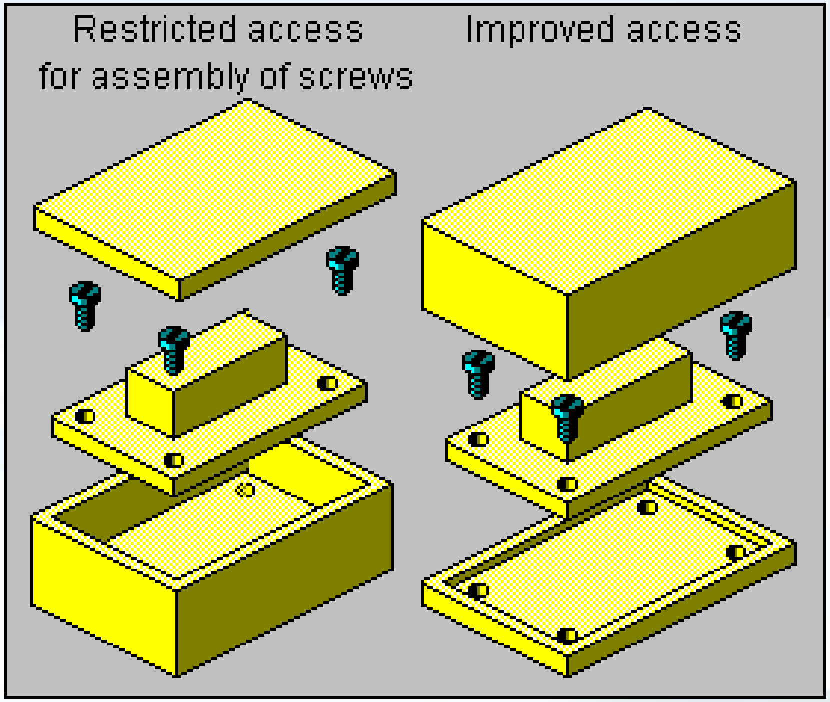
- **Depending on the skill set of the worker:**
- **Eliminate the need for workers to make decisions or adjustments**
- **Ensure accessibility and visibility for Operator**



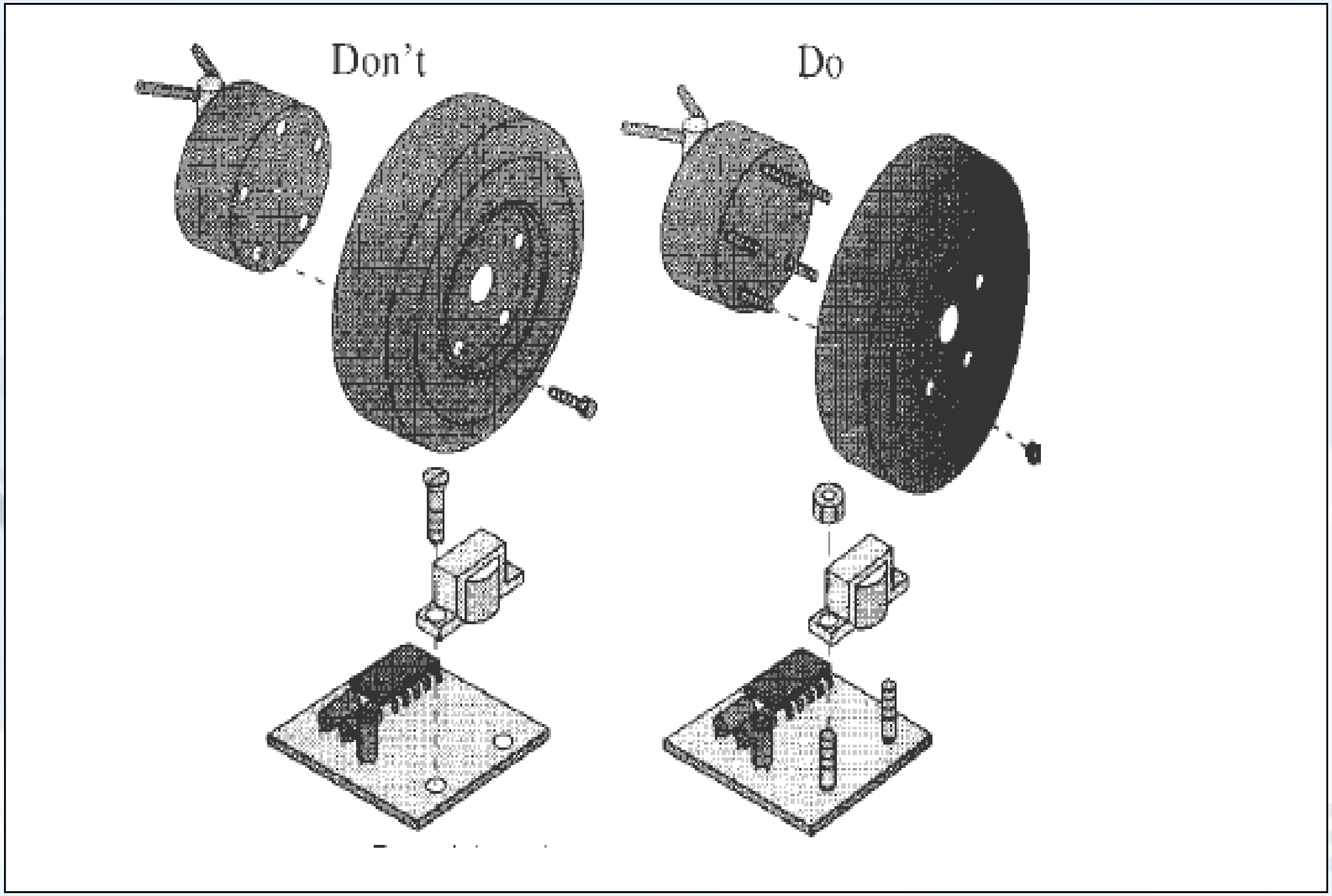


Manual Assembly Rule 1: Design for Accessibility & Visibility

- **Design to allow assembly in open spaces, not confined spaces. Do not bury important components**

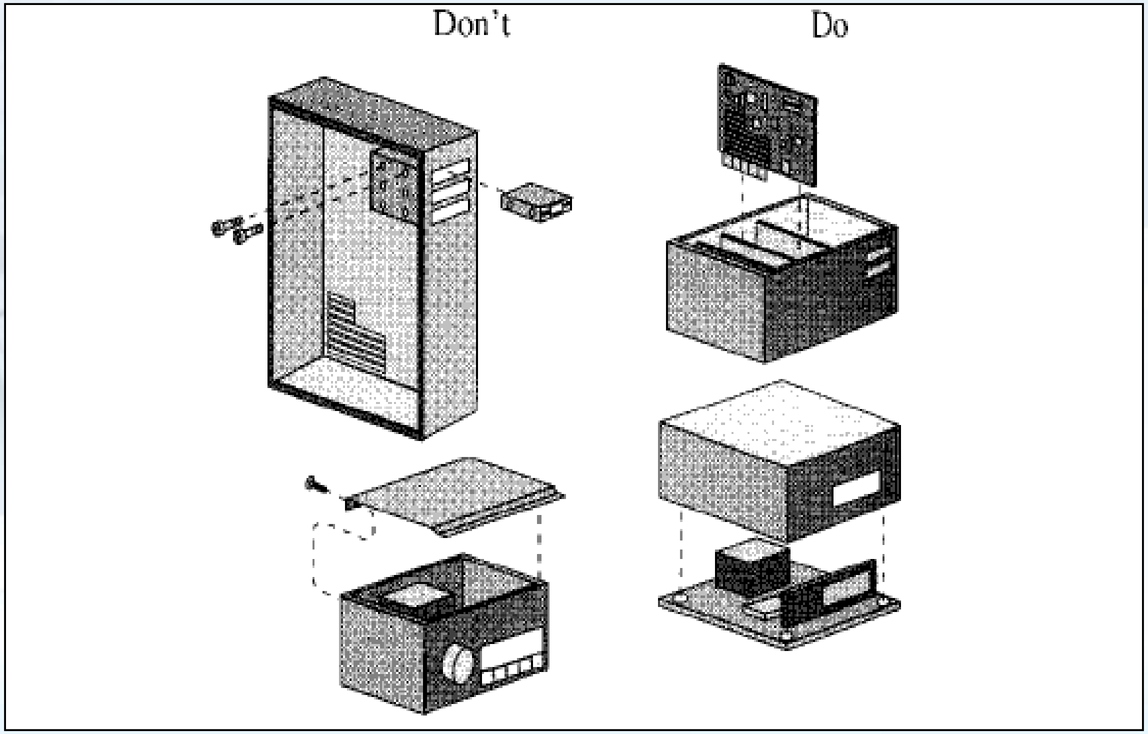


Manual Assembly Rule 2: Design to Make Insertion Easy

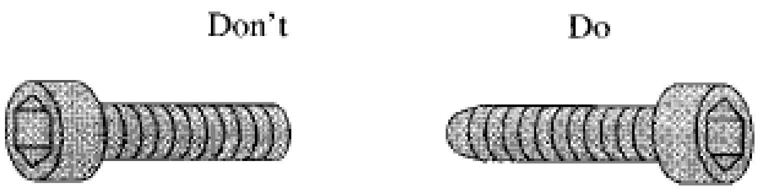


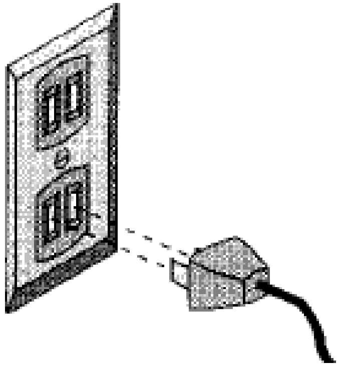
Manual Assembly Rule 3: Design for Assembly One Direction

- **Where possible assemblies should be designed so that a base piece is established, and remaining parts assembled from one, ideally vertical (Z) direction.**



Manual Assembly Rule 4: Design to Make Alignment Easy

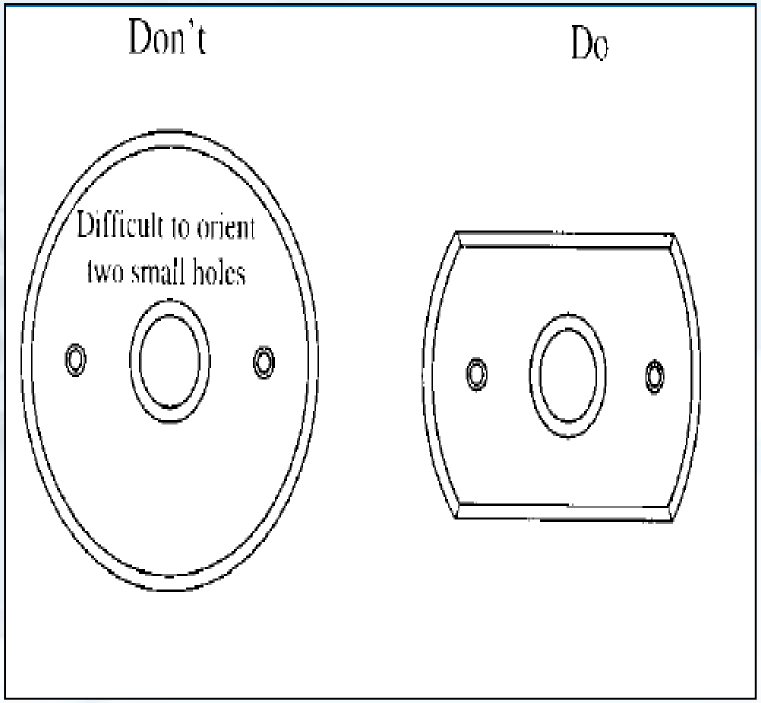


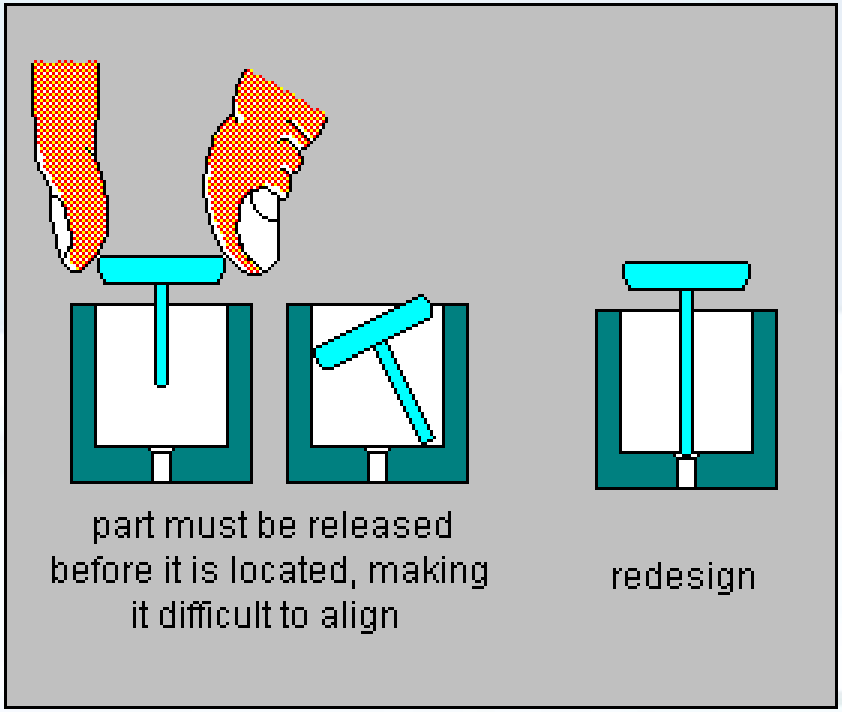


Design Parts to be Self Aligning

Manual Assembly Rule 4: Design to Make Alignment Easy

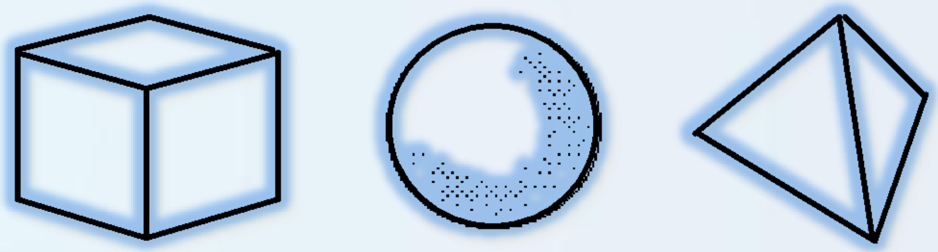
- **Design parts with orienting features make alignment easier.**



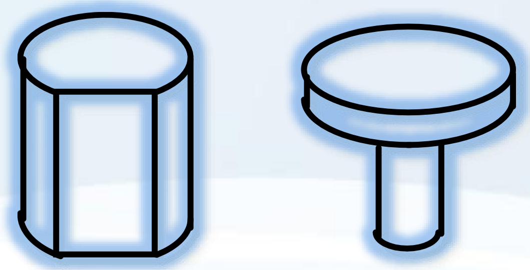


Manual Assembly Rule 5: Components Should be Symmetrical

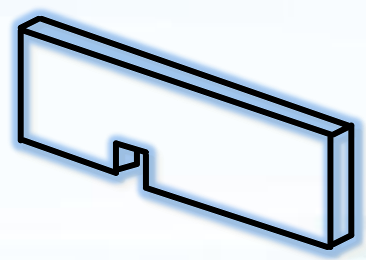
Symmetrical shapes have a predictable rest aspect $\Rightarrow$



Non-symmetrical shapes have an unpredictable resting aspect $\Rightarrow$

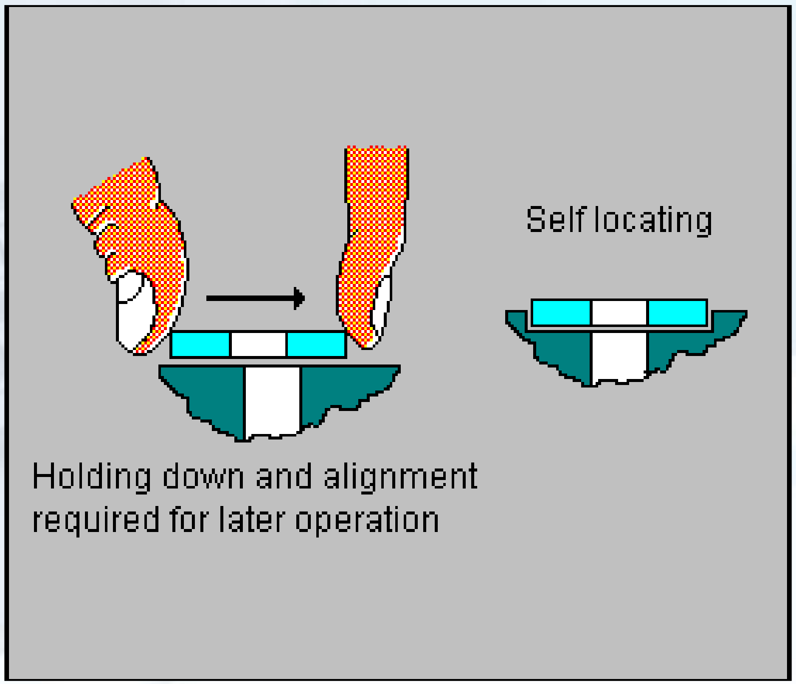


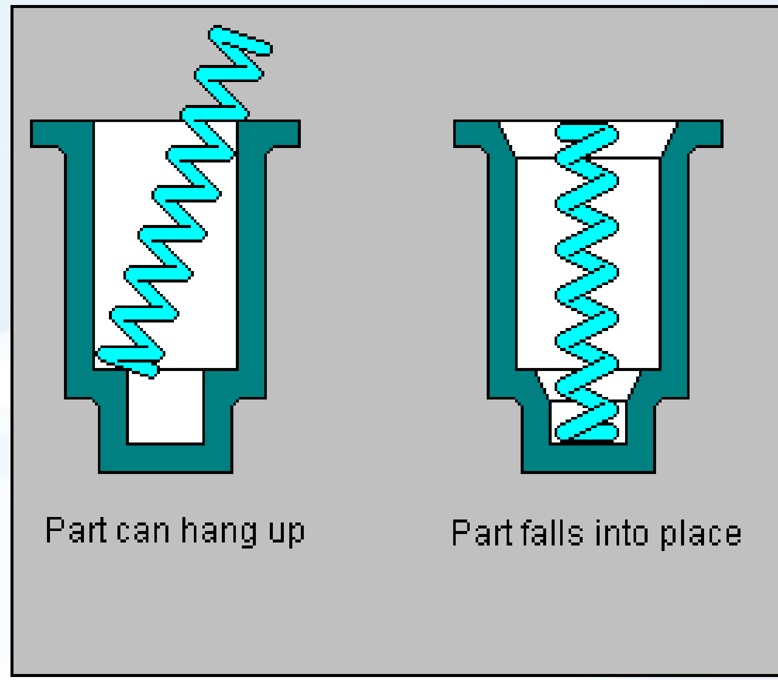
exaggerated assymetry and part falls on one of its flat faces $\Rightarrow$



Manual Assembly
Rule 6: Design to Minimize the Use of Assembly Tools

- **Eliminate the need for assembly tools and gauges (prefer self-locating parts)**





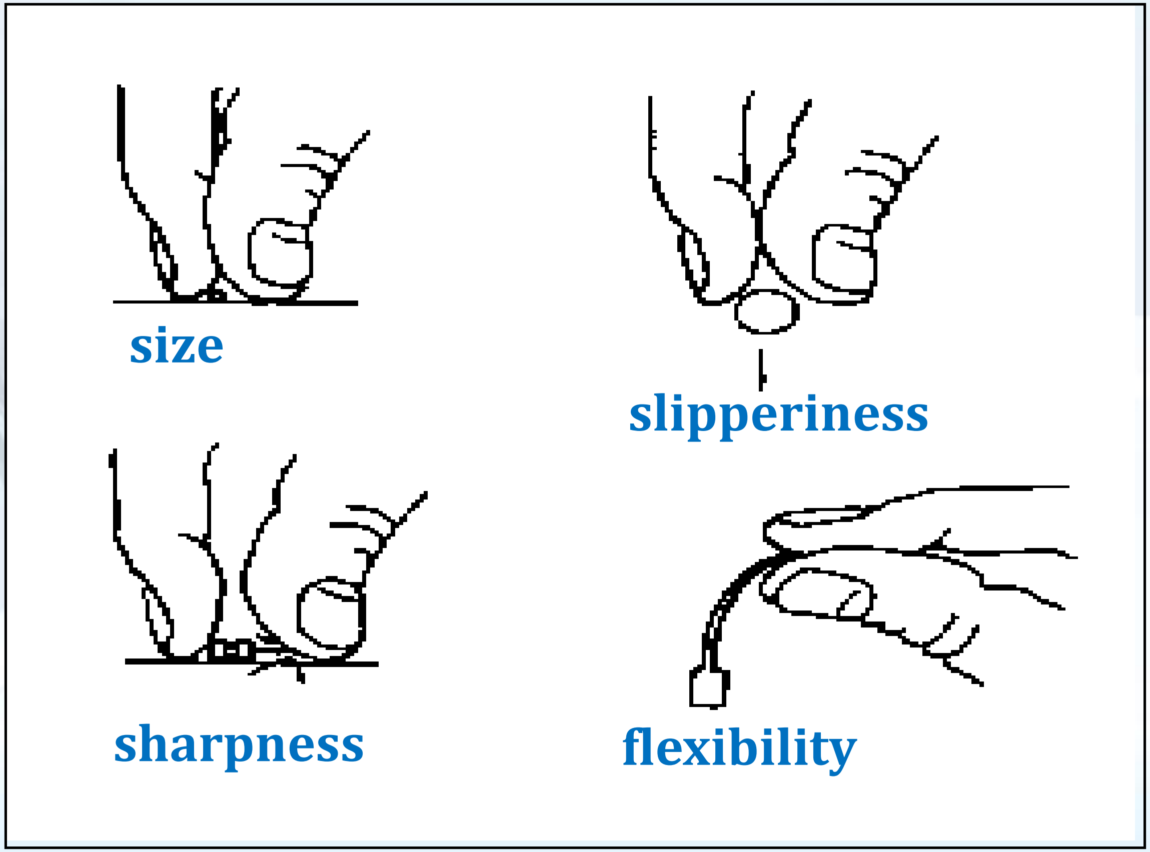
Manual Assembly Rule 7: Handling Difficulty

Are parts easy to handle, sharp, slippery, or fragile? Consideration must be given to:

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

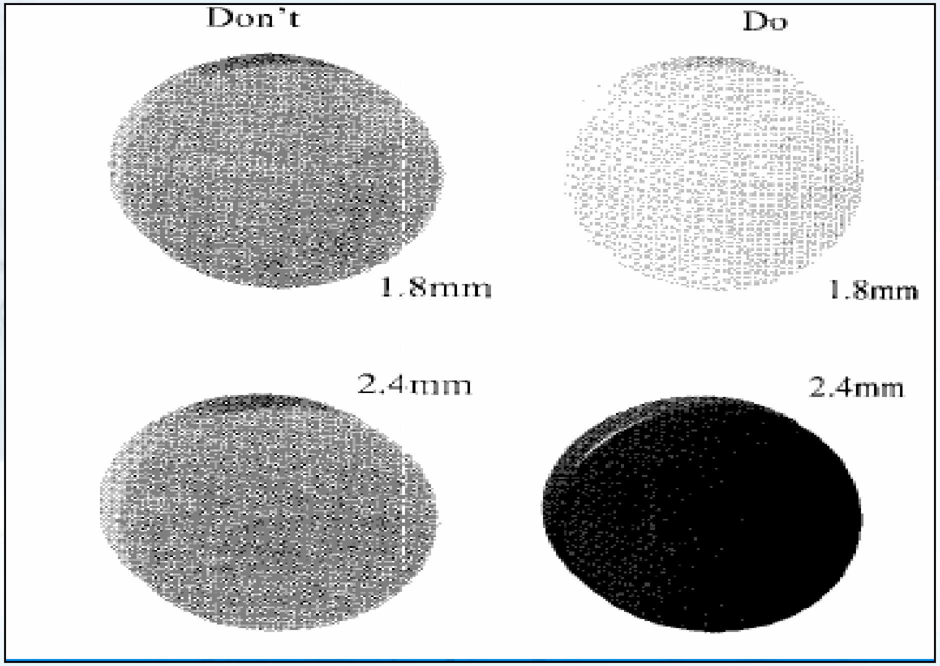
Manual Assembly Rule 7: Handling Difficulty

Each of these factors adds a degree of difficulty to the handling of the part by the assembler



Manual Assembly
Rule 8: Differentiate Similar Parts

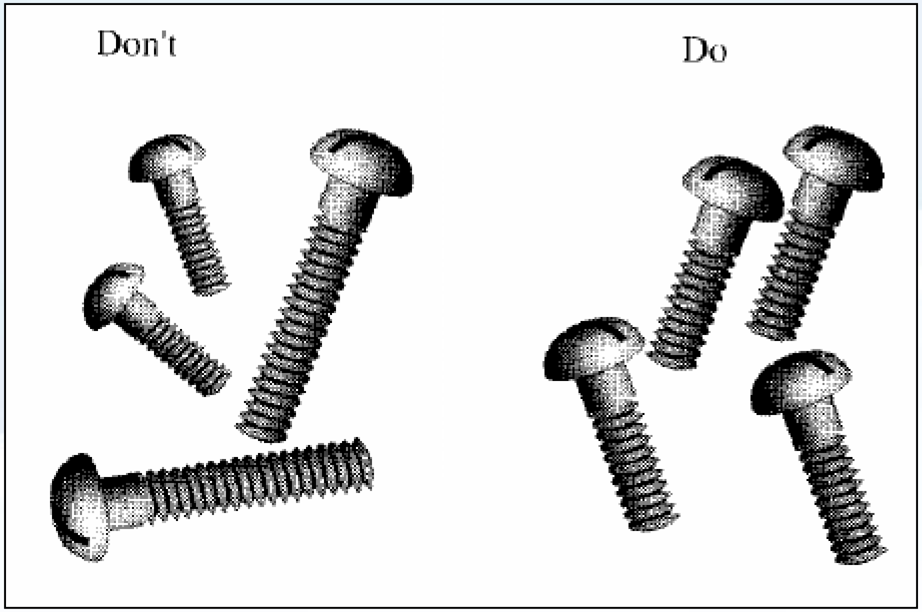
- **Distinguish "apparently similar" parts**
- **Distinguish different parts that are shaped similarly, or hard to distinguish, by non-geometric means, such as color coding**



Helps to Prevent "Mix-up" and/or "Wrong-Part" Error

Manual Assembly
Rule 9: Standardize Parts

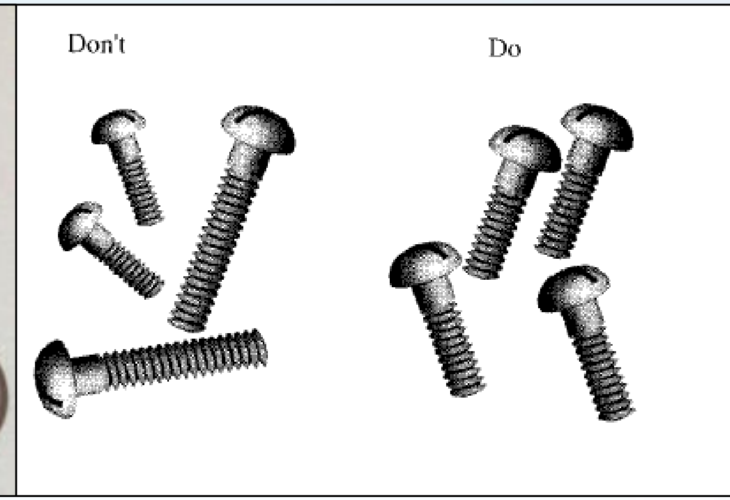
- **Use standardized products**
- **Standardize parts help to reduce variety of operations, choices, and inventory burden**



Improves both quality and cost

Manual Assembly
Rule 9: Standardize Parts

- **Products to be standardized – Fasteners, screws, nuts, bolts, washers, rivets, O Rings, and bearings**



Standardization of all parts are good. More the same, less cost to purchase or make.

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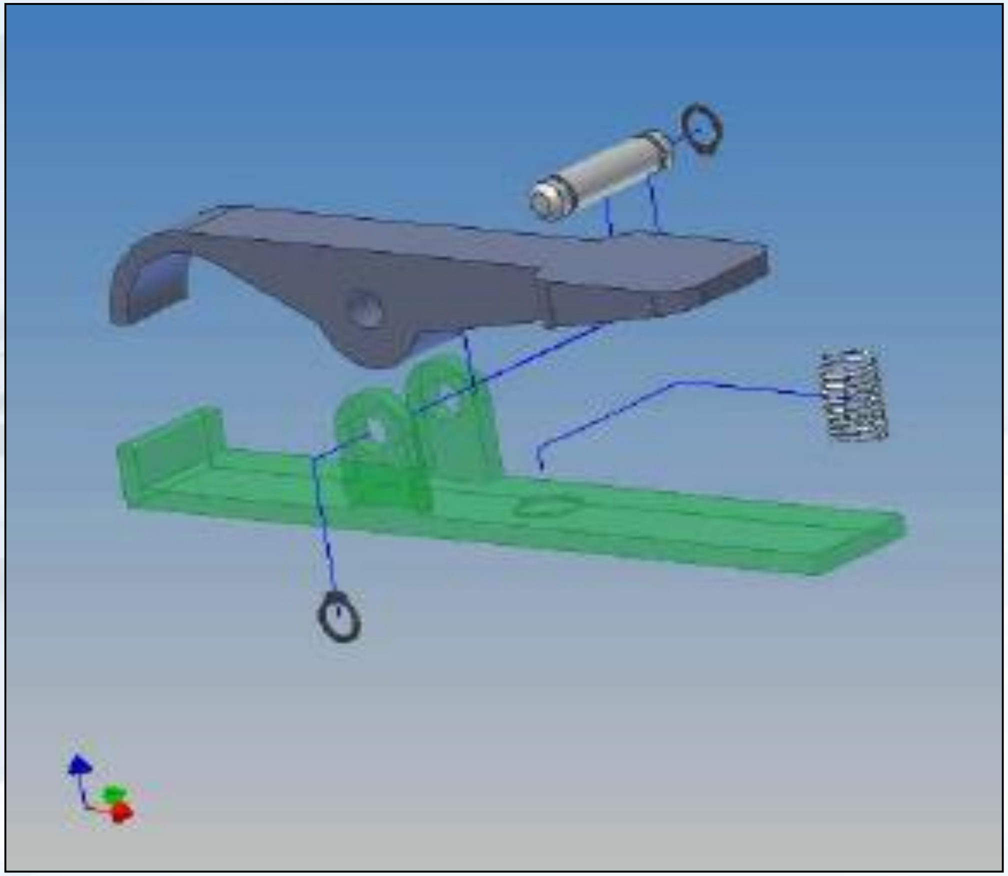
Breakout Exercise 5: Simplify the Design

- **Spring Loaded Clamp**



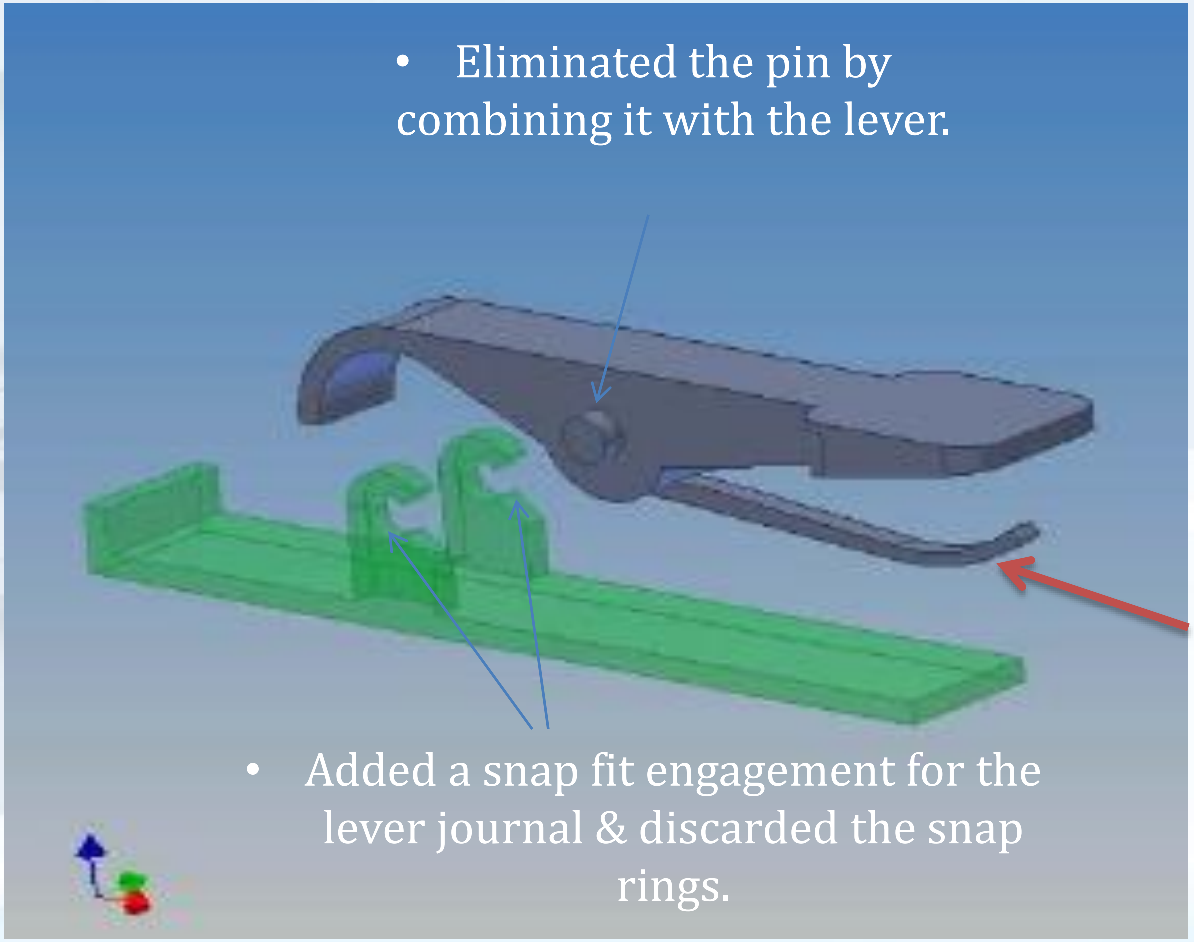
Part Count:

- 1 Base
- 1 Pin
- 2 Snap rings
- 1 Spring
- 1 Lever

Manual Assembly

Breakout Exercise: Debrief

Simplified Design



New Part Count

- 1 Base
- 1 Lever

Manual Assembly

- Incorporated spring into the lever

Manual Assembly Design Rules Summary

- **Obviously, the following guidelines depend on the skill of the worker:**
  - eliminate the need for workers to make decisions or adjustments
  - ensure accessibility and visibility
  - eliminate the need for assembly tools and gauges (i.e. prefer self-locating parts)
  - minimize the number of different parts - use "standard" parts
  - minimize the number of parts
  - avoid or minimize part orientation during assembly (i.e., prefer symmetrical parts)
  - prefer easily handled parts that do not tangle or nest within one another

Manual Assembly Design Rules Summary (cont'd)

- Benches or simple conveyors
- Assembly station has bins with un-oriented parts
- Simple jigs and fixtures with manual clamping
- Simple, light tools (manual/pneumatic/electric screwdrivers, solder irons, etc.)
- Inexpensive setup costs
- Assembly costs are nearly constant, and independent of volume (why ?)

Manual Assembly Design Rules Summary (cont'd)

- **Minimize thin, flat parts that are more difficult to pick up**
- **Avoid very small parts that are difficult to pick-up or require a tool such as a tweezers to pick-up**
  - This will increase handling and orientation time
- **Avoid parts with sharp edges, burrs or points**
  - These parts can injure workers or customers, they require more careful handling, they can damage product finishes, and they may be more susceptible to damage themselves if the sharp edge is an intended feature
- **Avoid parts that can be easily damaged or broken**
- **Avoid parts that are sticky or slippery (thin oily plates, oily parts, adhesive-backed parts, small plastic parts with smooth surfaces, etc.)**
- **Avoid heavy parts that will increase worker fatigue, increase risk of worker injury, and slow the assembly process**
- **Design the work station area to minimize the distance to access and move a part**
- **When purchasing components, consider acquiring materials already oriented in magazines, bands, tape, or strips**

Remember: The Better Assembly

- Can be assembled one-handed by a blind person wearing a boxing glove
- Is stable and self-aligning
- Tolerances are loose and forgiving
- Few Fasteners
- Few tools and fixtures
- Parts presented in the right orientation
- Parts asymmetric for easy feeding
- Parts easy to grasp and insert

Design Rules for
Hard Automation Assembly

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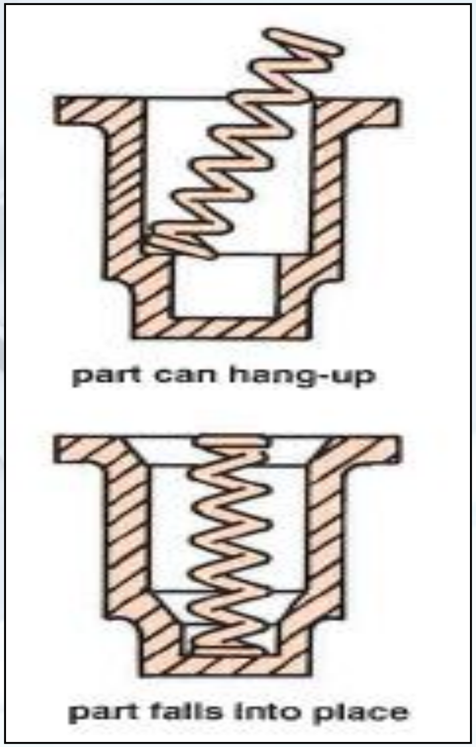
Hard Automation Assembly

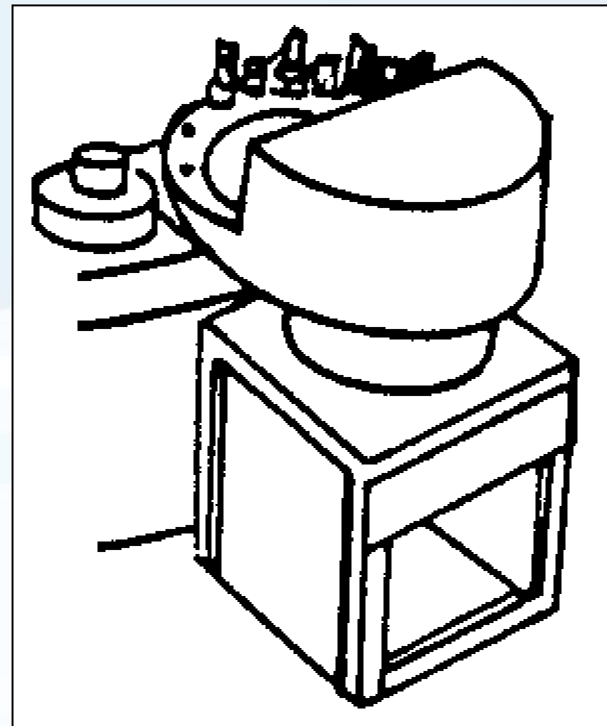
- **Machines built to assemble a specific product consist of :**
  - Transfer device with single purpose, and
  - parts feeder
- **Expensive**
- **Lengthy engineering development time to release for use**
- **Downtime may cause serious time, quality, and cost issues**
- **Designed to work on fixed cycle time; often inflexible to change in rate of production**

Hard Automation Assembly
Rule 1: Design Parts for Self-Loading

Use self-aligning and self-locating features



Use parts that can be fed automatically



Hard Automation Assembly Feeding Assembly Stations

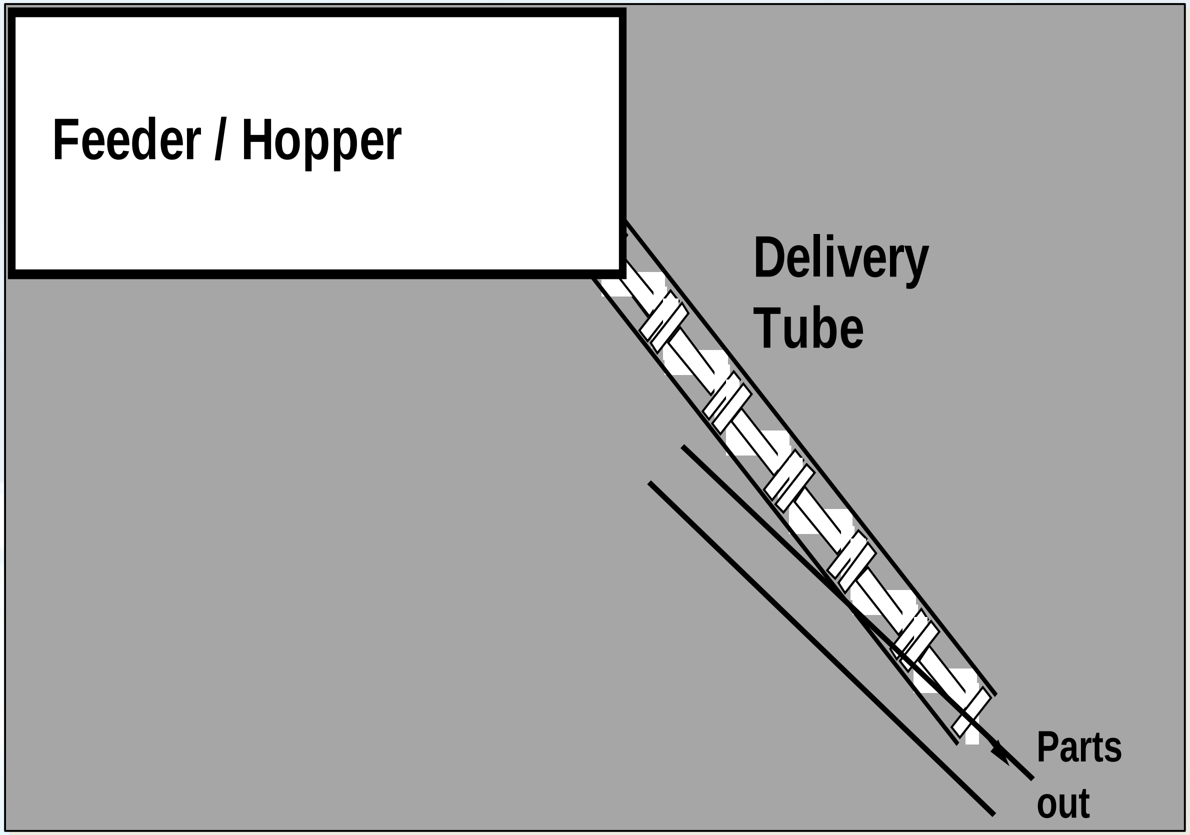
- **Parts will typically come in bulk from production and will need to be fed into each station either manually or by automated feeder.**
  - Is the part designed to be brought in bulk
  - Is the part designed to be fed via automated feeder for e.g., Hopper?

Planning Considerations

- **DFA considerations include ease of assembly to its neighbors or next assembly operation. Such as:**
  - Feeding the components: from a bin, bulk feeder (e.g. bowl feeder), or magazine, or continuous strips
  - Orienting the components: by human operator, by the feeder tracks, and by the robot / work head
  - Positioning and placing the components

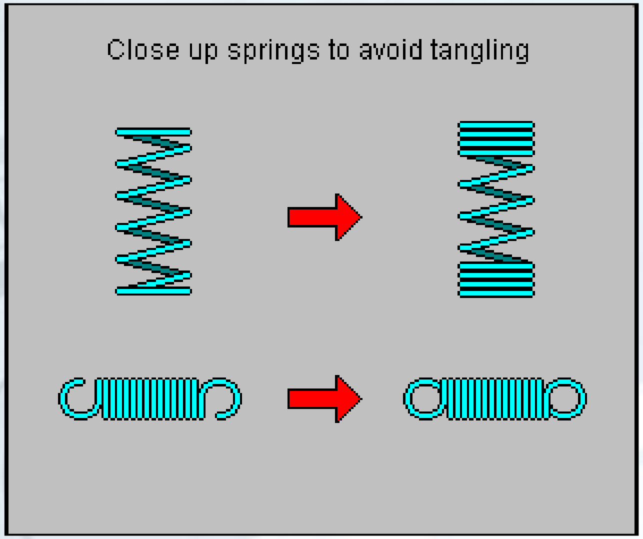
Hard Automation Assembly
Rule 2: Dimensions are Important to Feeding and Orienting

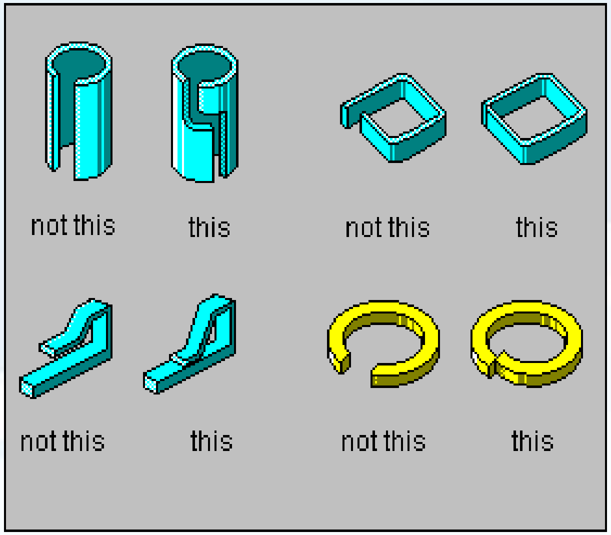
- **Loosely tolerancing non-functional dimensions can cause problems if the feeding and orienting method is not considered – jamming may occur if components are at extremes of limit**

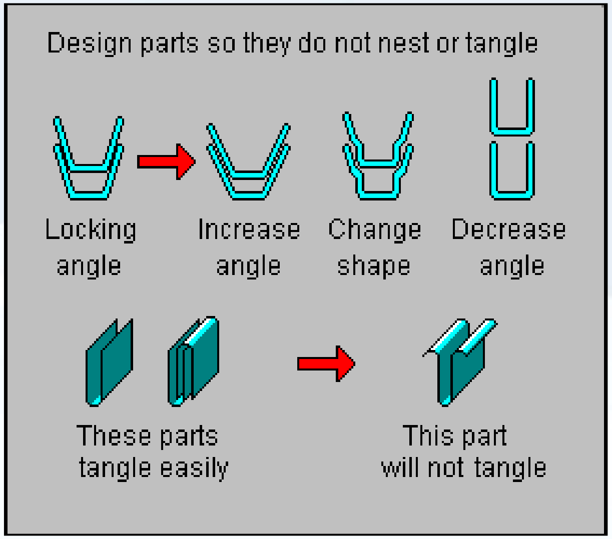


Rule 3: Design Parts to Prevent Tangling

- **Often a small design change can eliminate the tendency of components to tangle. Close ends and keep material thickness greater than gaps and slots:**



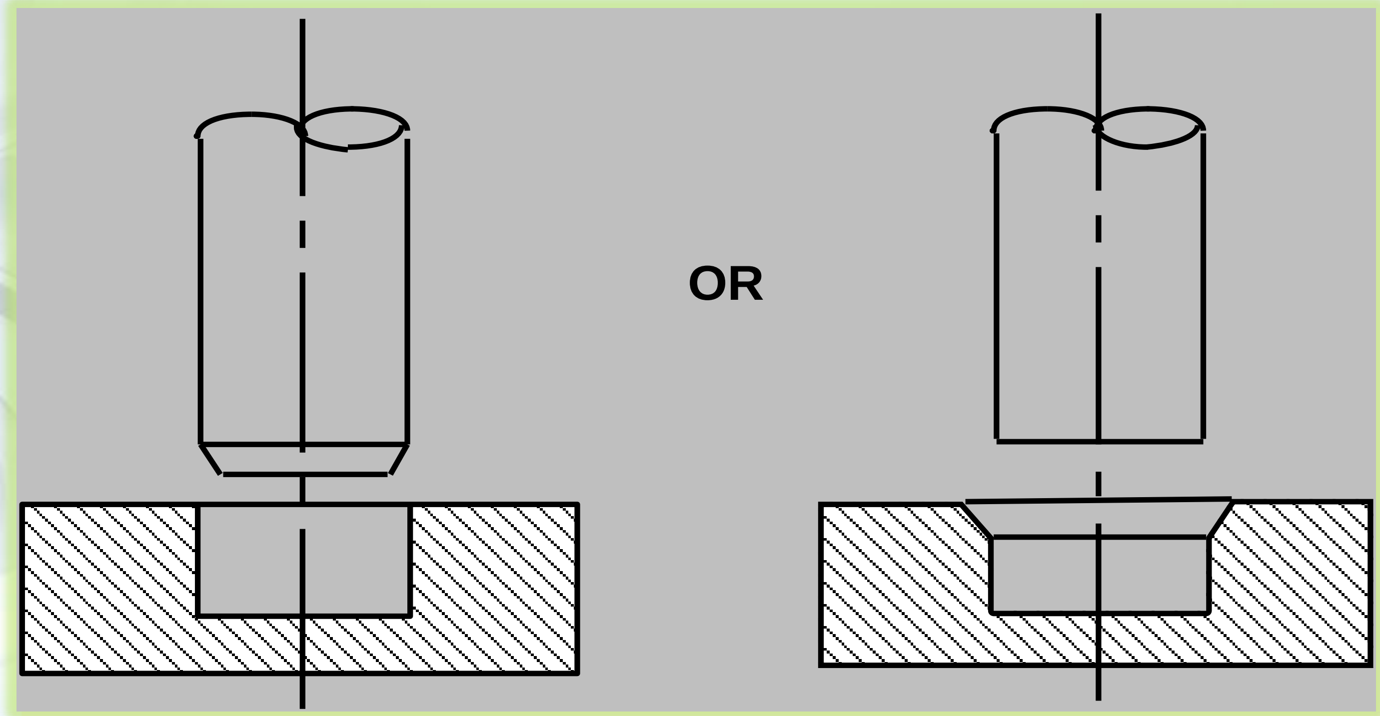




Tangle or "stuck" parts cause production slowdowns for both manual and automation assembly operations

Hard Automation Assembly
Rule 4: Provide a Lead-in or Chamfer

- **Where possible make chamfers and lead-in angles generous, and avoid sharp corners, to avoid jamming which can slow down the production process:**



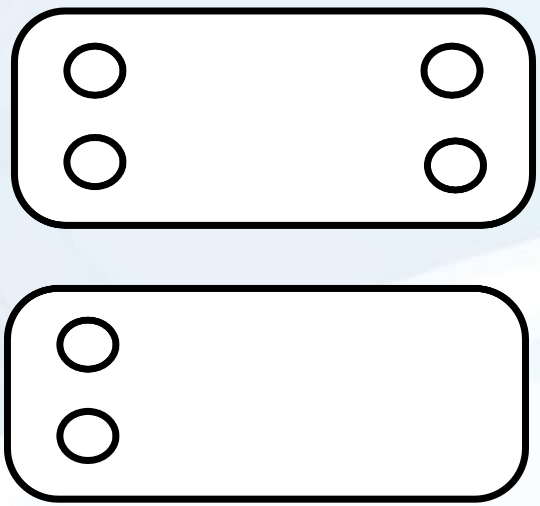
Hard Automation Assembly
Rule 5: Components Should Have the Least Number of Important Directions

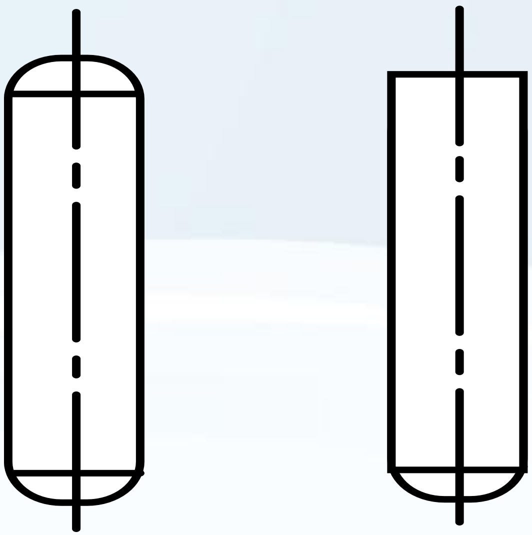
To reduce the chance of correct feeding and positioning:

A

is better than

B

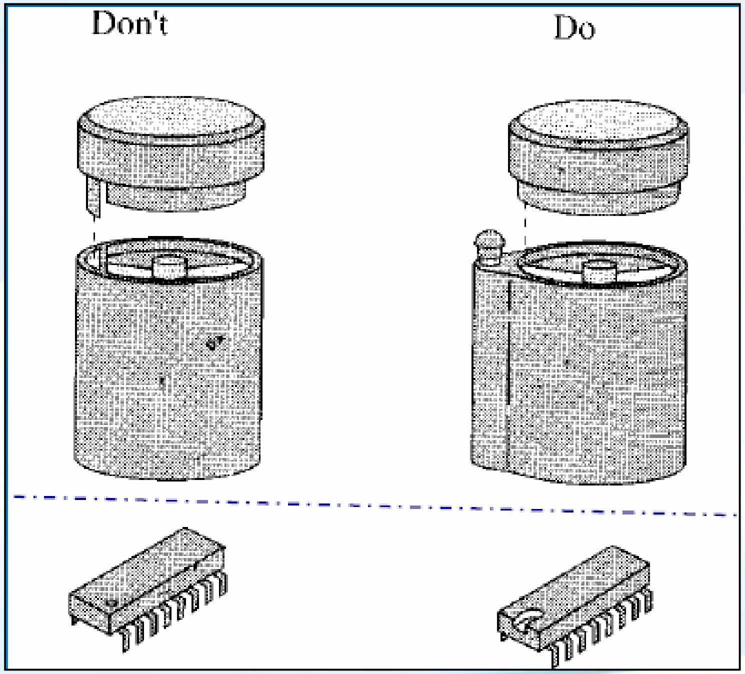




A is better than B

Hard Automation Assembly
Rule 6: Design Parts for Self-Alignment

- **Parts should easily indicate orientation for insertion**
- **Parts should have self-locking features so that the precise alignment during assemble is not required**
- **Parts should have marks (indentation) to make orientation easier**

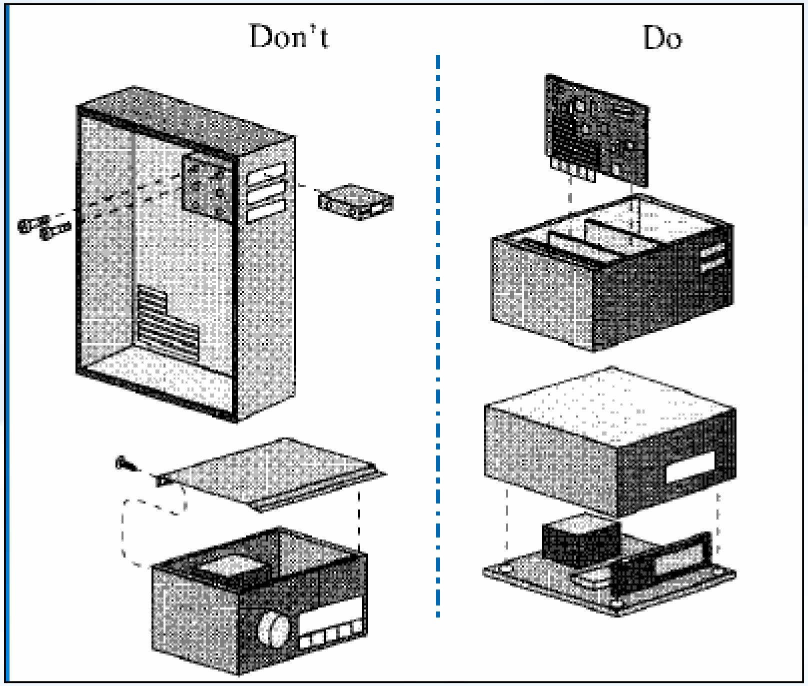


Hard Automation Assembly
Rule 7: Design Parts for Top –Down Assembly

- **If you cannot assemble parts from the top down exclusively, then minimize the number of insertion directions. Never require the assembly to be turned over.**

Case I

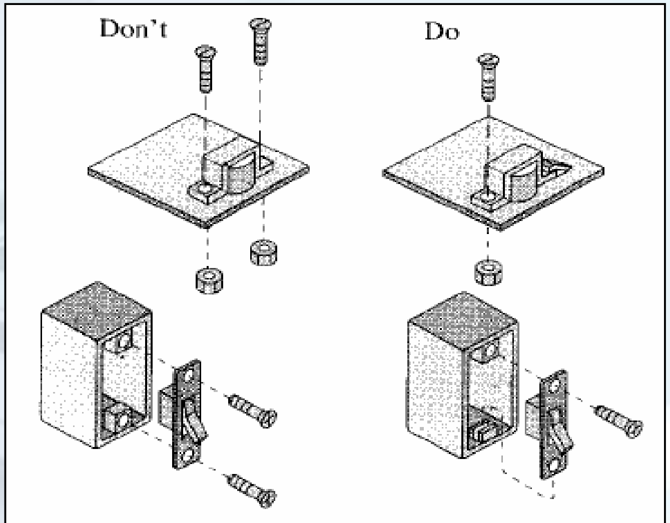
Case II



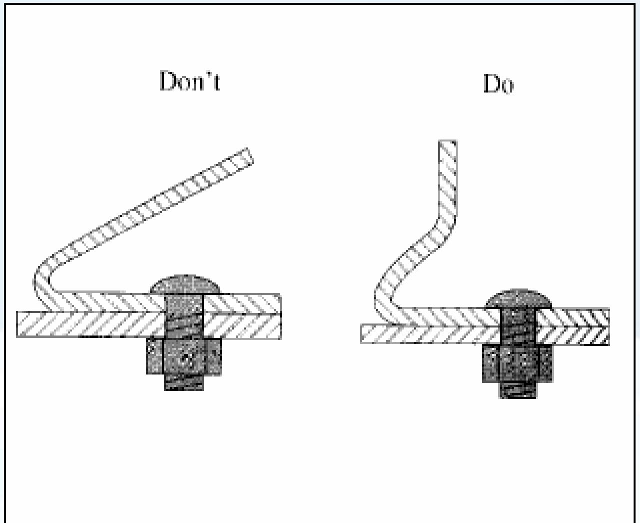
Hard Automation Assembly

Rule 8: Avoid Designing with Screws and Bolts

- **Joining Options: Avoids screws and bolts; design to eliminate fasteners and to place them away from obstructions**



Eliminate fastners.



(b) Place fasteners away from obstructions.

Small components (i.e. screws and bolts) can often "jam" the automation assembly line or feeder.

Hard Automated Assembly
Rule 9: Standardize on Components

- **Components can be difficult to differentiate, particularly small similar shaped ones**

- **It is relatively common for feeders to become jammed because wrong parts have been fed in by operators**

- **Considerable savings in storage, inventory, ordering, etc.**

Hard Automation Design Rules Summary

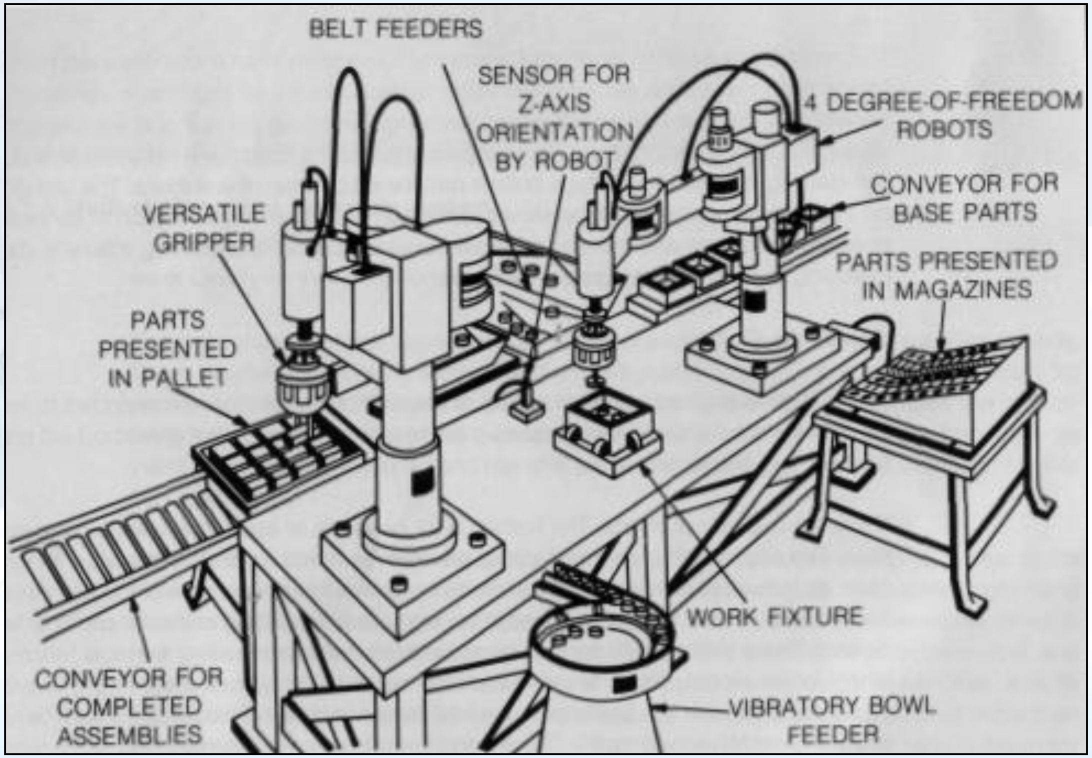
The main different here is that assembly is performed by machines instead of by humans

- **Use self-aligning and self-locating features**
- **Avoid screws/bolts**
- **Use the largest and most rigid part as the assembly base and fixture; assembly should be performed in a layered, bottom-up manner**
- **Use standard components and materials**
- **Avoid tangling or nesting parts**
- **Avoid flexible and fragile parts**
- **Avoid parts that require orientation**
- **Use parts that can be fed automatically**
- **Design parts with a low center of gravity**
- **Sometimes it is too difficult to make parts symmetrical, often non-functional features are added to a part to facilitate part feeding, grasping, and orientation**

Design Rules
for Robotic Assembly

Robotic Assembly

- Similar to non-synchronous special purpose assembly stations, except robots replace the single-purpose workheads
- Use of robots allows flexibility in product types and production rates

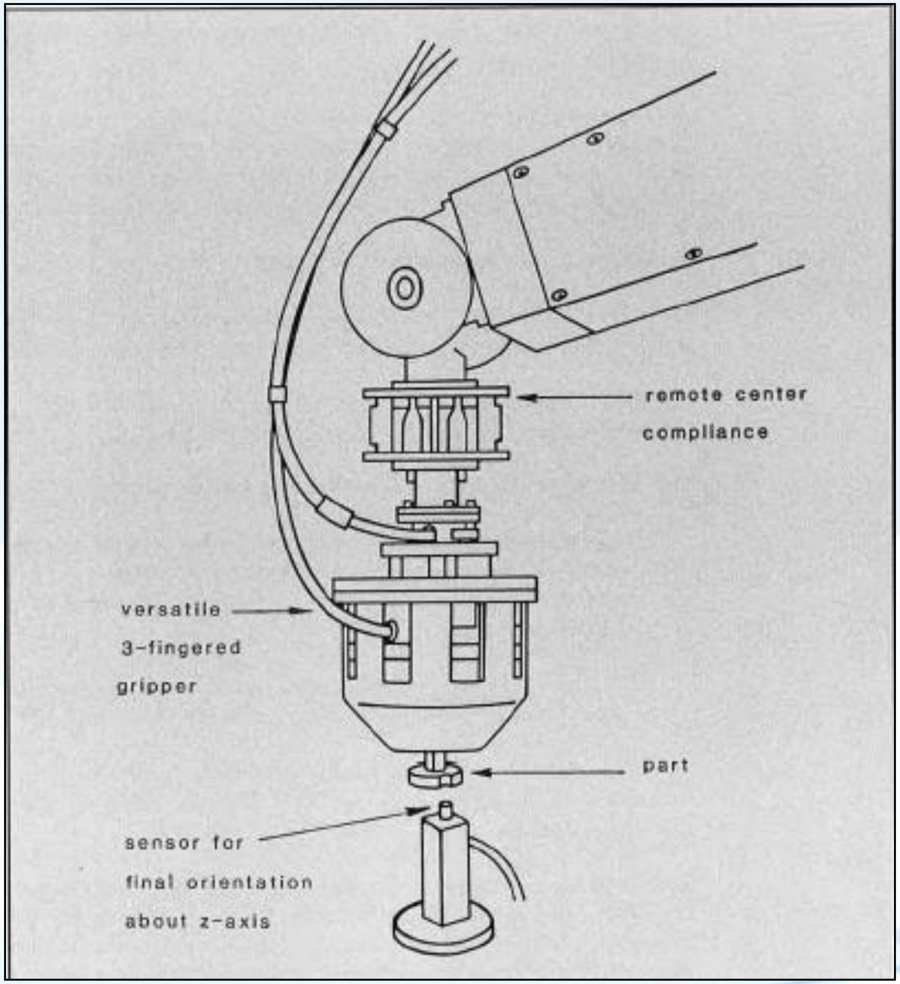


Robotic Assembly

- Like automation assembly except work heads are replaced by robots
- Allows for more assembly operations to be done at one robot work station
- Considerable flexibility in production rate & design changes
- Expensive
- Long lead time to develop

Robotic Assembly
Rule 1: Design for Compatibility

- **Design the part so that it is compatible with the robot's end effector**
- **Design the part so that it can be fed in the proper orientation**
- **Avoid flexible and fragile parts**

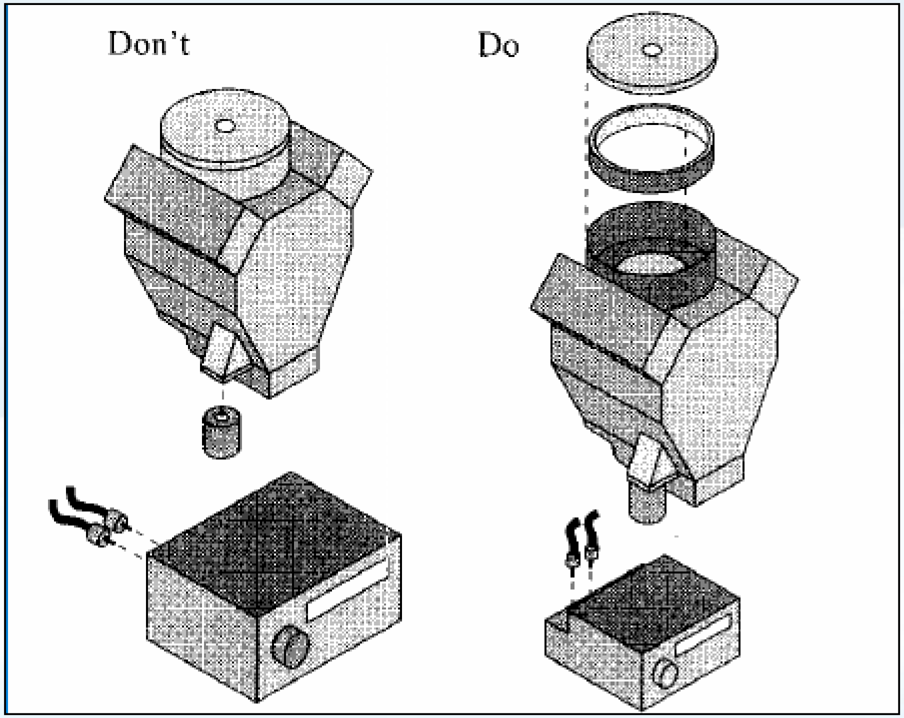


Rule 2: Design from Large to Small

- **Use the largest and most rigid part as the assembly base and fixture. Design the first part large and wide for stability, then assemble smaller parts on top of it, sequentially.**

Case I

Case II

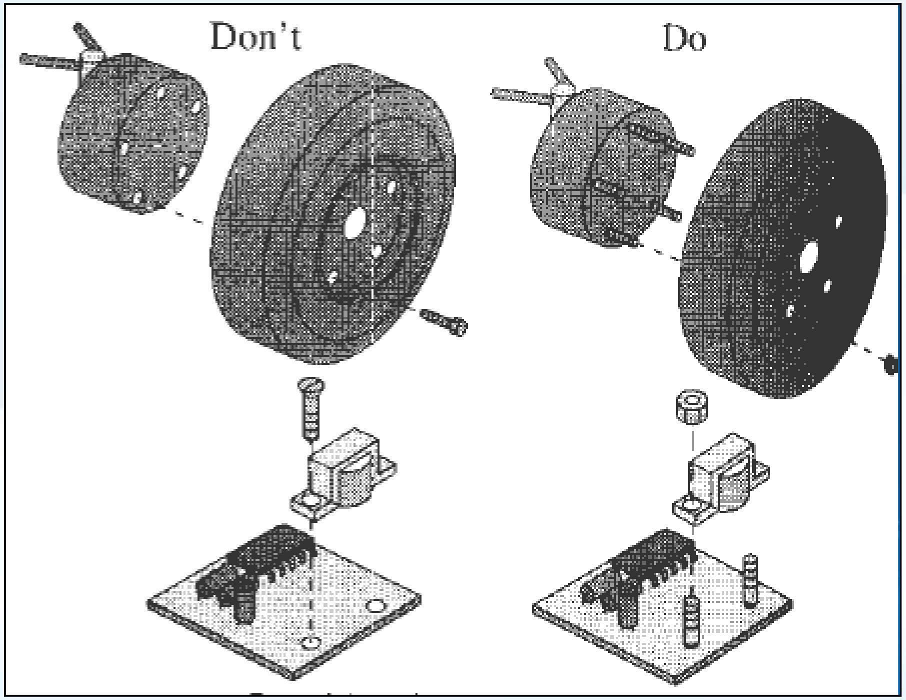


Robotic Assembly
Rule 3: Design for Easy Attachment

- **Design the mating parts for easy insertion or attachment**
- **Provide allowance (tolerance) on each part to compensate for variation in part dimensions**

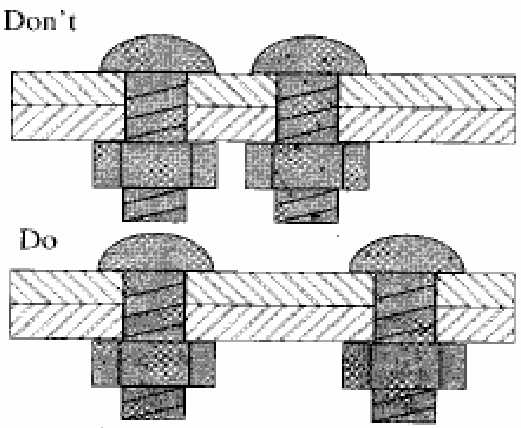
Case I

Case II

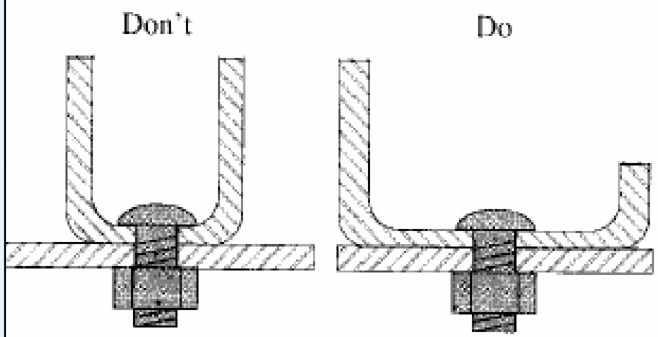


Robotic Assembly

Rule 4: Allow Proper Spacing for Ease of Assembly

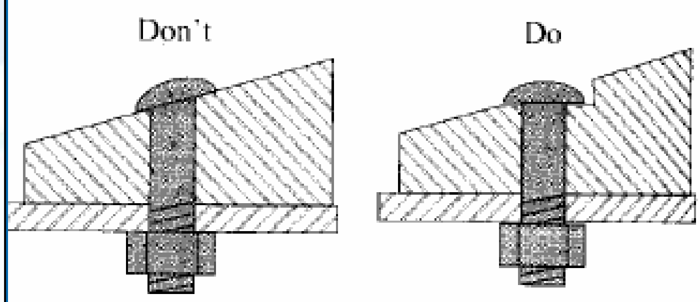


Proper spacing insures allowance for a fastening tool.



Deep channels should be sufficently wide to provide access to fastening tools. No channel is best.

Question to ask:
Can Robot Process easily locate assembly feature?



Providing flats for uniform fastening and fastening ease.

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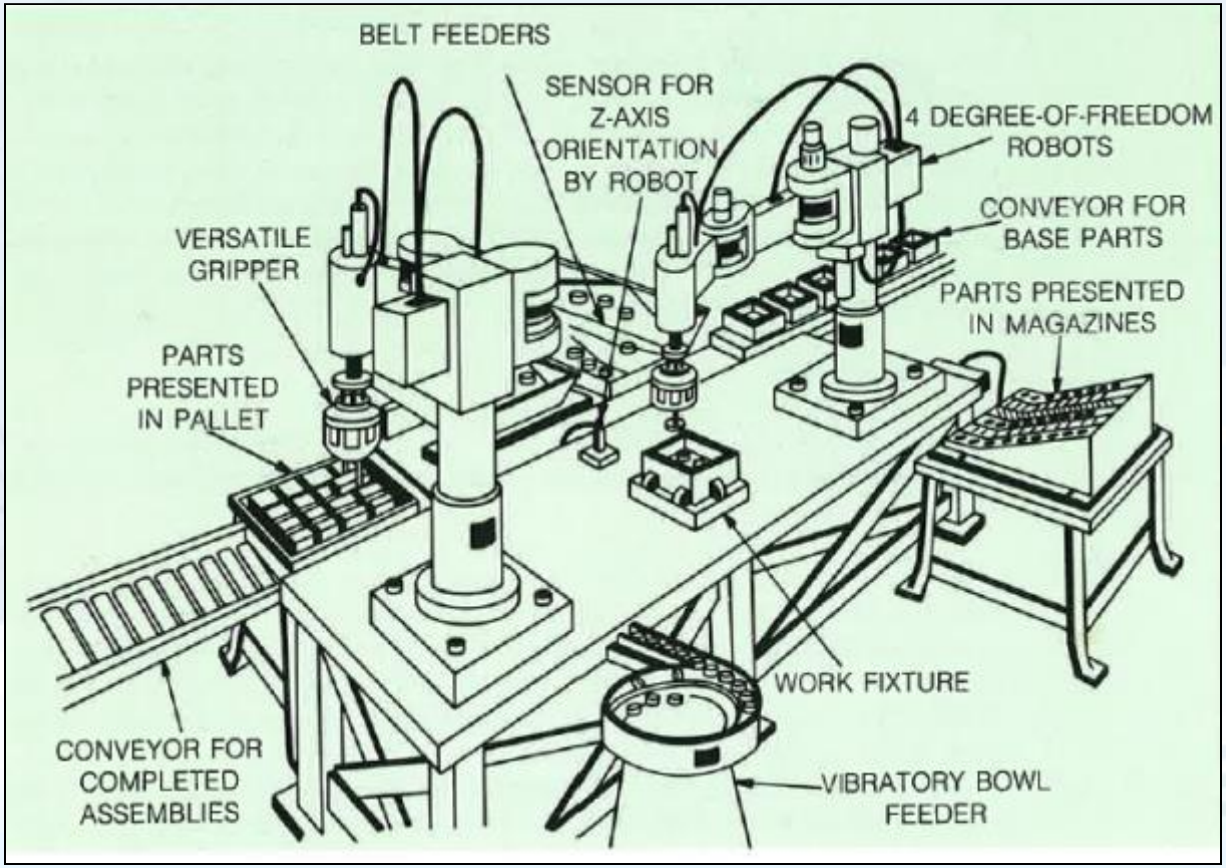
Combination Assembly Method

- **Multi-station assembly lines may have a combination of special purpose automatic, robotic, and manual assembly stations**



Design Rules for Soft Automation / Robotic Assembly

- **Compared to humans, robots are extremely inflexible**
  - However, they can be programmed to do one thing over and over again with high speed and accuracy compared to humans
- **Design the part so that it is compatible with the robot's end effector**
- **Design the part so that it can be fed in the proper orientation**

Making the Assembly Decision

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Choosing Assembly Method

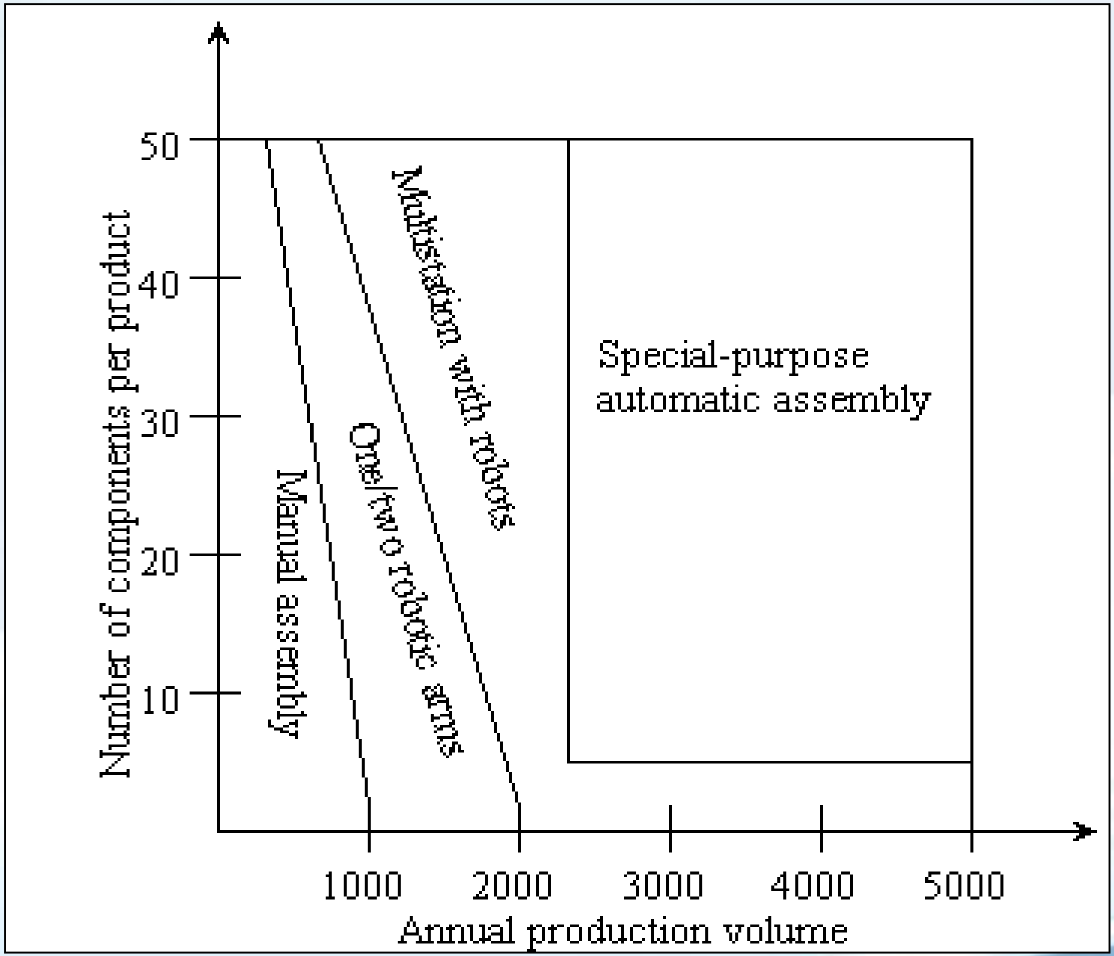
- Low volume (< 1000 parts per year) => manual assembly
- High volume (> million parts per year) => high-speed automated assembly
- Somewhere in between these limits, and based on some other considerations (labor costs, technical requirements, e.g., in spray painting) robotic assembly may be optimal

High-speed (Special Purpose) Transfer Assembly

- **Machines are built to produce specific product**
- **Components:**
  - Part feeders [indexed/asynchronous]
  - Single purpose work heads
  - Transfer devices (usually equipped with work heads)
- **Very expensive and time-consuming to build**
- **Very high production rate**
- **Down time due to defective parts may be a severe problem**
  - [Example: defective part-mix in a bowl-feeder]
  - Implication: incoming QC must be stringent
- **Inflexible: changing hard-automation system requires fabrication of new jigs/fixtures/machines and may take a long time and cost a lot**

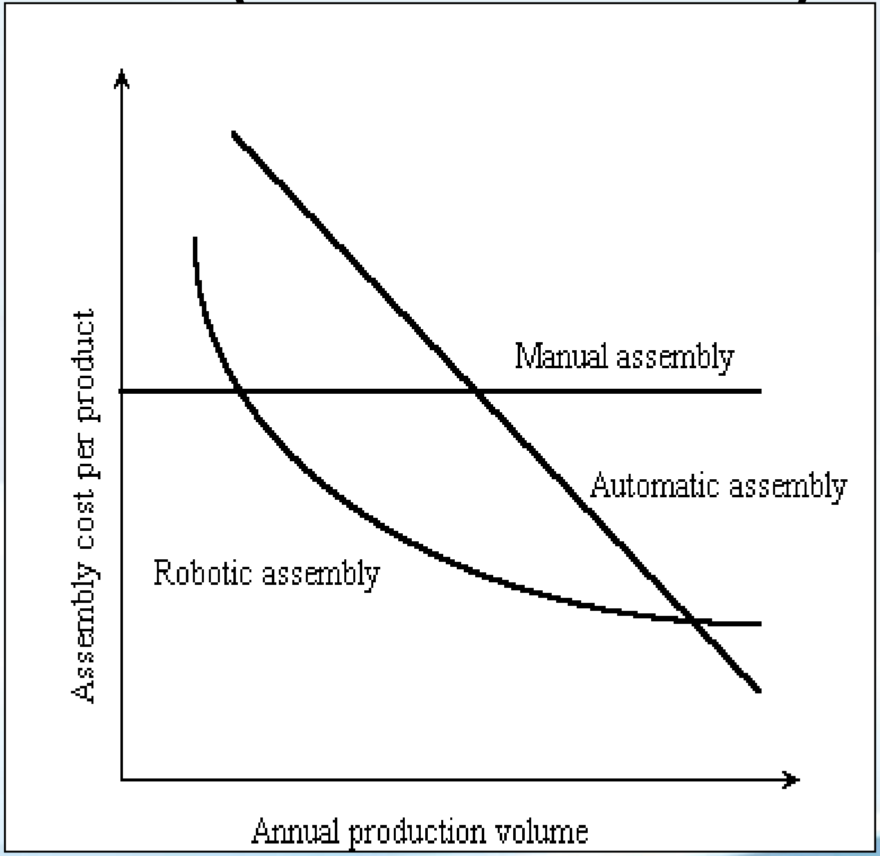
Comparison of Assembly Methods

- **The higher the volume (production range) the more advance assembly method is considered and/or selected**



Comparison of Assembly Methods

- **Highly automated assembly cost per product goes down as volume increases**
- **The non-linear cost for robotic assembly reflects the non-linear cost of robots (even small ones cost)**



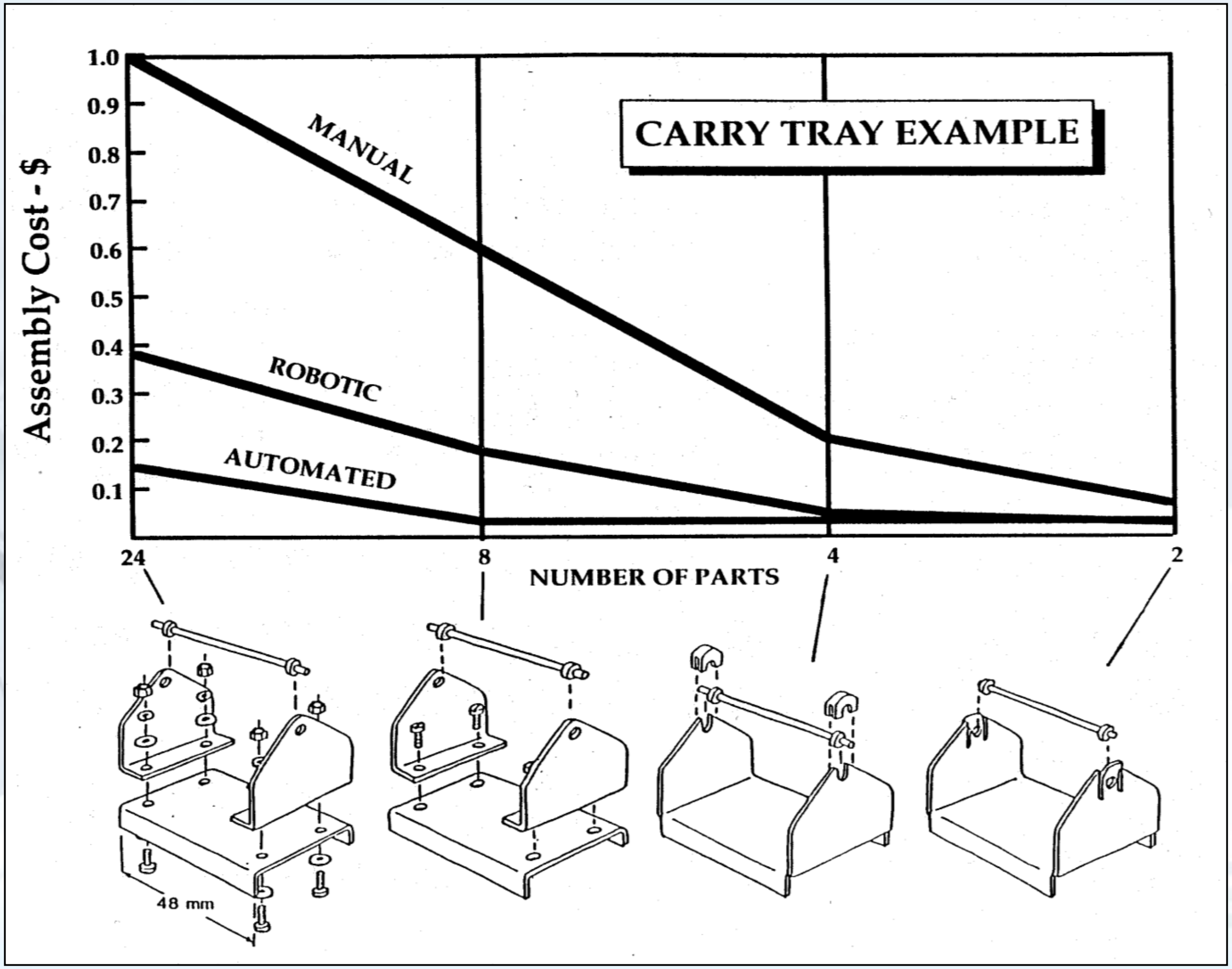
Choosing Assembly Method

- **Factors to keep in mind:**
  - Only 10% of products have volumes required for automated assembly
  - Only 10% of products have few enough variants for dedicated assembly
  - 95% of products are unsuitable for automated assembly due to low labor costs

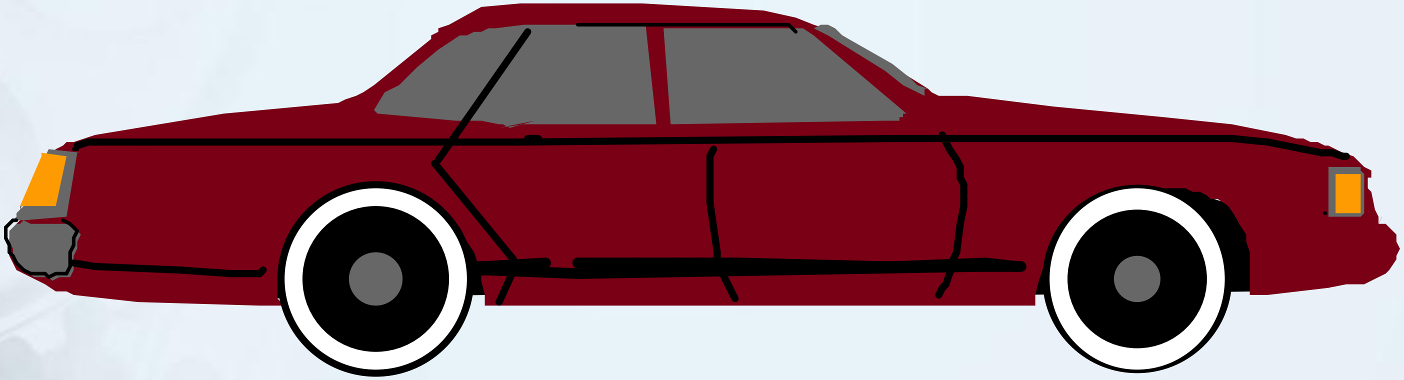
Higher volume and lower variants more dedicated and automated assembly

More dedicated and automated assembly leads to less flexibility for product design changes

Breakout Exercise 2 Example



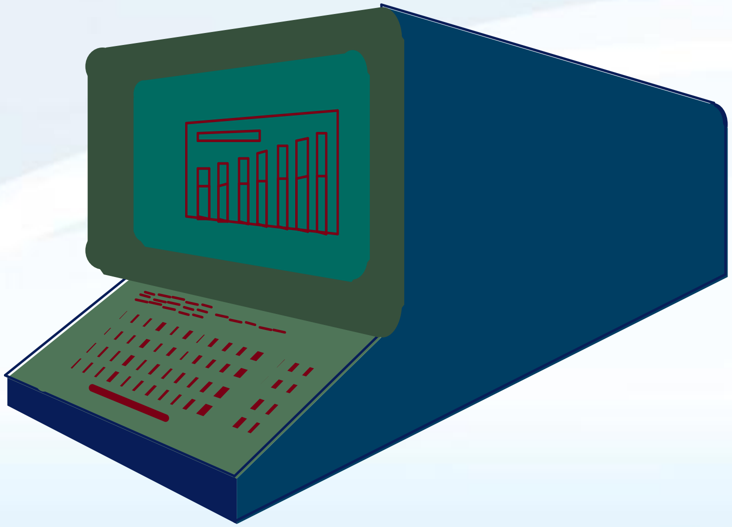
Example: DFA on Ford Taurus



Savings resulting from the use of DFA techniques on Ford's TAURUS carline have been estimated to be > $1 billion

NCR 2760 Point-of-sale Terminal

- Assembled blindfolded at DFA conf. in 1.5 mins.
- Reduced number of parts by 80%
- Reduced number of vendors by 65%
- Eliminated special assembly tools
- Estimated lifetime labor cost reduction of $1.1 million
- Estimated savings from eliminating 1 screw: $12,500



Breakout Exercise 6: Choose Assembly Method

- **Discuss as a team and identify a subassembly case from existing product stream.**
- **Collect the basic information about that assembly.**
- **Analyze the case and select the assembly method with adequate justification.**

Chapter 6

QUALITY

Optimizing the Design for Production Readiness
Design for Manufacturing

Sequence of Analysis

Concept Design

Design for Assembly

Design for Manufacturing

Detailed Design

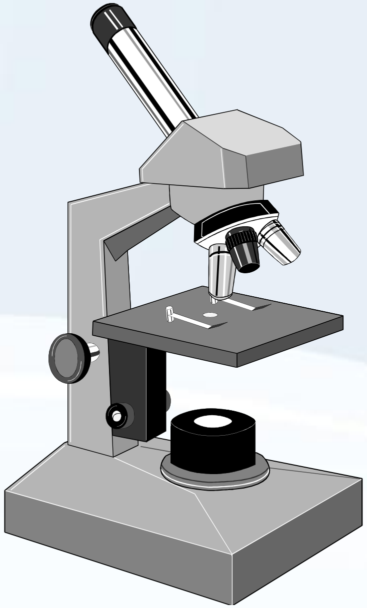
Apply General Design Principles

Optimize Design for Part Count and Assembly

Apply DFA Design Rules

Design for Assembly and Choose Assembly Method

Optimize Design for Production Process



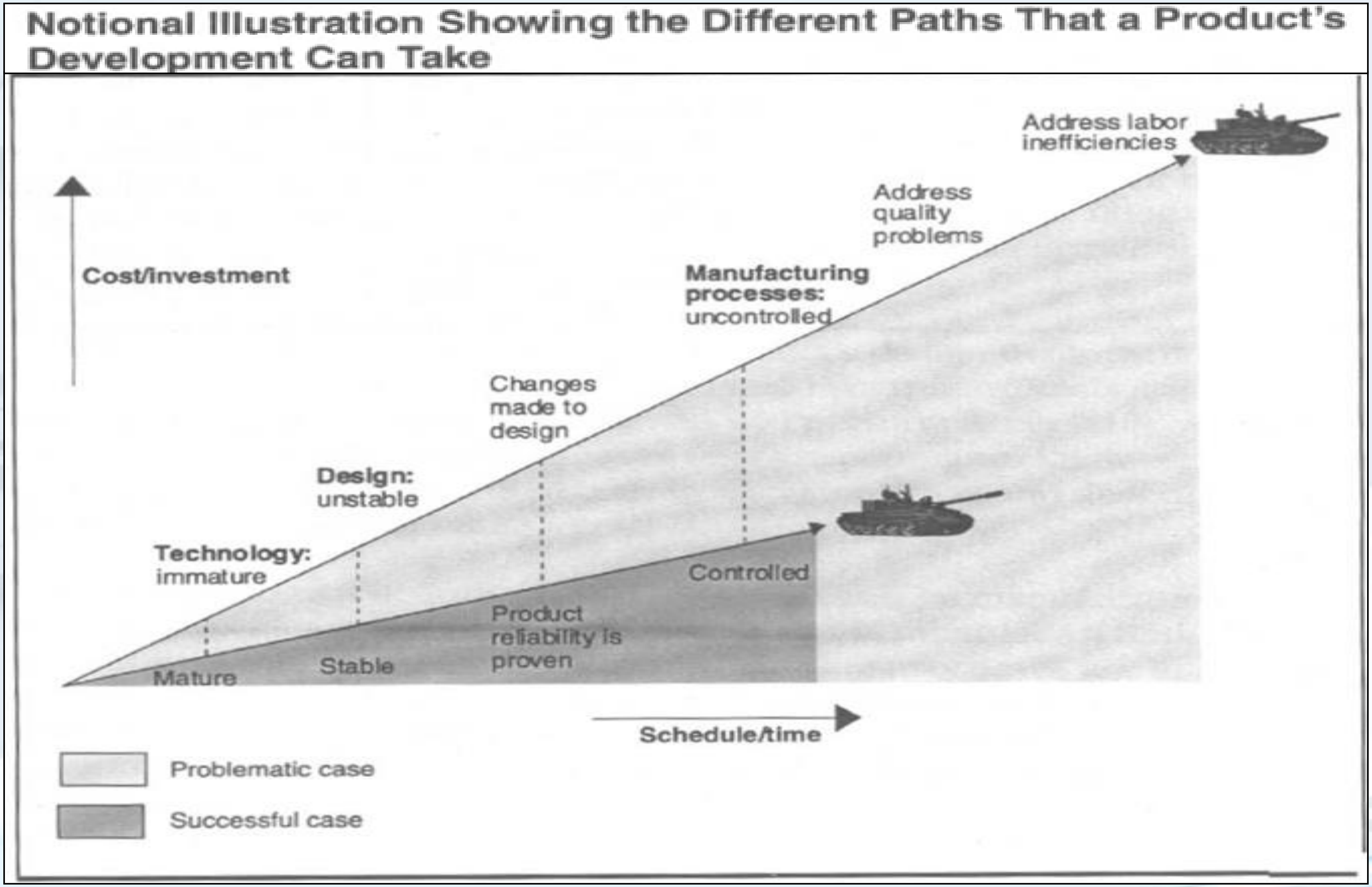
Why Design for Manufacturing?

- Mechanical engineering designs generally include off-the-shelf components and fabricated parts.
- Knowing the strengths and limitations of the fabrication techniques makes for higher quality and more cost competitive designs.

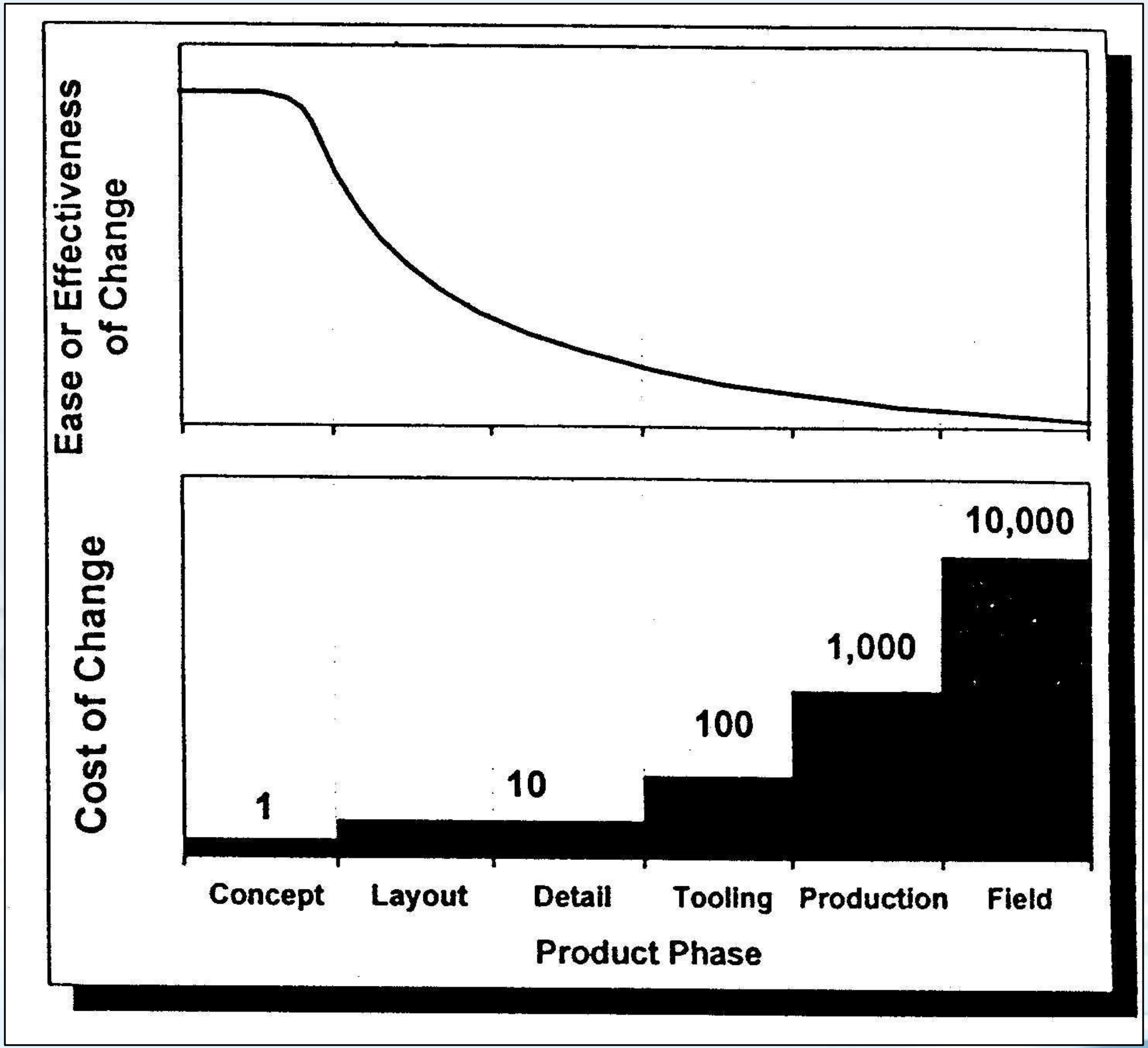
Product Development Process

How can we emphasize manufacturing issues throughout the development process?

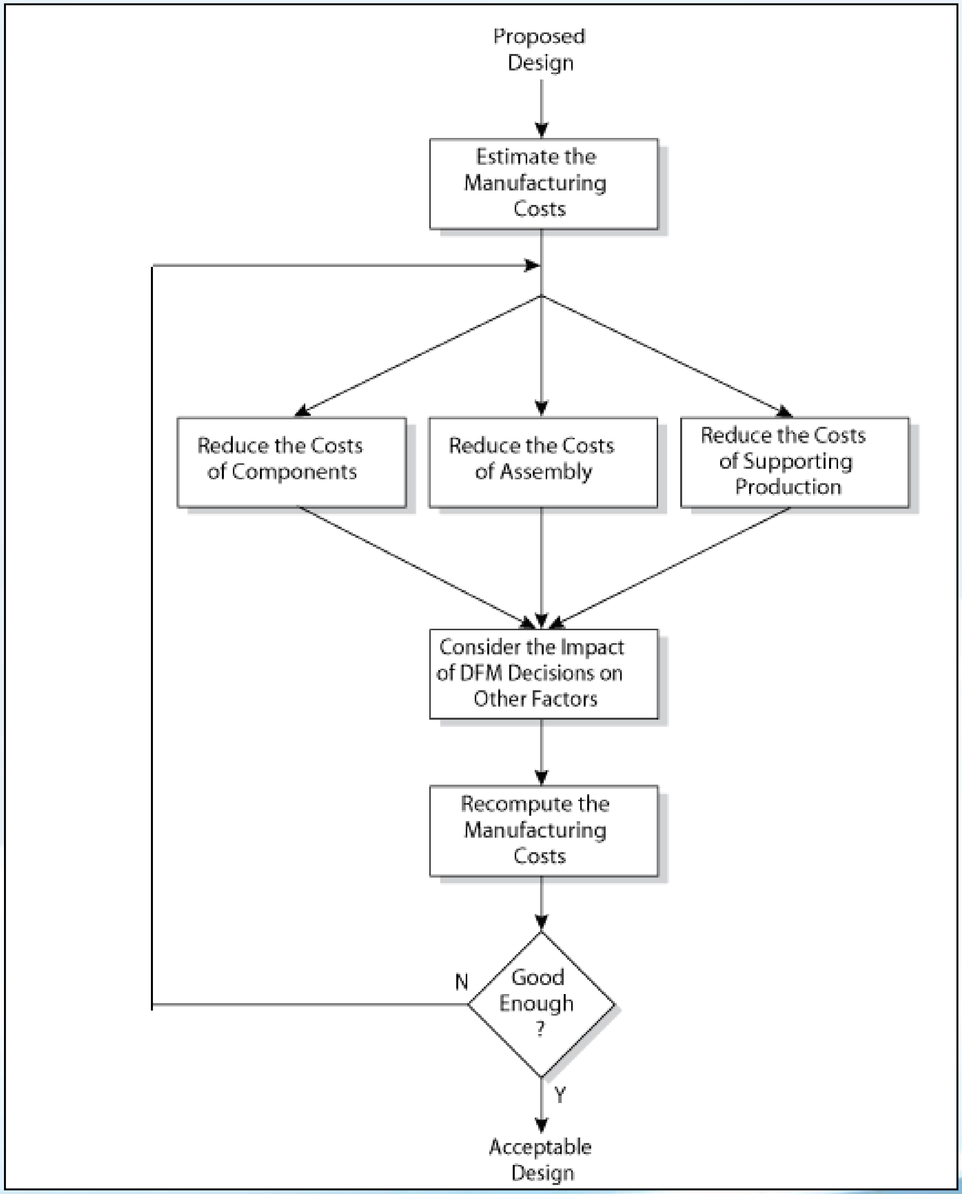
Product Development Process



Cost & Ease of Modifications



Best Practices to Product Development



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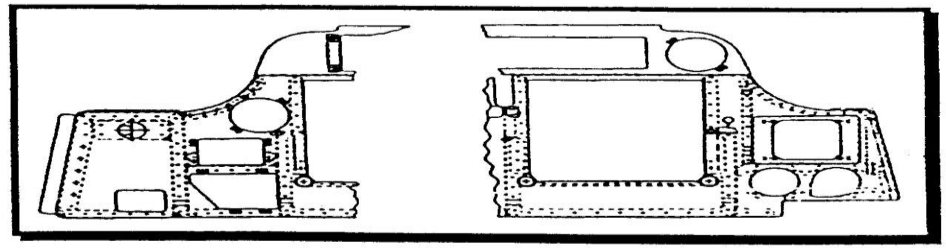
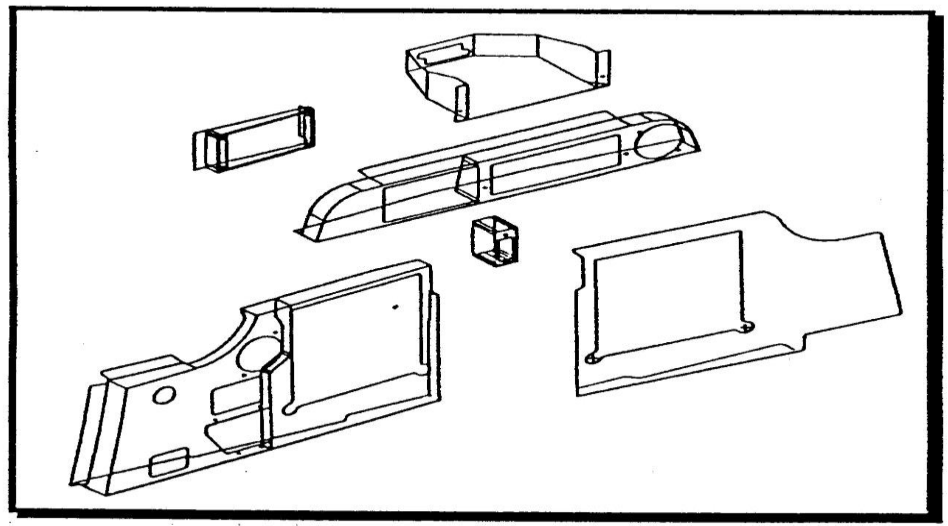
ORIGINAL



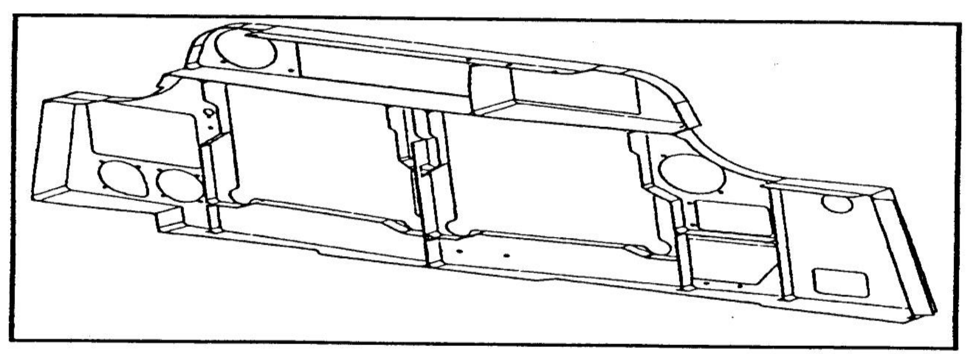
OPTION 1



PILOTS INSTRUMENT PANEL

LONG BOW APACHE AH-64D HELICOPTER BOEING COMPANY

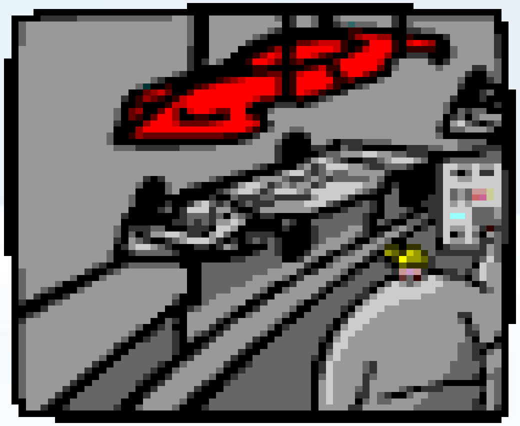
OPTION 2



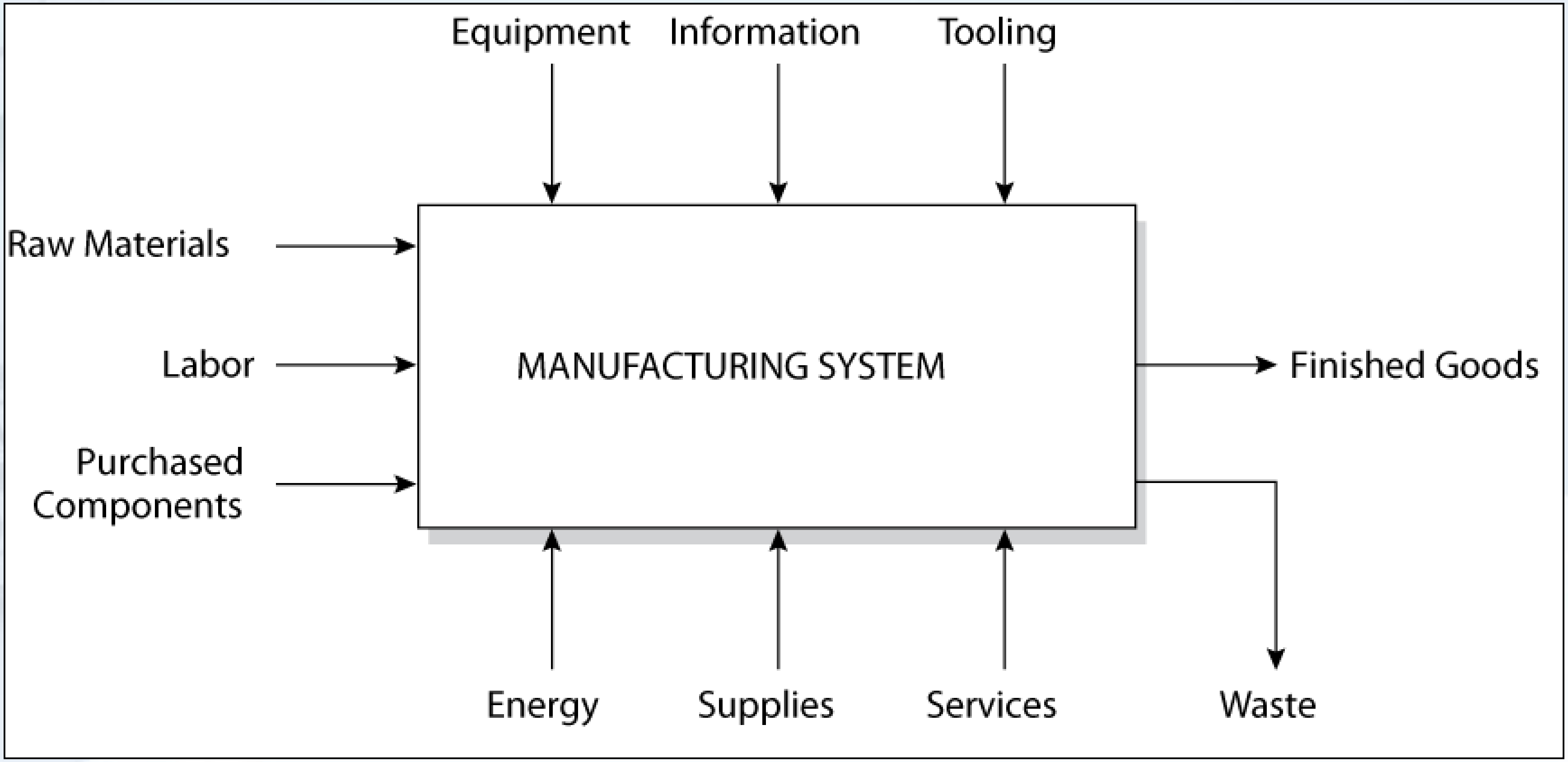
Design for Manufacturing

- **Design For Manufacturing (DFM) focuses on ensuring that product design help make the components and assembly easy to manufacture**

'Optimization of the manufacturing process…'



Understanding Manufacturing System



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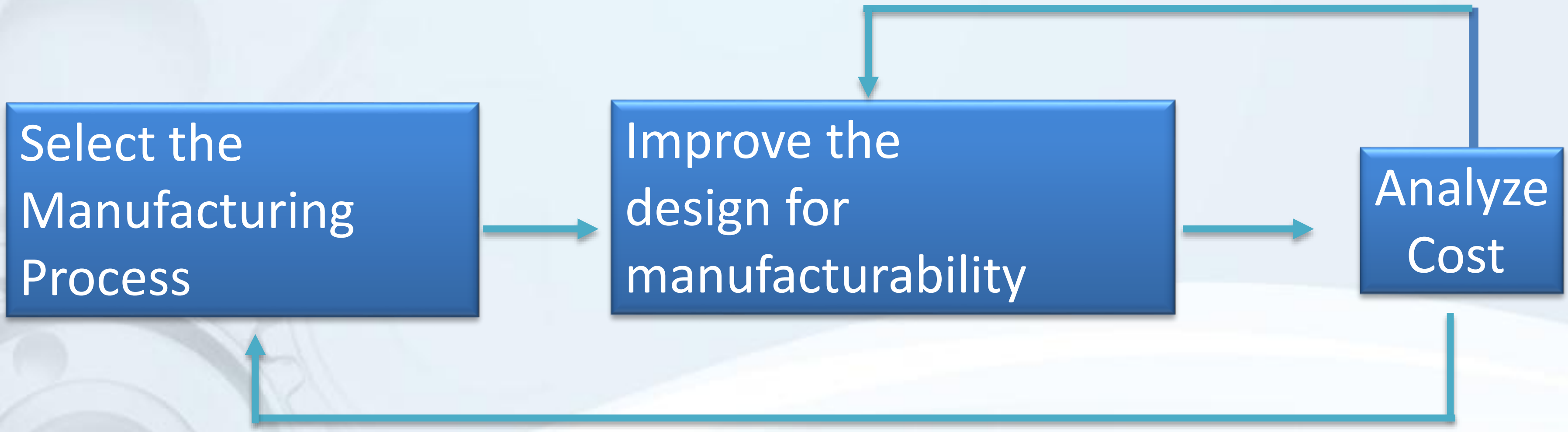
Optimizing the Design for Production Readiness

Design for Manufacturing

Design for Manufacturing (DFM)

DFM integrates product design and process planning into one common activity, where M = Primary Mfg. Process



- Broad process knowledge
- Comparative cost knowledge

- Do's & Don'ts (Rules/checklist)
- Cost-of-features knowledge

- Quote
- Hist. data
- Models
- Software

Design for Manufacturing Guidelines

- Another aspect of DFMA is to make each part easy to produce (manufacture) which is the basis of Design for Manufacturing
- There are guidelines available in DFM handbooks and other available literature for each type of process within an organization
- Adopt DFM guidelines/Design Checklists for each of the processes in the organization which can be first updated from available literature and then updated using information gleaned from the process or production
- After launch failure data can update the DFMEA or PFMEA and then be used to update the DFMA Rules checklists

Basic Principles

The following principles are applicable to virtually all manufacturing processes, will aid in manufacturing products at minimal cost

- **Simplicity:** The product with the fewer parts, the least intricate shapes, & precision adjustments will be the least costly.
- **Standard Materials and Components:** Use of widely available materials and off-the-shelf parts enables the benefit of mass production to be realized by even low quantity units.
- **Standardized Design of the Product:** Specify the same material, parts, and sub-assemblies for as much as possible.
- **Liberal Tolerances:** Tight tolerances typically are most costly.
- **Use of the Most Processible Materials:** Use the most processible materials as long as their functional characteristics and cost are suitable.

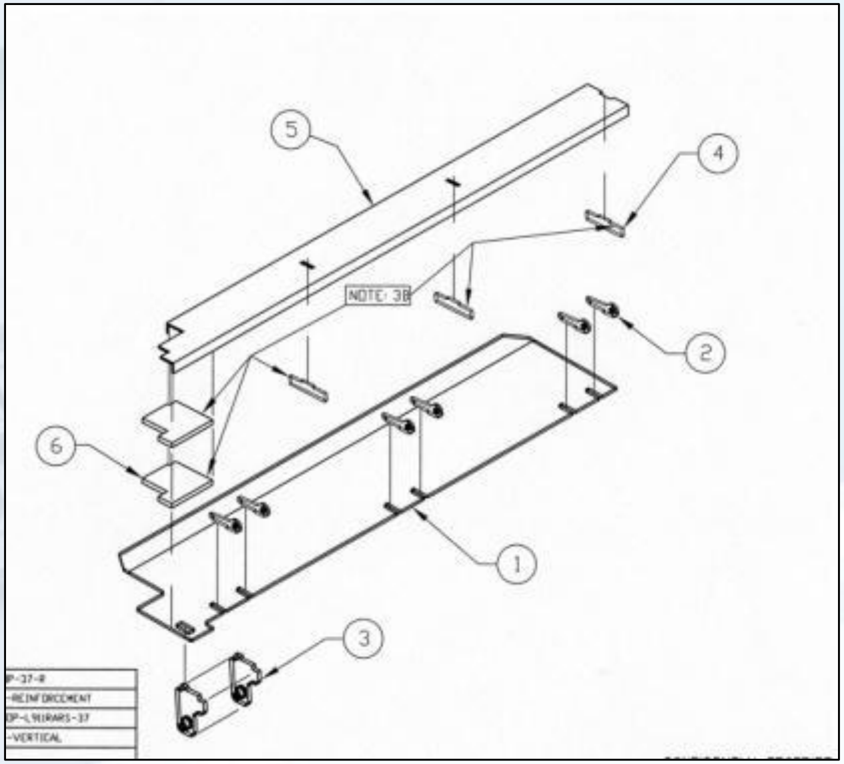
Basic Principles (cont'd)

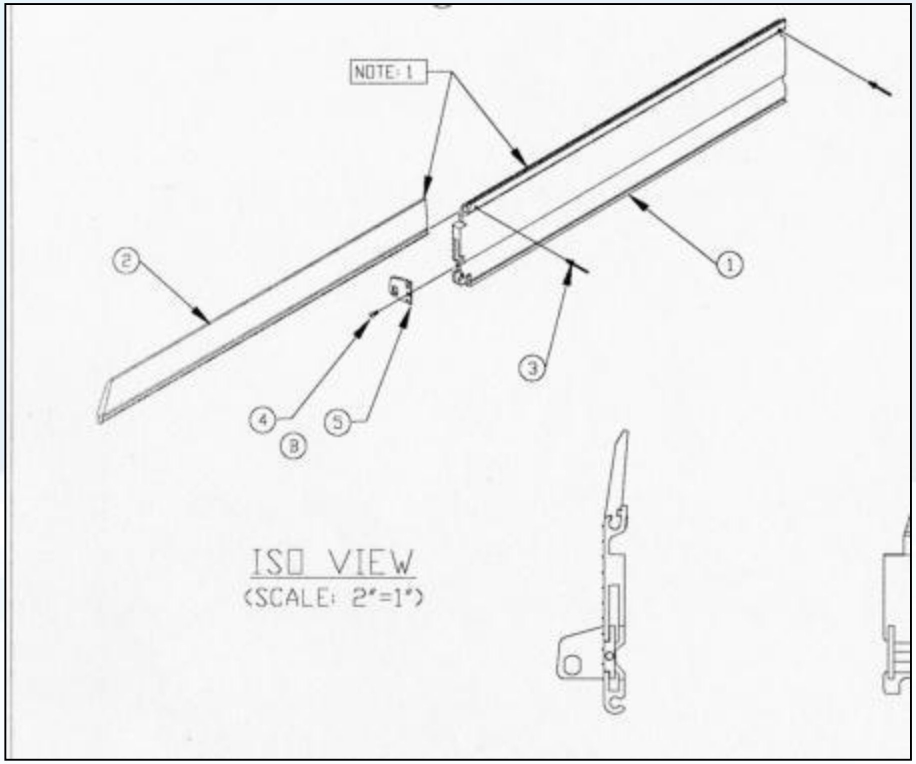
- **Teamwork with Manufacturing Personnel:** The most producible designs are provided when design and manufacturing work closely together to collaborate on the best outcome.
- **Avoidance of Secondary Operations:** Consider the cost of operations and the design order to eliminate or simplify when possible.
- **Design Appropriate to the Expected Level of Production:** The design should be suitable for a production method that is economical for the quantity forecasted.
- **Utilize Special Process Characteristics:** Take advantage of the special capabilities of the manufacturing process.
- **Avoid Process Restrictiveness:** On parts drawings, specify only the final characteristics needed.

Simplicity

- **Description:** **minimize the number of parts, intricate shapes, and manufacturing operations**
- **Motivation:** **generally provides reduced cost, improved reliability, easier servicing, and improved robustness**
- **Example:** **Braun Lift**

Part Count Reduction





Standard Materials and Components

- **Description:** Use standard off-the-shelf parts and widely available materials
- **Motivation:** eases purchasing, simplifies inventory management, and avoids tooling investments
- **Example:** Screws

Standardized Design of the Product

- **Description:** For similar products, specify the same materials, parts, and subassemblies as much as possible.
- **Motivation:** provides economies of scale, simplifies operations, and simplifies inventory management
- **Example:** Braun Lift

Liberal Tolerances

- **Description:** make tolerances as forgiving as possible
- **Motivation:** tight tolerances are expensive (in a non-linear fashion)
- **Example:** Figure 1.3.1 (Next Slide)

Liberal Tolerances

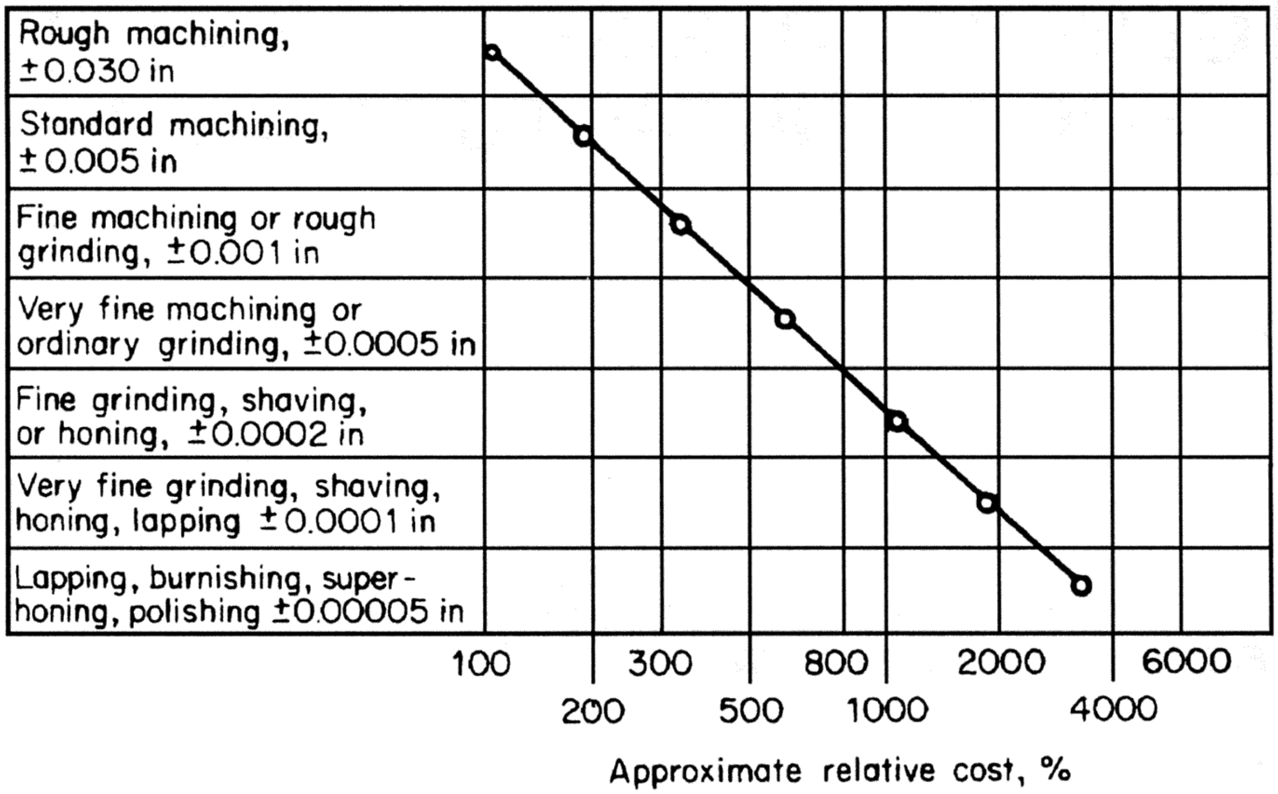


FIGURE 1.3.1 Approximate relative cost of progressively tighter dimensional tolerances. (*From N. E. Woldman,* Machinability and Machining of Metals, *McGraw-Hill, New York. Used with the permission of McGraw-Hill Book Company.*)

Use Easily Processed Materials

- **Description:** take advantage of materials that have been developed for easy processibility
- **Motivation:** while material may cost more, it will often provide lower overall cost
- **Example:** "Free-Machining" Grades, Many polymer grades are tuned to a process

Teamwork with Manufacturing Personnel

- **Description:** collaborate with the people who will be producing your product (the earlier the better)
- **Motivation:** they provide a unique body of knowledge and useful insights
- **Example:**

Avoidance of Secondary Operations

- **Description:** minimize the need for secondary operations
- **Motivation:** secondary operations (e.g. deburring, inspection, painting, and heat treating) can be as expensive as the primary manufacturing operation
- **Example:** Pre-painted steel, investment casting, MIM in firearms

Understand and Utilize Manufacturing Process Characteristics

- **Description:** understand and take advantage of the special capabilities of various manufacturing processes
- **Motivation:** can often eliminate manufacturing operations and reduce the number of parts
- **Example:** injection molding snap fits and living hinges

Avoid Process Restrictiveness

- **Description:** on part drawings, specify only the final characteristics needed; do not specify the process to be used
- **Motivation:** potential cost savings

DFM Methodology Comparison

DFM TECHNIQUE \ CRITERIA	(1) IMPLEMENTATION COST AND EFFORT	(2) TRAINING AND/OR PRACTICE	(3) DESIGNER EFFORT	(4) MANAGEMENT EFFORT	(5) PRODUCT PLANNING/ TEAM APPROACH	(6) RAPIDLY EFFECTIVE	(7) STIMULATES CREATIVITY	(8) SYSTEMATIC	(9) QUANTITATIVE	(10) TEACHES GOOD PRACTICE	OTHER ADVANTAGES	DISADVANTAGES	APPLICATIONS
DESIGN AXIOMS	●	◒	●	●	●	●	●	◒	○	●	A,B,E,F	A,B	A,B,C,D,E
DFM GUIDELINES	●	●	●	●	○	●	●	○	○	●	A,C,E,F	C	A
BOOTHROYD-DEWHURST DFA METHOD	◒	◒	○	◒	◒	●	●	●	●	●	A,E,H		A
TAGUCHI METHOD	◒	○	○	○	●	◒	◒	●	●	◒	D	B	A,B,C,D,E,F
MANUFACTURING PROCESS DESIGN RULES	◒	◒	◒	●	◒	◒	◒	●	●	●	F,G,H	E,F	C,E
DESIGNER'S TOOLKIT	◒	○	○	●	◒	○	◒	●	◒	◒	F,G,H	E,F,G	F
COMPUTER-AIDED DFM	◒	◒	◒	●	◒	◒	◒	◒	●	◒	G,H		A,B,C,E,F
GROUP TECHNOLOGY	○	◒	●	○	●	○	◒	◒	◒	○	A,D,G,H	B	A
FMEA	◒	◒	○	○	●	◒	◒	◒	◒	◒	E,F		A,B,D
VALUE ANALYSIS	●	◒	○	○	●	○	●	◒	◒	●	A,E	H	A,B,C,D,E,F

● BETTER ◒ AVERAGE ○ WORSE

DFM METHODOLOGY COMPARISON (CONTD)

KEY TO ADVANTAGES

- Narrow range of possibilities
- Results in inherent robustness
- Ready reference to best practices
- Emphasises effects of variations
- Helps identify and prioritize corrective action
- Provides both guidance and evaluation
- Can shorten design /tooling cycle
- Can reduce tooling and fixturing cost

KEY TO DISADVANTAGES

- Interpretation not always simple
- Requires “buy in” on part of user
- Exceptions are not indicated
- Rates only ease of assy.Does not address part handling or other related mfg. Parameters
- Development requires input from experienced experts familiar with specific process capabilities and needs
- To be used on a regular basis implementation must be user friendly
- Must be developed and/or customised for each specific application
- Often requires difficult to obtain information

KEY TO APPLICATIONS

Mechanical and electromechanical devices and assemblies

Electronic devices and system

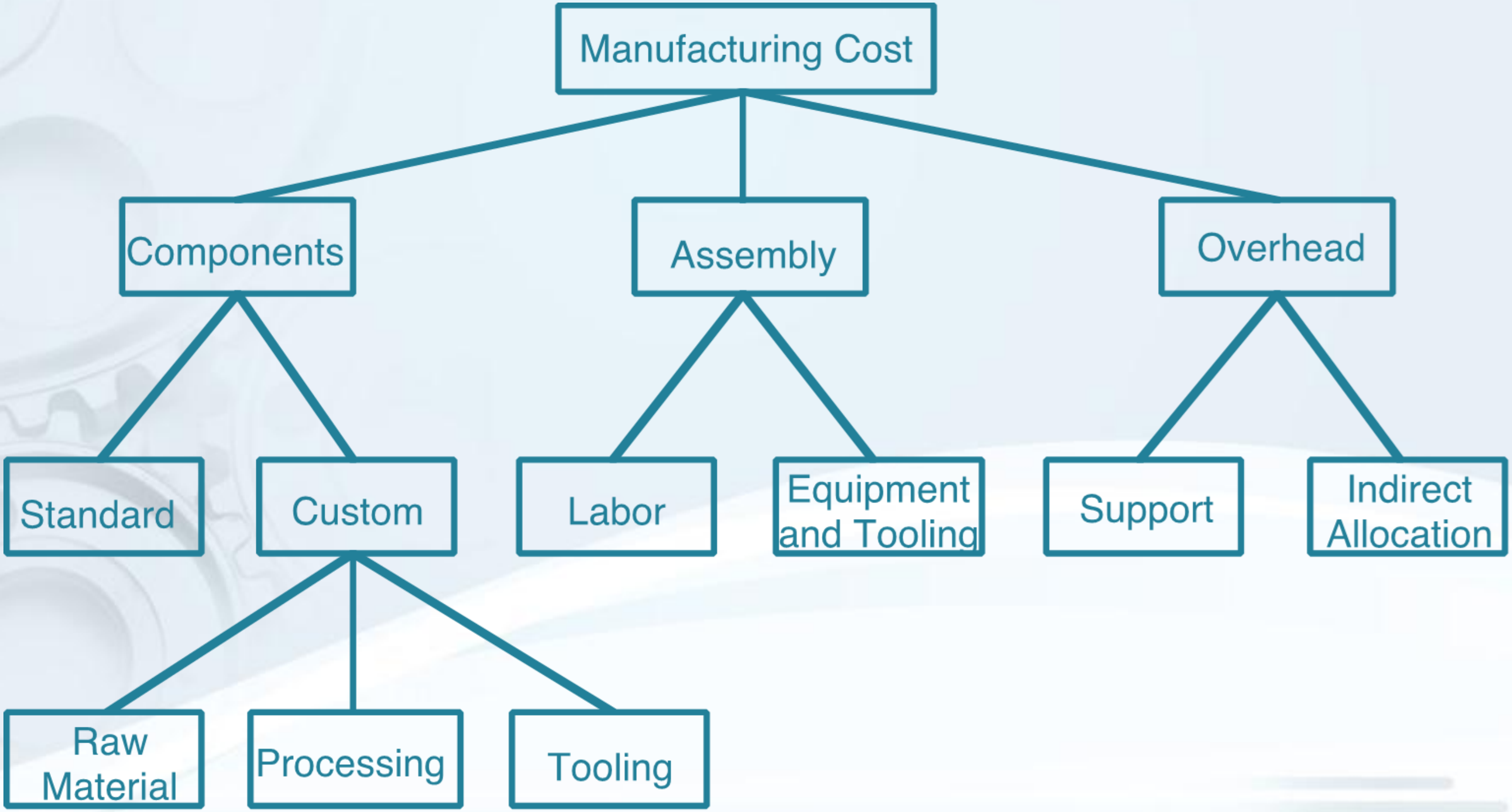
Manufacturing and other processes

Software instrumentation and control system integration

Material transformation processes

Specified and or unique manufacturing facilities such as flexible assembly systems

Understanding Manufacturing Costs



Major DFM objectives

- **Reduce component costs**
- **Reduce assembly cost**
- **Reduce production support costs**

The DFM Process (5 steps)

- Estimate the mfg. costs
- Reduce the costs of components
- Reduce the costs of assembly
- Reduce the costs of supporting production
- Consider the impact of DFM decisions on other factors.

Estimate mfg. costs

- **Cost categories**
  - Component vs. assembly vs. overhead
  - Fixed vs. variable
  - Material vs. labor
- **Estimate costs for standard parts**
  - Compare to similar part in use
  - Get a quote from vendors
- **Estimate costs of custom made parts**
  - Consider material costs, labor costs, and tooling costs
  - Depend on the production volume as well
- **Estimate costs of assembly**
  - Summing up all assembly operations (time by rate)
- **Estimate the overhead costs**
  - A % of the cost drives

Reduce the costs of components

- Identify process constraints and cost drivers
- Redesign components to eliminate processing steps
- Choose the appropriate economic scale for the part process
- Standardize components and their processes
- Adhere the black-box component

Reduce the costs of assembly

- Integrate parts
- Maximize ease of assembly
- Consider customer assembly (do-it-yourself) technology driven products

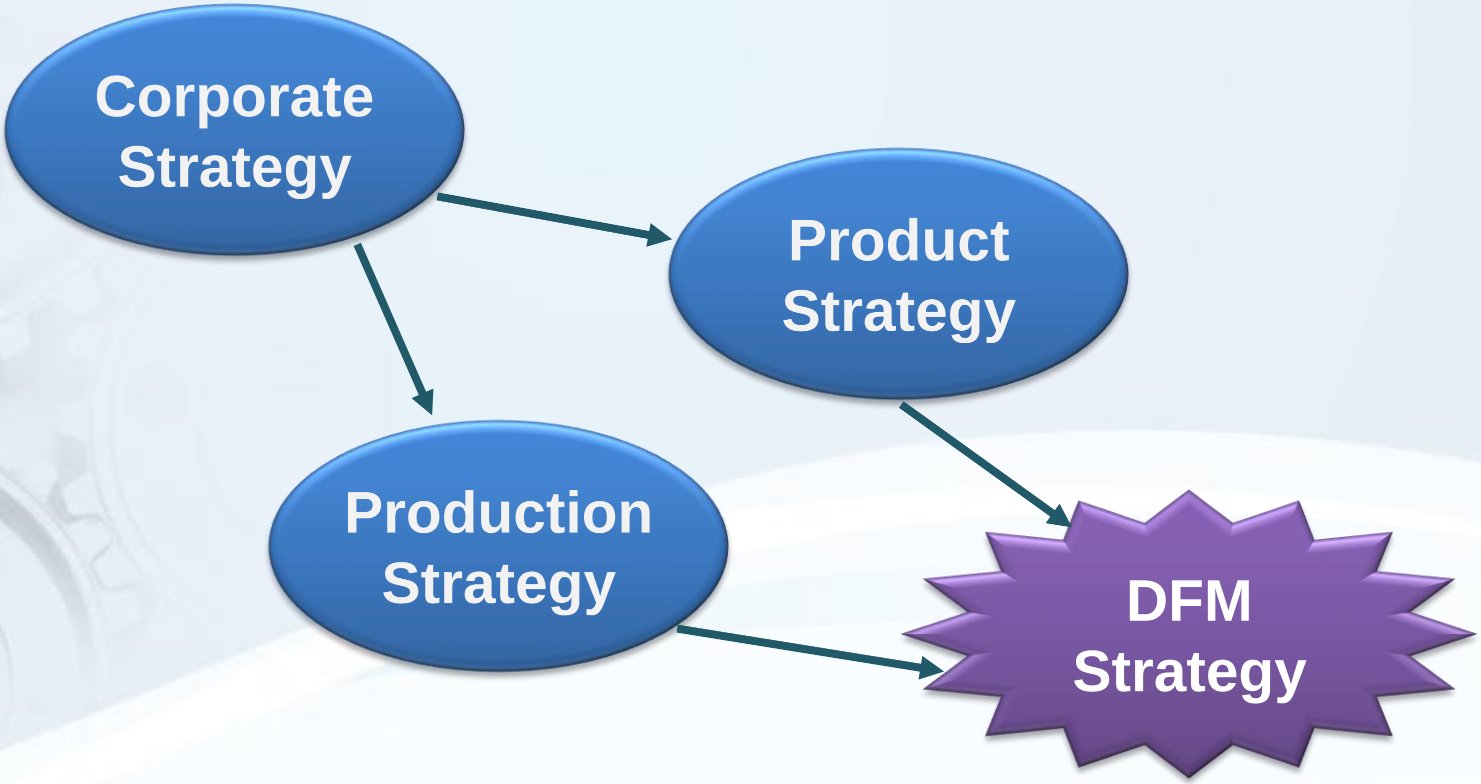
Reduce the costs of supporting production

- **Minimize systematic complexity (such as plastic injection modeling for one step of making a complex product)**
- **Error proofing (anticipate possible failure modes in the production system and take appropriate corrective actions early in the development process)**

Considering impacts

- **Development time**
- **Development cost**
- **Product quality**
- **External factors such as**
  - component reuse and
  - life cycle costs

DFM Strategy is Contingent



General Principles

- **Design for Fixturing:** Keep in mind fixturing follows the datum lines of the design. If the datum is standardized for various features of one assembly or component, the fixture location can stay consistent.
- **Design for Tooling by Reducing Tooling Complexity:** Use standardized tools on similar machines.
- Reduce Number of Setups by Accomplishing More on One Machine Using Standardized Tools.
- Specify Optimal Tolerances by using Designed Experiments.
- Reduce Number of Tools.
- **Understand Tolerance Step-up Functions:** In other words, .001 inches specifies CNC turning, .0001 inches specifies grinding, .00001 inches specifies honing and polishing. Be careful that the design only asks for the tolerances needed.

Design for Ease of Fabrication

- For high volume products, use die castings or stampings to reduce machining
- Use near net shapes for molded and forged parts to minimize machining and processing effort
- Design for ease of fixtures by providing large solid mounting surface and parallel clamping surfaces
- Avoid designs requiring sharp corners or points in cutting tools – they break easier
- Avoid thin walls, thin webs, deep pockets, or deep holes to withstand clamping and machining without distortion
- Avoid tapers and contours, as much as possible, in favor of rectangular shapes
- Avoid undercuts that require special operations and tools
- Avoid hardened or difficult machined materials, unless essential to requirements
- Put machined surfaces on same plane or with same diameter to minimize number of operations
- Design work pieces to use standard cutters, drill bit sizes, or other tools
- Avoid small holes (drill bit breakage greater) and length to diameter ratio greater than chip clearance and straightness deviation

Design for Manufacturing

- Design within process capabilities and avoid unneeded surface finish requirements
- Mistake-proof product design and assembly (Poka-Yoke)
- Design for parts orientation and handling
- Minimize flexible parts and interconnections
- Design for efficient joining and fastening
- Design modular products
- Design for automated production
- Use near net shapes for molded and forged parts to minimize machining and processing effort

Design for Manufacturing (cont'd)

- Design for ease of fixturing by providing large solid mounting surface and parallel clamping surfaces
- Avoid designs requiring sharp corners or points in cutting tools – they break easier
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- Design work pieces to use standard cutters, drill bit sizes or other tools

Manufacturing Processes

Machining	Casting	Bulk Def	Sheetmetal	Polymer	Assembly
Turning	Sand	Forging	Blanking	Extrusion	Welding
Facing	Shell Mold	Rolling	Punching	Injection Molding	Brazing
Boring	Plastic Mold	Wire Drawing	Bending	Compression Molding	Soldering
Planning	Ceramic Mold	Tube Drawing	Drawing	Blow Molding	Resistance Welding
Milling	Die	Extrusion	Deep Drawing	Transfer Molding	Adhesive Bonding
Drilling	Perm. Mold	Colming	Ironing	Coating	Press / Snap Fit
Grinding	Centrifugal	Roll Forming	Spinning	Thermo-forming	Man. Assy
Sawing	Investment		Stretching		
EDM					
Wire EDM					
Chem Milling					
ECM					
Laser					

Manufacturing Processes (cont'd)

Shaping	Forming	RP	Treatment	Assembly
Casting Sintering Electrolytic Depositon	Forging Extruding Bending Shearing Pressing	SLA SLS 3D Printing LENS UC	Harden Heat Treatment Sintering and burning Magnetizing Photochemical Reactions Lazing	Welding Brazing Soldering Resistance Welding Adhesive Bonding Press / Snap Fit

Design Guidelines for Parts Manufactured from Injection Molding Equipment

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Summary of Processes Plastic and Rubber Components

Process	Description	Advantage	Limitations
Compression molding	Molding material, generally preformed, is manually placed between the mold halves and heated under pressure to form the part	Tooling relatively inexpensive; reduced flow lines and internal stress.	Intricate shapes with side draws and undercuts are difficult.
Transfer Molding	Material is placed in a heating chamber from which after softening, it is forced by a plunger into the molde cavity	More rapid production rates than with compression molding. Parts can be more intricate and delicate	Tooling is more expensive than with compression molding, material is lost in sprues and runners
Injection Molding	Material is fed into a heated cylinder, from which it Is injected by plunger action into the mold cavities. The process is normally automatic	Rapid production of intricate parts with molded-in color and little need for subsequent operations	Tooling is costly. The process is less suitable for large parts or small quantities
Rotational Molding	A heated metal mold, rotating on two axes, is charged with plastic material, which coats the interior surface. The heate causes the material to fuse.	Molds are inexpensive. Large parts are relatively inexpensive to produce.	Limited to hollow shapes, which cannot be too intricate. The process is slow and is not competitive for small parts.
Blow molding	Air pressure is applied inside a small hollow plastic piece (called a parison) expands it against the walls of the mold cavity, whose shape it assumes	An economical process for rapid mss production of containers and other hollow products	Limited to hollow products, not suitable for small quantities. Tolerances are relatively broad, and wll thickness is difficult to control
Extrusion	Material is fed into a heated cylinder, which it is fed by a rotating screww through a die orifice of the desired cross section. The material is cooled, and after hardening , cut to length.	Production is rapid and tooling is inexpensive. Very complex cross sections can be produced	Limited to parts of constant cross section. Tolerances are relatively broad.
Thermoforming	The plastic sheet is heated and placed over a mold. A vacuum between the sheet and the mold causes the sheet to be drawn against the mold, taking its shape	Tooling and equipment are inexpensive. Production rates are good. Large parts can be produced.	Ribs, bossess, and other sections heavier than the basic sheet thickness are not feasible. Wall become thinner at deep draws.

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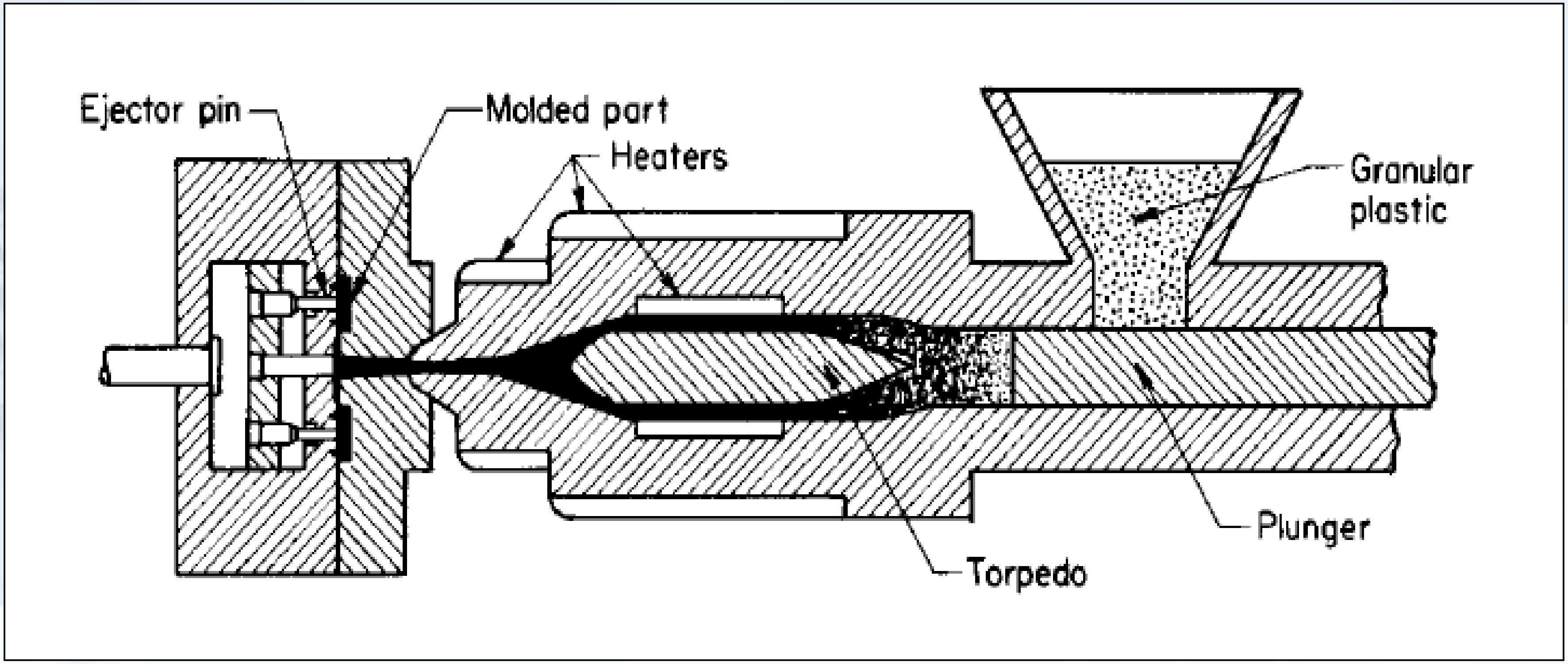
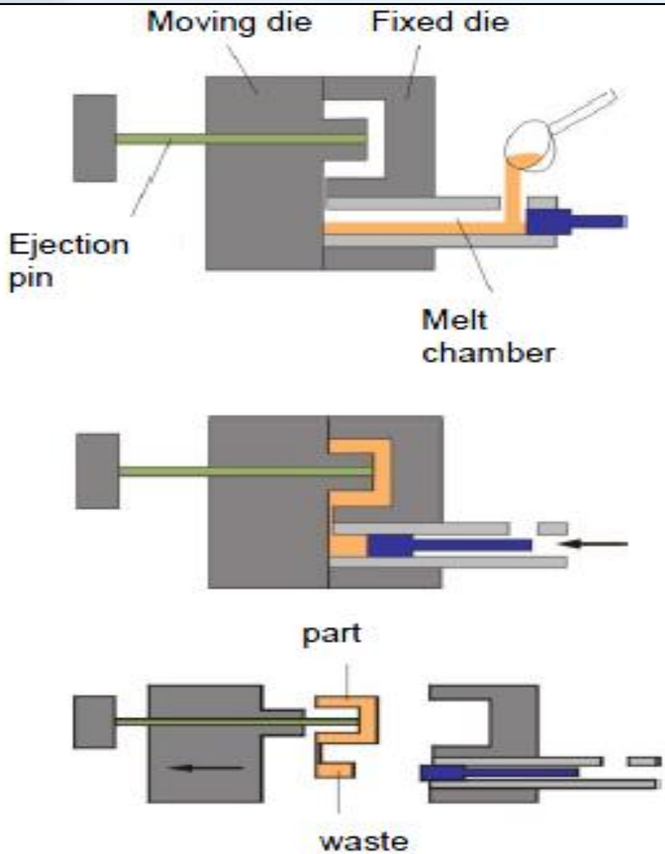
Injection Molding

- **Material is fed into a heated cylinder, which it is injected by a plunger action into the mold cavities**



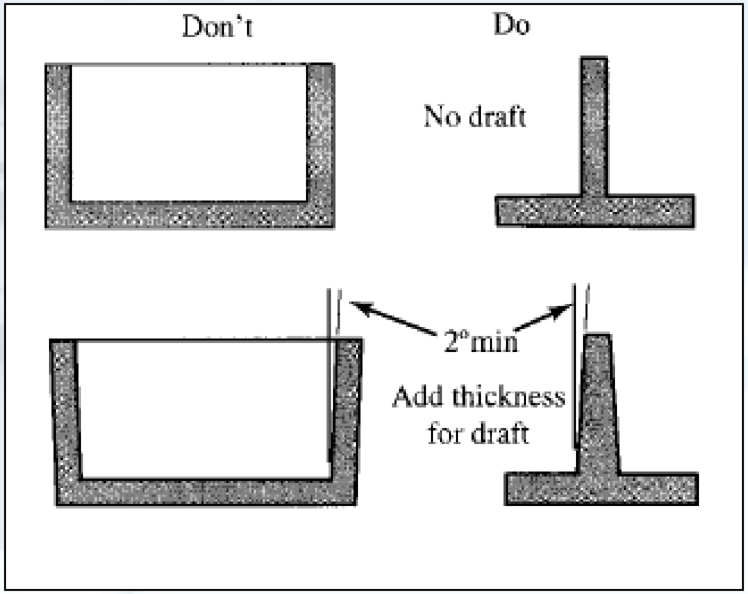
Injection Molding Components & Finish Parts

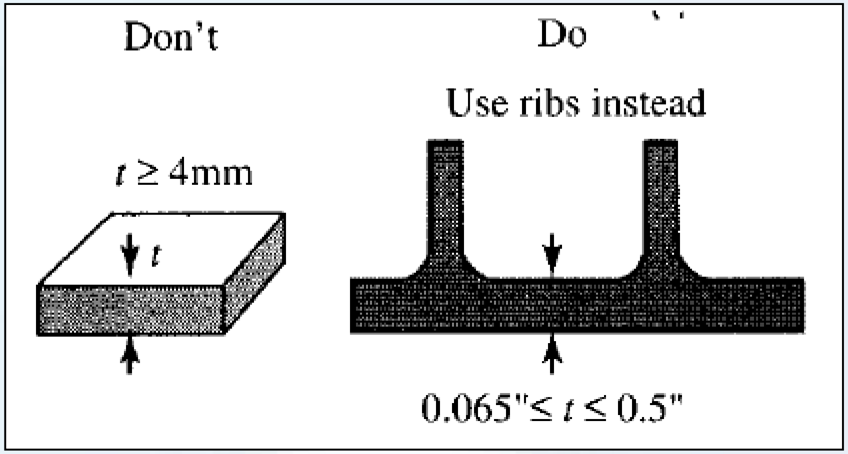
Rapid production of intricate parts with mold-in color and little need for subsequent operations



Injection Molding DFM Design Guidelines

Provide adequate draft angle for easier mold removal





Minimize section thickness, cooling time is proportional to the square of the thickness, reduce cost by reducing the cooling time

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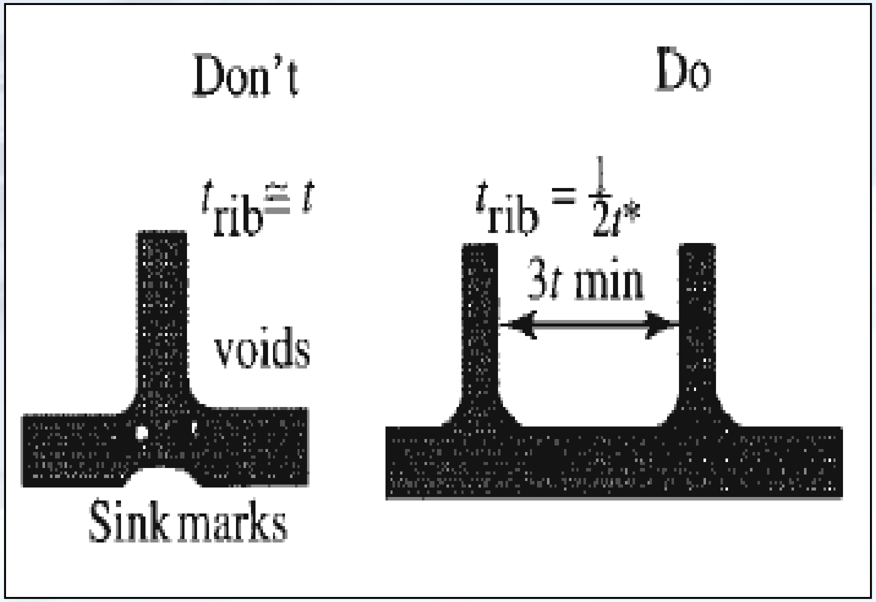
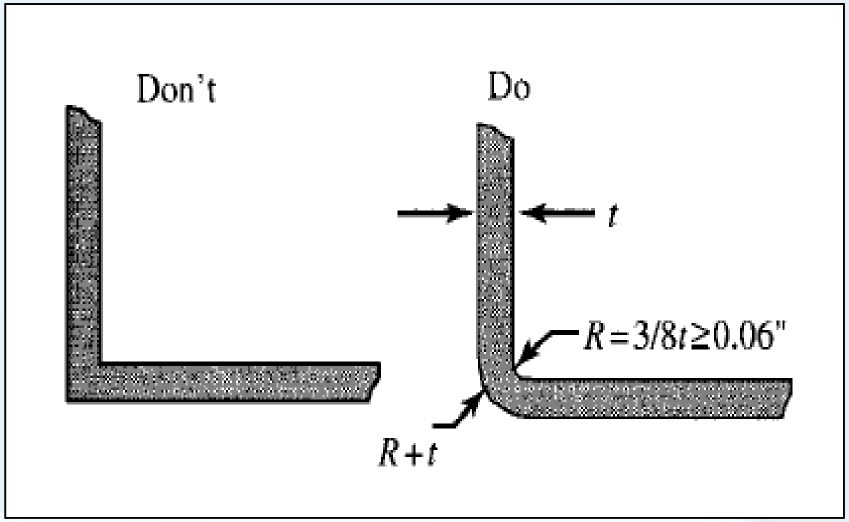
Injection Molding DFM Design Guidelines

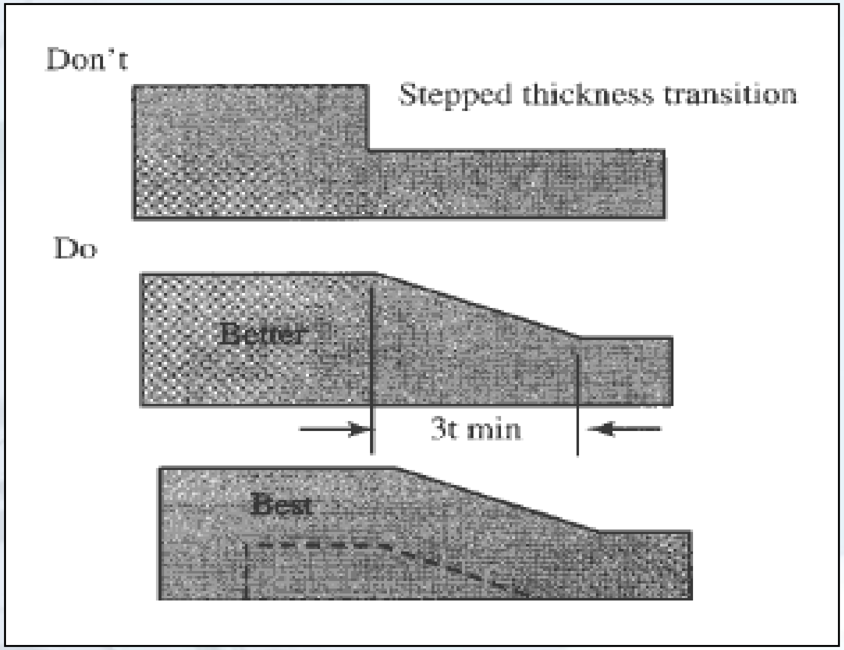
Keep rib thickness less than 60% of the part thickness in order to prevent voids and sinks

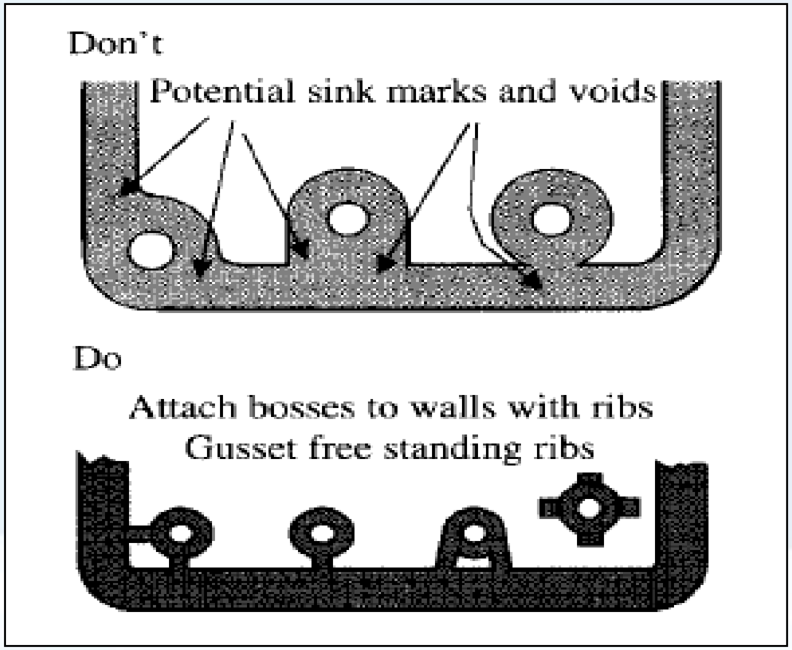




Avoid sharp corners, they produce high stress and obstruct material flow

Injection Molding DFM Design Guidelines





Provide smooth transition, avoid changes in thickness when possible

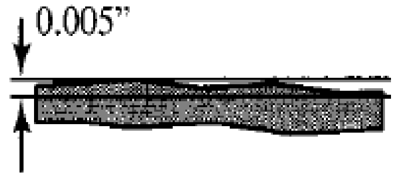
Keep section thickness uniform around bosses

Injection Molding DFM Design Guidelines

- **Use standard general tolerances, do not tolerance:**

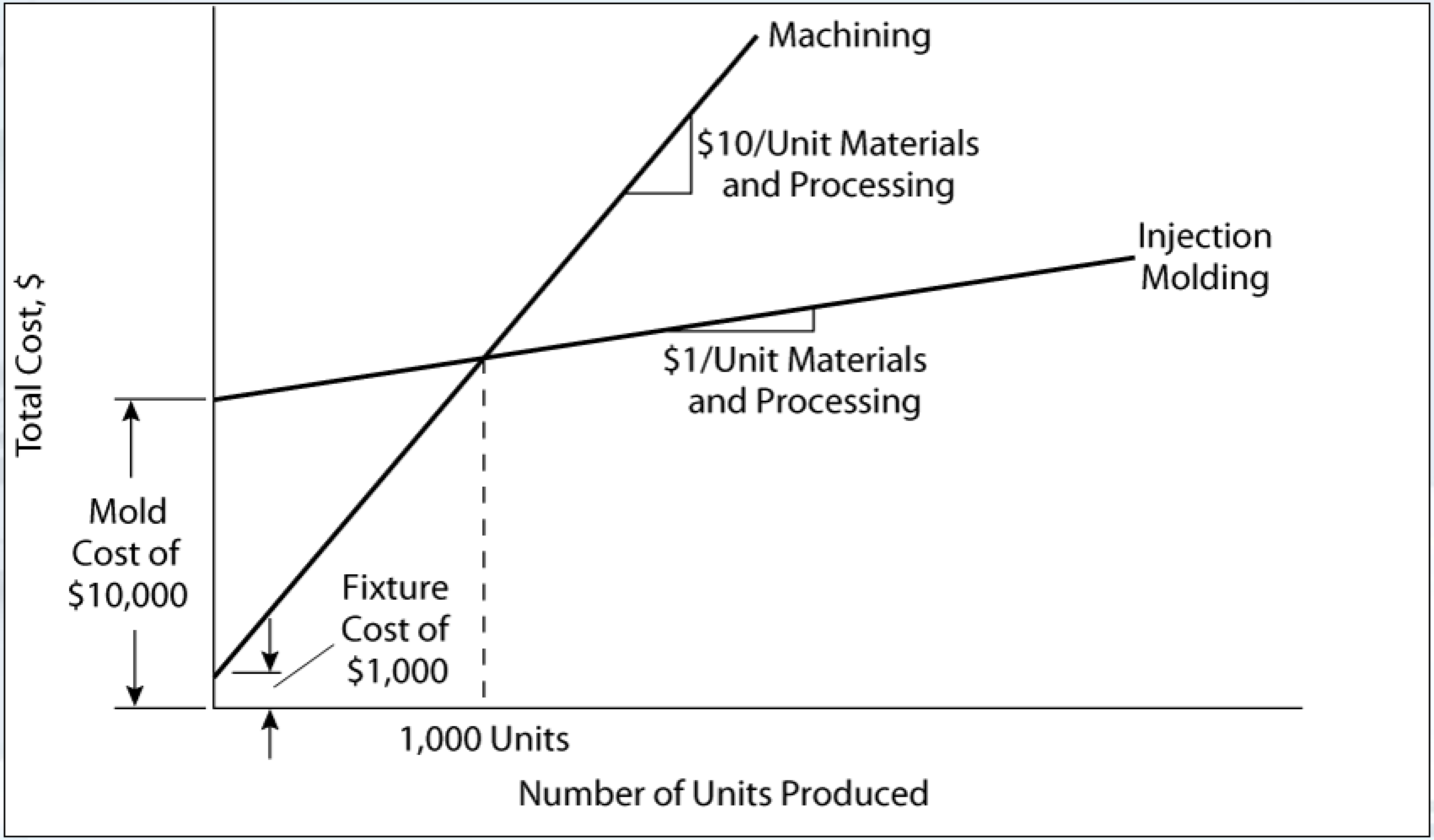
Dimension	Tolerance	Dimension	Tolerance
0 ≤ d ≤ 25	± 0.5 mm	0 ≤ d ≤ 1.0	± 0.02 inch
25 ≤ d ≤ 125	± 0.8 mm	1 ≤ d ≤ 5.0	± 0.03 inch
125 ≤ d ≤ 300	± 1.0 mm	5 ≤ d ≤ 12.0	± 0.04 inch
300	± 1.5 mm	12	± 0.05 inch

- **Minimum thickness recommended: .025 in or .65mm, up to 0.125 for large parts**
- **Round interior and exterior corners to .01 - .015 in radius (min.) prevents an edge from chipping.**



Standard thickness variation.

Comparison of Processes



Design Guidelines for Parts Manufactured from Rotational Molding Equipment

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Summary of Processes Plastic and Rubber Components

Process	Description	Advantage	Limitations
Compression molding	Molding material, generally preformed, is manually placed between the mold halves and heated under pressure to form the part	Tooling relatively inexpensive; reduced flow lines and internal stress.	Intricate shapes with side draws and undercuts are difficult.
Transfer Molding	Material is placed in a heating chamber from which after softening, it is forced by a plunger into the molde cavity	More rapid production rates than with compression molding. Parts can be more intricate and delicate	Tooling is more expensive than with compression molding, material is lost in sprues and runners
Injection Molding	Material is fed into a heated cylinder, from which it Is injected by plunger action into the mold cavities. The process is normally automatic	Rapid production of intricate parts with molded-in color and little need for subsequent operations	Tooling is costly. The process is less suitable for large parts or small quantities
Rotational Molding	A heated metal mold, rotating on two axes, is charged with plastic material, which coats the interior surface. The heate causes the material to fuse.	Molds are inexpensive. Large parts are relatively inexpensive to produce.	Limited to hollow shapes, which cannot be too intricate. The process is slow and is not competitive for small parts.
Blow molding	Air pressure is applied inside a small hollow plastic piece (called a parison) expands it against the walls of the mold cavity, whose shape it assumes	An economical process for rapid mss production of containers and other hollow products	Limited to hollow products, not suitable for small quantities. Tolerances are relatively broad, and wll thickness is difficult to control
Extrusion	Material is fed into a heated cylinder, which it is fed by a rotating screww through a die orifice of the desired cross section. The material is cooled, and after hardening , cut to length.	Production is rapid and tooling is inexpensive. Very complex cross sections can be produced	Limited to parts of constant cross section. Tolerances are relatively broad.
Thermoforming	The plastic sheet is heated and placed over a mold. A vacuum between the sheet and the mold causes the sheet to be drawn against the mold, taking its shape	Tooling and equipment are inexpensive. Production rates are good. Large parts can be produced.	Ribs, bossess, and other sections heavier than the basic sheet thickness are not feasible. Wall become thinner at deep draws.

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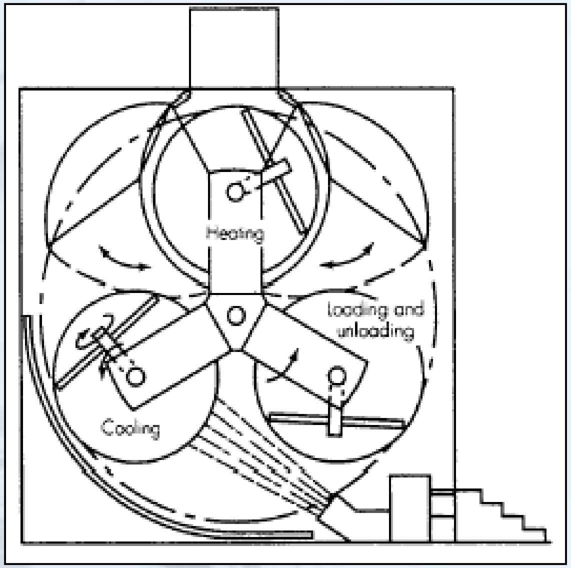
Rotational Molding

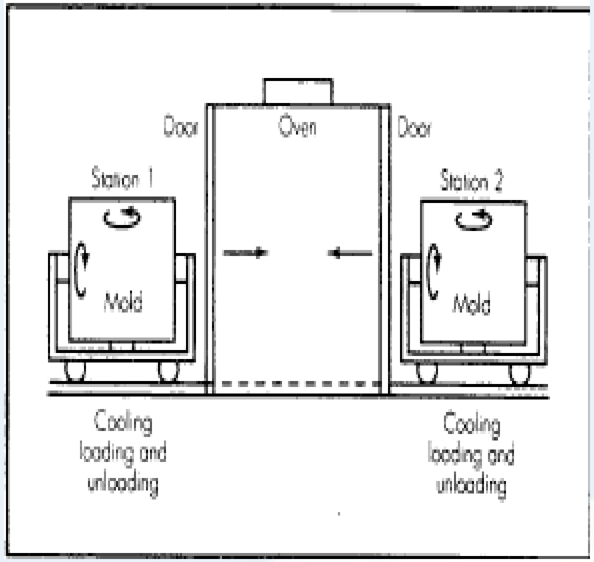
Rotational molding process consist of six steps:

- **A predetermined amount of plastic, powder or liquid form, is deposited in one half of a mold**
- **The mold is closed**
- **The mold is rotated bi-axially inside an oven**
- **The plastics melt and form a coating over the inside of the mold**
- **The mold is removed from the oven and cooled**
- **The part is removed from the mold**

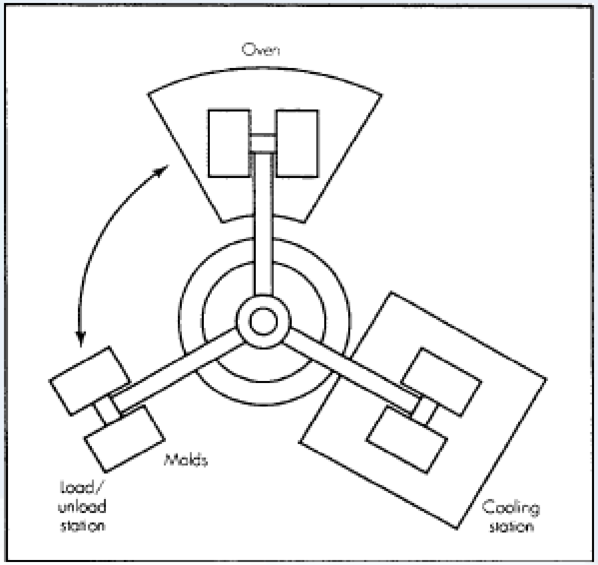
Rotational Molding Machines



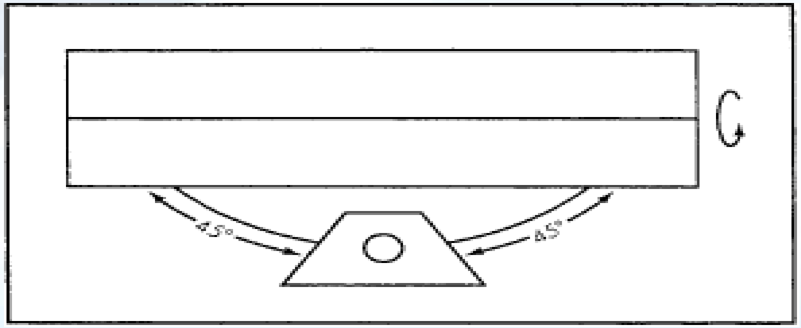
Vertical Wheel Machine



Shutter Machine



Turret Machine



Rock and Roll Machine

Rotational Molding

Advantages:

- **Molds are relatively inexpensive**
- **Rotational molding machines are much less expensive than other type of plastic processing equipment**
- **Different parts can be molded at the same time**
- **Very large hollow parts can be made**
- **Parts are stress free**
- **Very little scrap is produced**

Rotational Molding

Limitations

- Can not make parts with tight tolerance
- Large flat surfaces are difficult to achieve
- Molding cycles are long (10 – 20 min.)

Material

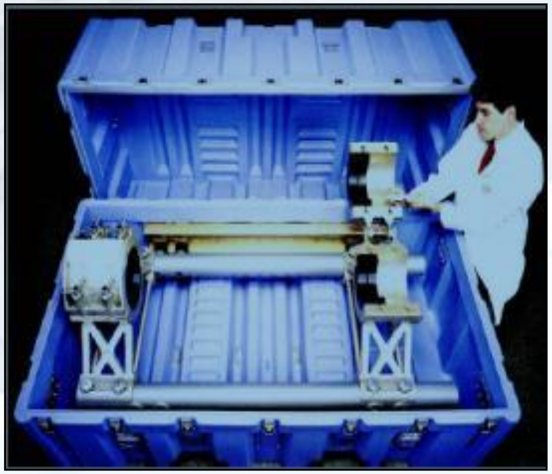
- Polyethylene (most common)
- Polycarbonate (high heat resistance and good impact strength)
- Nylon (good wear and abrasion resistance, good chemical resistance, good toughness and stiffness)

Rotational Molding

Nominal Wall Thickness:

- **Polycarbonate wall thickness is typically between .06 to .375 inches, .125 inches being an ideal thickness**
- **Polyethylene wall thickness is in the range of .125 to .25 inches, up to 1 inch thick wall is possible**
- **Nylon wall thickness is in the range of .06 to .75 inches**

Rotational Molding Examples

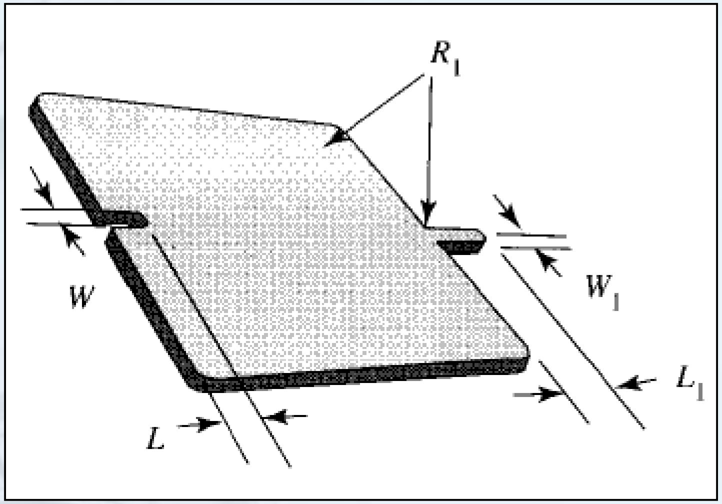


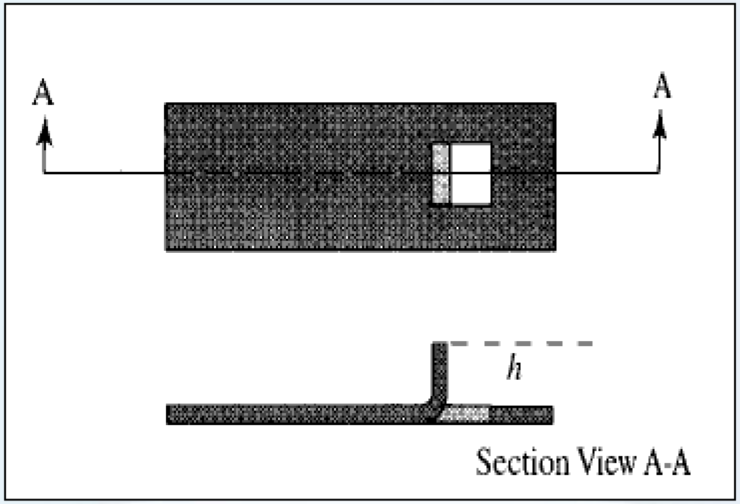
Design Guidelines for Parts Manufactured from Sheet-Metal Forming

Summary of Processes Formed Metal Parts

Process	Description	Advantage	Limitations
Metal Extrusion	Billet of metal is forced by a hydraulic ram through a die hole of the desired shape. The metal emerges from the die in solidified from and closely confroms in cross section to the shape & dimensions of the die opening	Intricate cross-sectional shapes, including those with undercuts or those that are hollow, can be produced. Tooling costs are low.	Limited to ductile metals and also in the maximum size of cross section. Parts of nonuniform cross-section require additional operations.
Metal Stamping	Metal, in sheet form, is cut to the desired outline shape and is bent, formed, coined, or drawn to a different three dimensional shape through a limited number of strokes of power press to which the die is attached.	Rapid production of uniform parts which are sometimes quite intricate. Labor and material costs are low.	Wall thickness must be essentially uniform. Edges may be rough. Tool costs may be high.
Fine Stamping	Like Metal Stamping except: Material is tightly clamped during the operation. The punch-die clearance is very small, and the punch doe not actualy enter the die. The press motion is slower during shearing	Improved surface finish and squareness of sheared edges. Parts have higher dimensional accuracy and better flatness.	Tooling and equipment costs are higher than with conventional stamping. Production rates are lower.
Cold-headed parts	A blank of metal, cut from wire or rod protrudes from a stationary die and is formed by shaped punch which moves axially against the blank to a diameter larger than the blank	Best suited to high volume production of small parts. Parts have smooth surface and improved physical properties. There is not scrap loss.	Undercuts, thin walls. Reentrant shapes normally are not feasible. The size of the part is limited.
Rolled Formed sections	A strip of sheet metal is fed continuously through a series of contoured rolls in tandem. As the stock passes through the rolls, it is gradually formed into a shape with the desired uniform cross-sections	The best application are longer parts with complex cross-sectional shapes. Production is rapid. Surface finish and dimensional consistency are good	Parts must have the same cross section for the whole length. Tooling and setup costs are high.
Forging	A blank of material is heated to the softening point and then subjected to one or more blows by a shaped die. The resultant forging approximates the shape of the finish part.	Controlled grain structure provides enhanced mechanical strength to forge parts. Forgings are light in weight per unit of strength. Low loss of material, few internal flaws	Machining is usually required to provide accurate finished dimensions; otherwise tooling and processing costs are high.
Powder-metal parts	Metal powder is placed in a die cavity and compacted by the application of high tonnage pressure at toom temperatur. The part is then heated to a temperature just below the melting point to fuse the metal particles.	Rapid production of parts with high dimensional accuracy, smooth surfaces, and excellent bearing properties. Parts can be somewhat intricate in shape. Scrap is low	Size of parts is limited, and not all shapes can be produced. Tooling costs limit the process to high production applications. Undercuts are not feasible. There are also strength limitations

Sheet-metal Forming DFM Design Guidelines



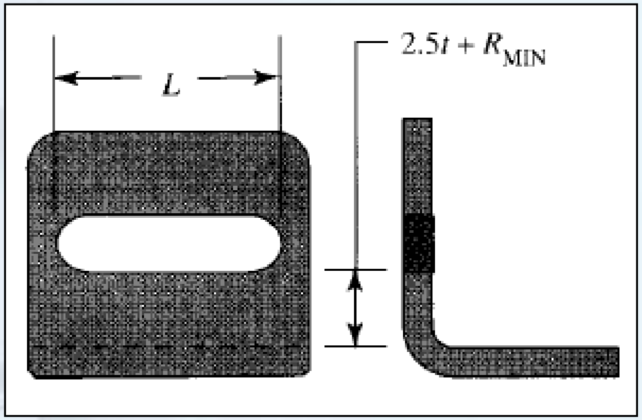


Design for ease of blanking:

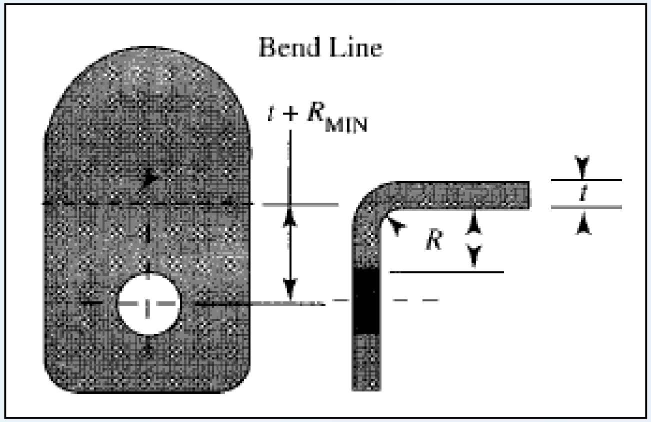
- W=0.040” min for materials thinner than 0.047” – wider if possible
- $W_1 \geq$ material thickness: wider if possible
- L=5W maximum depth, less if possible
- L_1 = 5W maximum length; less if possible

Shear and form operations should have a minimum height (h) of 2 ½ the blank thickness

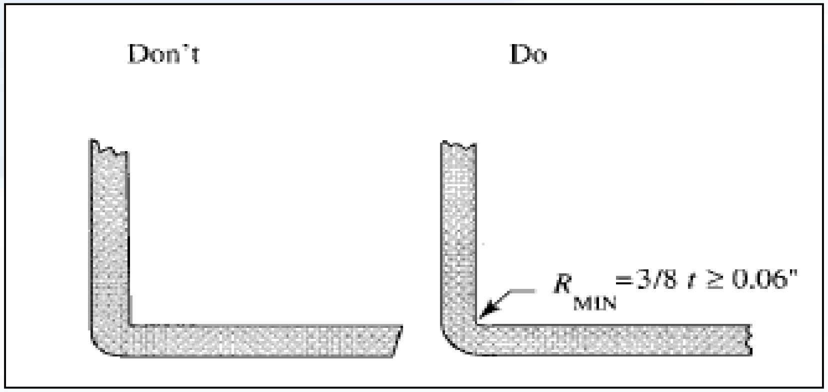
Sheet-metal Forming DFM Design Guidelines



Position opening away from bends

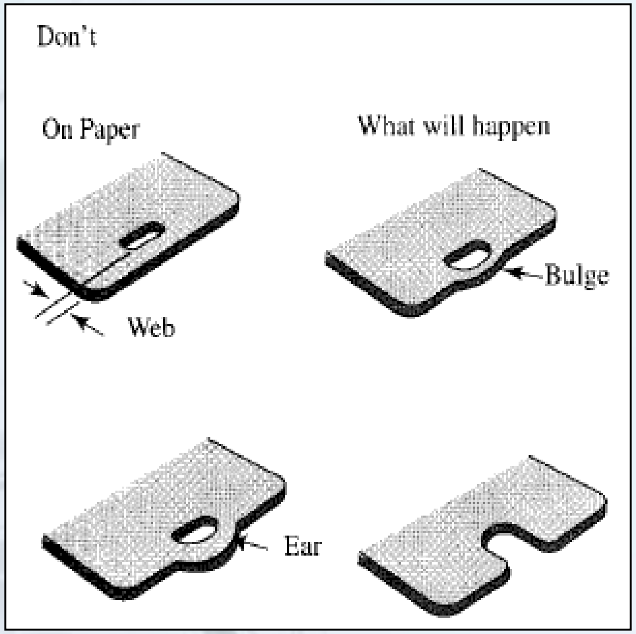


Position holes away from bends



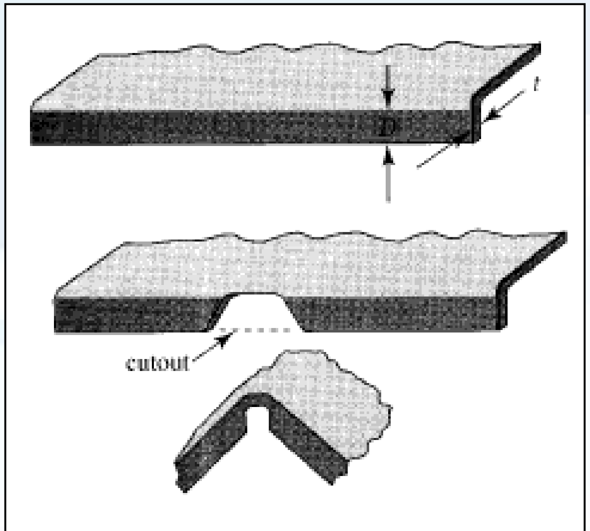
Avoid sharp corners or material that will tear

Sheet-metal Forming DFM Design Guidelines

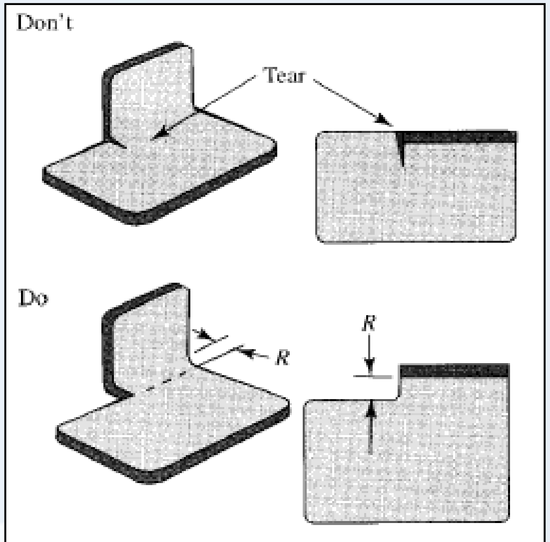


A narrow web will cause bulging. Provide an ear in the blank or include the hole as a notch.

If D $\geq$ 2t, a cutout is needed to bend flange



If $D \geq 2t$. A cutout is needed to bend flange.



Offset bends.

Offset bends

Design Guidelines for Parts Manufactured from Casting Equipment

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DFM Design Guidelines – Casting

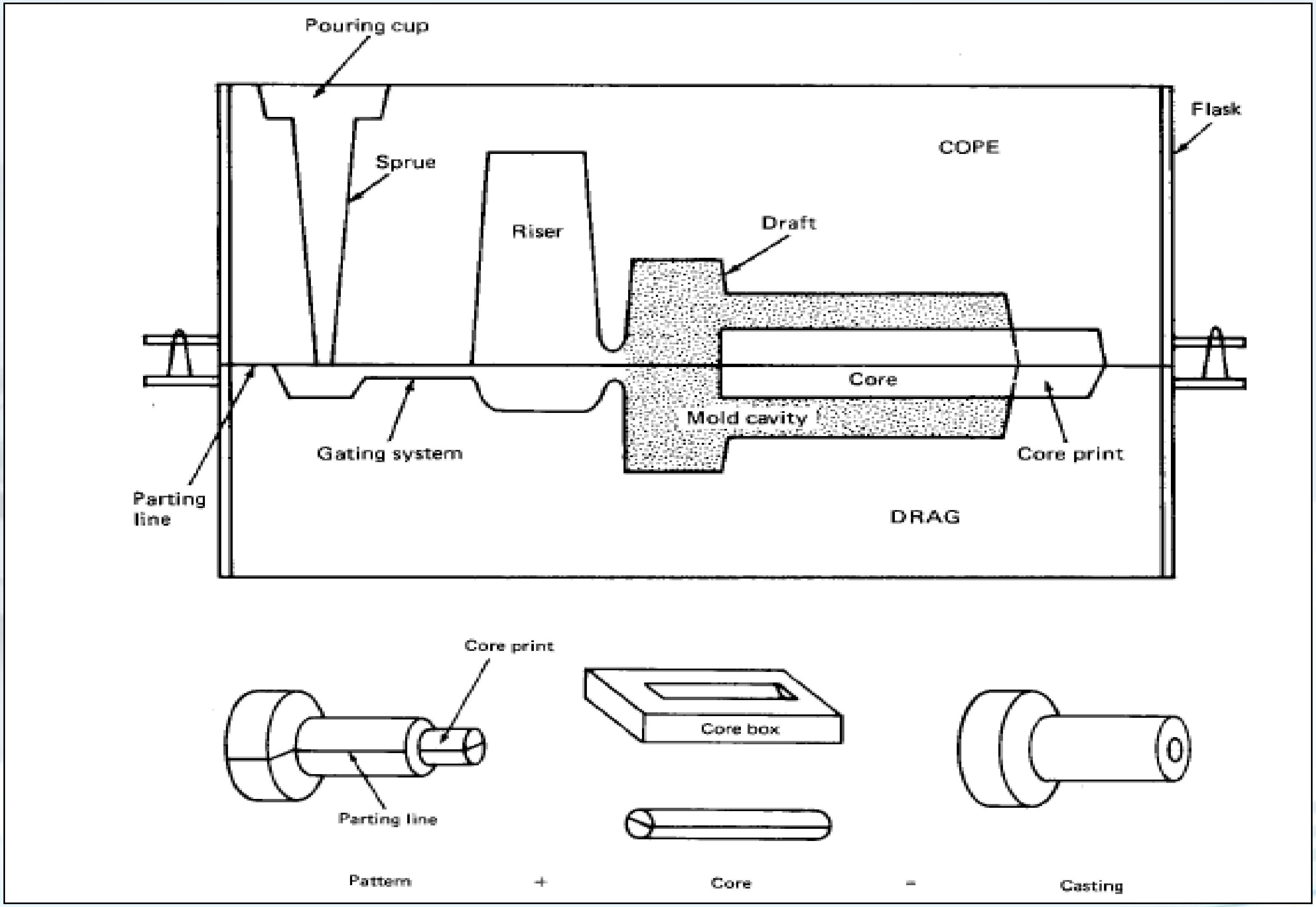
Casting, One of the oldest manufacturing processes, dates back to 4000 B.C. when copper arrowheads were made

- **Casting processes basically involve the introduction of molten metal into a mold cavity, where upon solidification the metal takes on the shape of the mold cavity**
- **Simple and complicated shapes can be made from any metal that can be melted**
- **Example of cast parts: frames, structural parts, machine components, engine blocks, valves, pipes, statues, ornamental artifacts……**
- **Casting sizes range from a few mm (teeth of a zipper) to 10m (propellers of ocean liners)**

Casting Processes

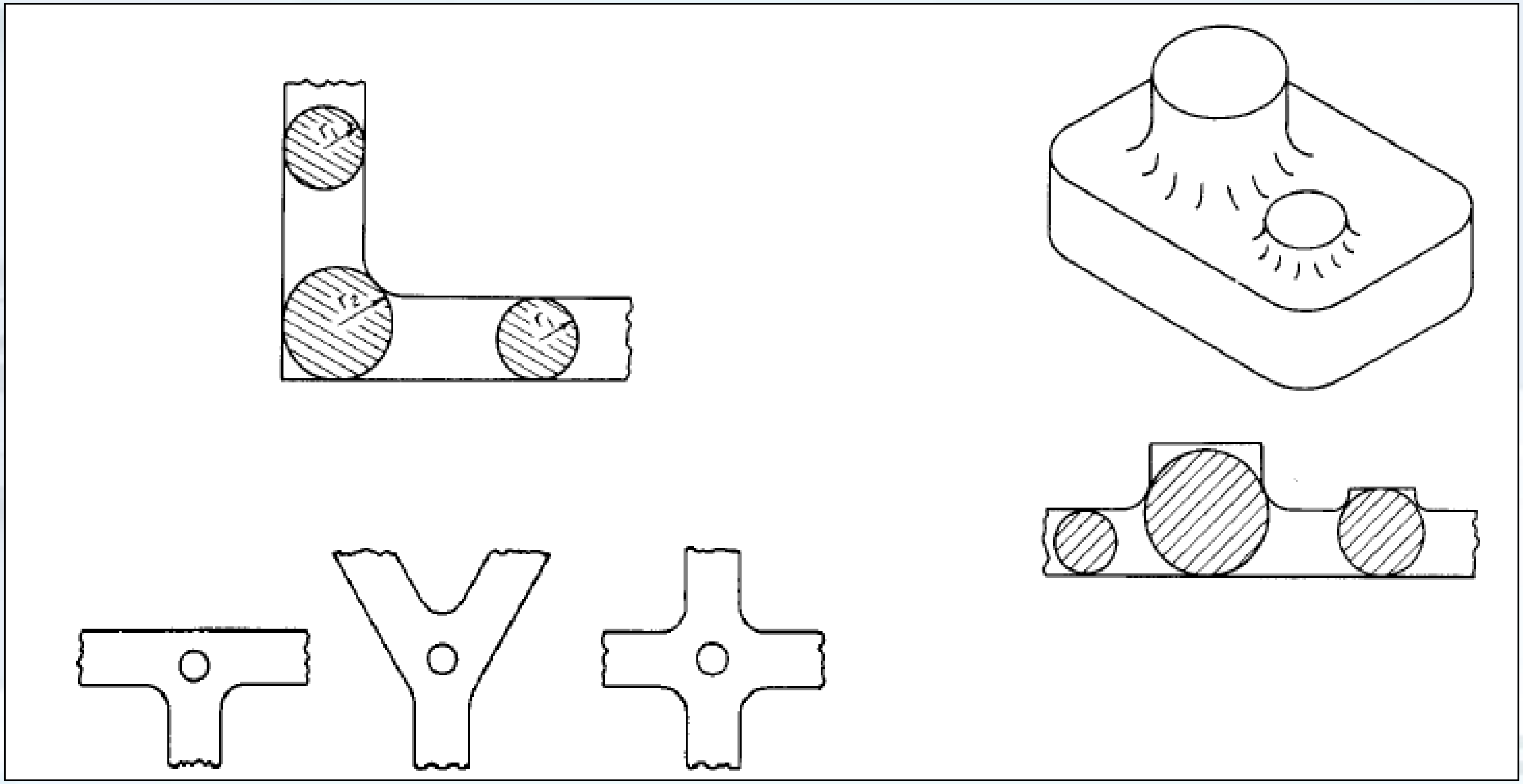
1. **Preparing a mold cavity of the desired shape with proper allowance for shrinkage.**
2. **Melting the metal with acceptable quality and temperature.**
3. **Pouring the metal into the cavity and providing means for the escape of air or gases.**
4. **Solidification process, must be properly designed and controlled to avoid defects.**
5. **Mold removal.**
6. **Finishing, cleaning and inspection operations.**

Sand Casting Terminology

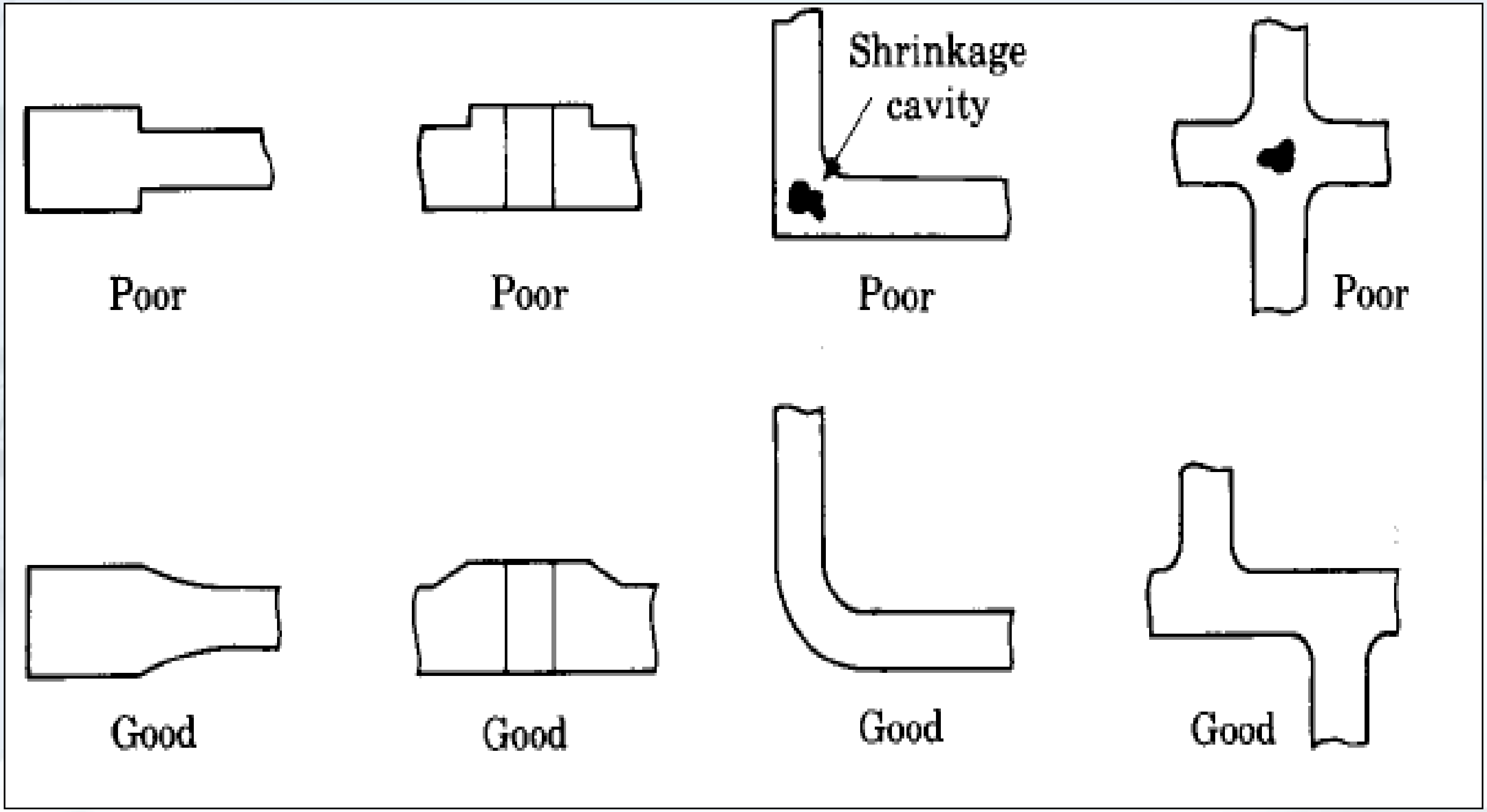


Casting Defects

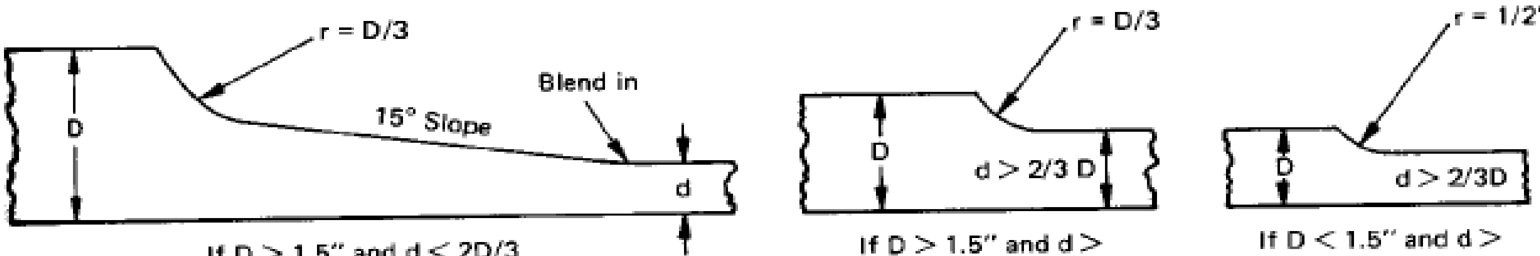
Hot Spots – thick sections cool slower than other sections causing abnormal shrinkage. Defects such as voids, cracks, and porosity are created



Casting Defects and Design Consideration



DFM Design Guidelines – Casting



If D > 1.5″ and d < 2D/3 then r = D/3 with a 15° slope between the two parts.

If D > 1.5″ and d > 2/3 D then r = D/3

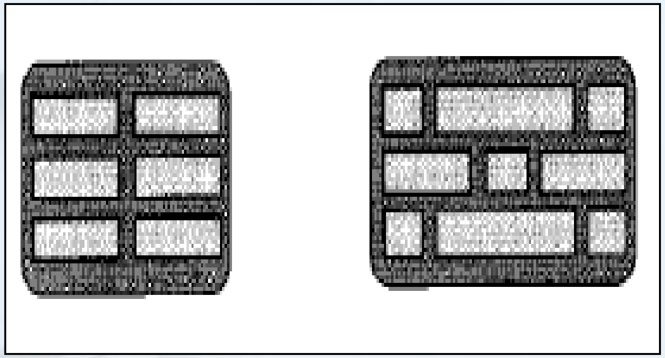
If D < 1.5″ and d > 2/3 D then r = 1/2″

TABLE 13.2 Recommended Minimum Section Thicknesses for Various Engineering Metals and Casting Processes

Material	Minimum		Desirable		Casting Process
	mm	in.	mm	in.	
Steel	4.76	3/16	6.35	1/4	Sand
Gray iron	3.18	1/8	4.76	3/16	Sand
Malleable iron	3.18	1/8	4.76	3/16	Sand
Aluminum	3.18	1/8	4.76	3/16	Sand
Magnesium	4.76	3/16	6.35	1/4	Sand
Zinc alloys	0.51	0.020	0.76	0.030	Die
Aluminum alloys	1.27	0.050	1.52	0.060	Die
Magnesium alloys	1.27	0.050	1.52	0.060	Die

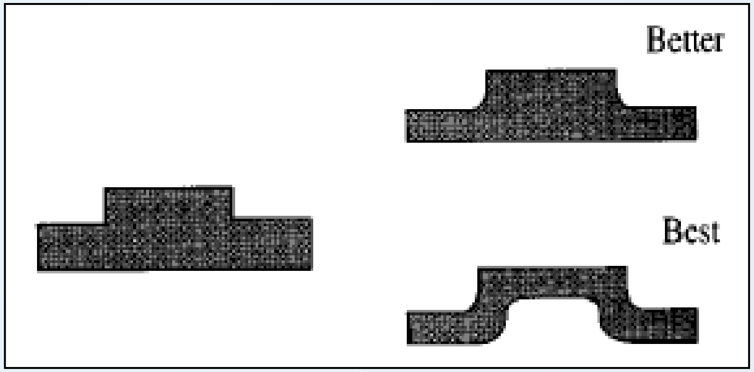
DFM Design Guidelines – Casting

Don't Do



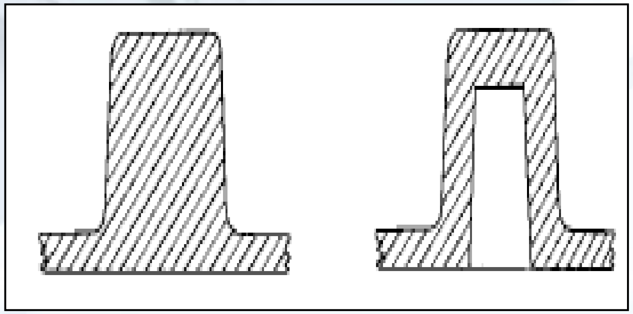
Stagger ribs to prevent hot spots

Don't Do

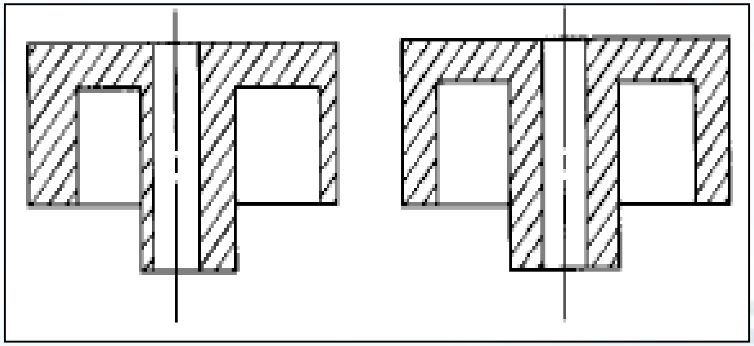


Avoid abrupt changes in section thickness

Don't Do



Don't Do



Maintain section thickness uniform

Design Guidelines for Parts Manufactured from Machining

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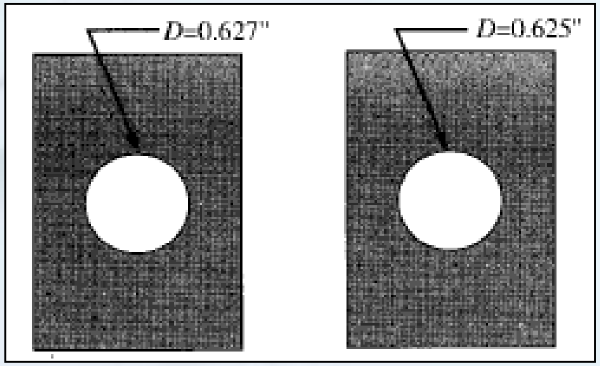
Summary of Machining Processes

Process	Most Suitable Material	Typical Application	Normal Dimensional Tolerances, mm (in)	Remarks
Turning	Various machinable material	Rollers, pistons, pins, shafts, rivets, valves, tubing, and pipe fitting	+/- 0.025 (0.001)	Both turning and facing performed with single point or form tools
Drilling	Various machinable materials	Holes for pins, shafts, fasteners, screws threads, clearance, and venting	+/- 0.15, - 0.025 (+0.006, -0.001)	Diameters from 0.025 to 150mm (0.001 to 6 in)
Milling	Various machinable materials	Flat surfaces, slots, and contour in all kinds of mechanical devices	+/-0.05 (0.002)	Common and versatile at all levels of production
Planing and shaping	Various machinable materials	Primarily for flat surfaces such as machinery bases and slides bust also for contoured shapes	+/-0.13 (0.005)	Most suitable for low-quantity production
Broaching	Various machinable materials	Square, rectangle, or irregular holes, slots, and flat surfaces	+/-0.025 (0.001)	Most suitable for mass production

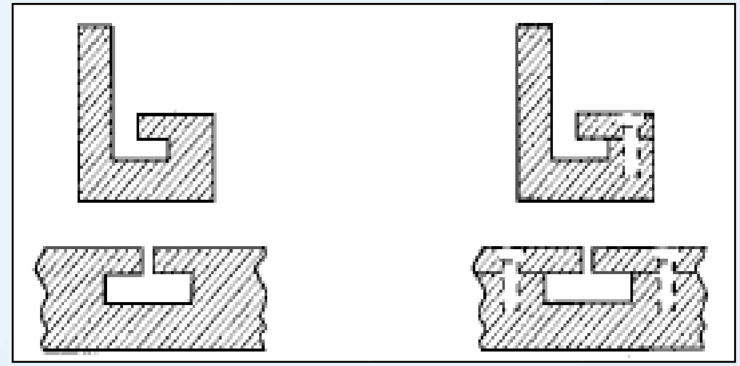
DFM Design Guidelines – Machining

Don’t Do



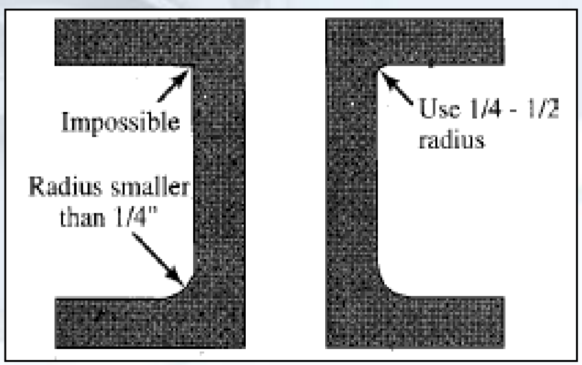
Use standard dimensions

Don’t Do



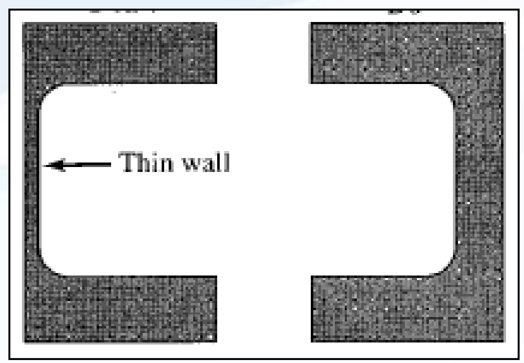
Do not design impossible to machine hollows or overhangs

Don’t Do



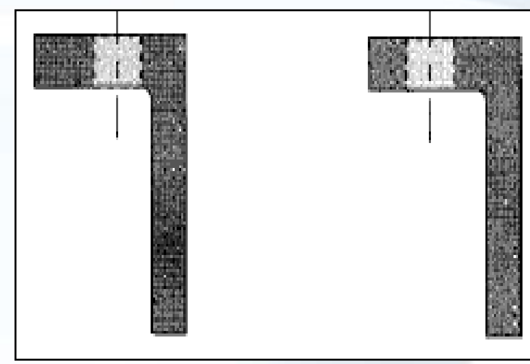
Design for reasonable internal pockets radii

Don’t Do



Avoid thin walls that break when machining

Don’t Do

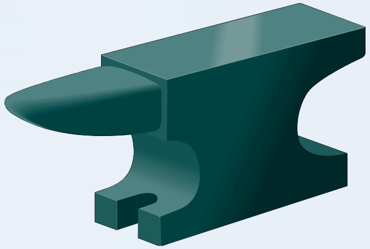


Place holes away from corner

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?

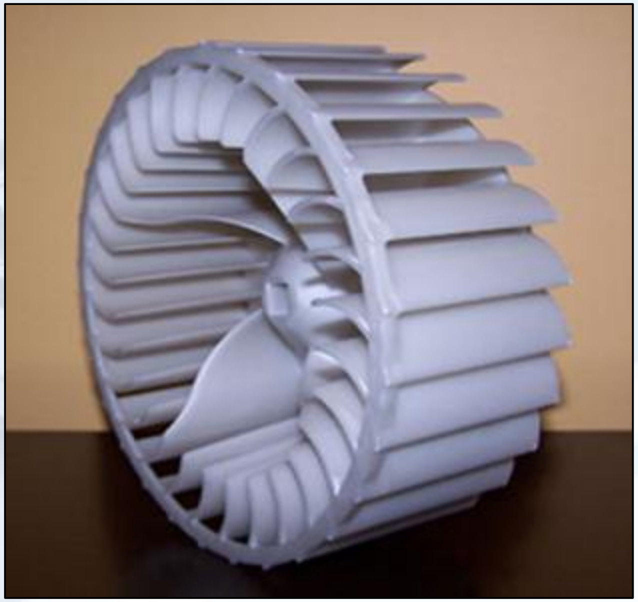
Is the product configured with access for and the parts shaped for the implementation of automation?

Remember

- **Complete DFA first, then DFM. That way you're not wasting your time optimizing the manufacturing processes on component parts that you might end up eliminating from the assembly.**

Exercise: DFM Guidelines

- **These parts are produced from the respective processes. Identify the design features to make the design more manufacturing "friendly".**



Injection Molded Fan Blade

Sheet metal formed Bracket

Additional Design Consideration

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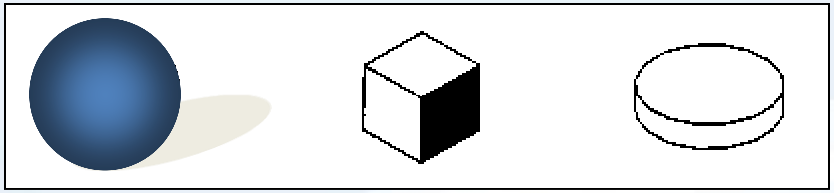
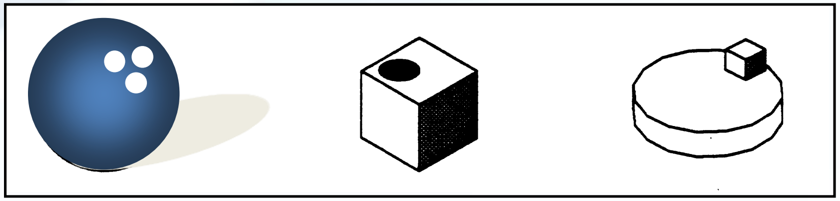
Mistake Proofing Issues

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



symmetrical parts



asymmetrical parts

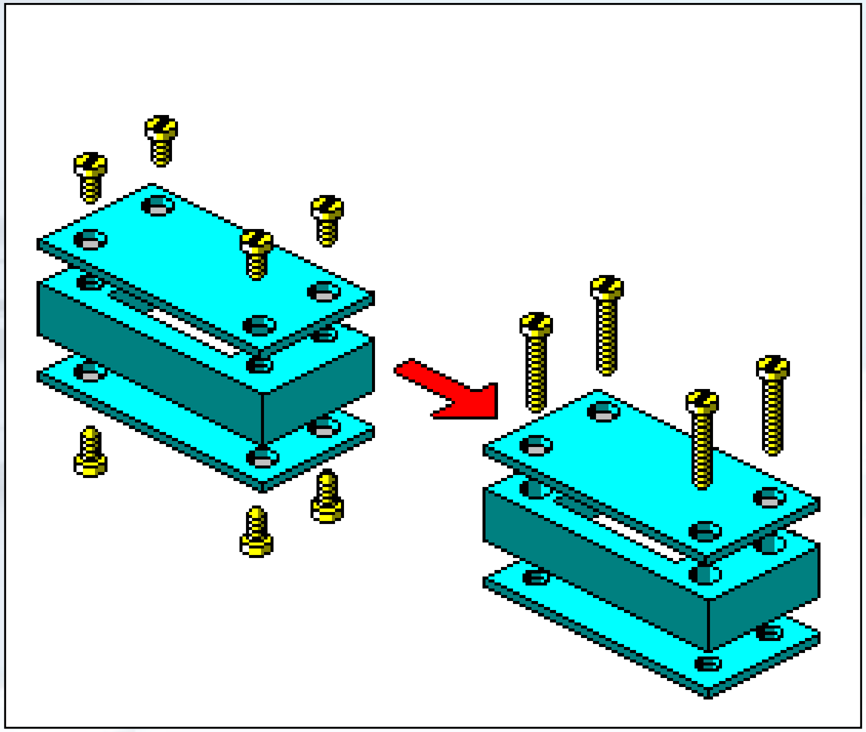
Mistake Proofing Issues

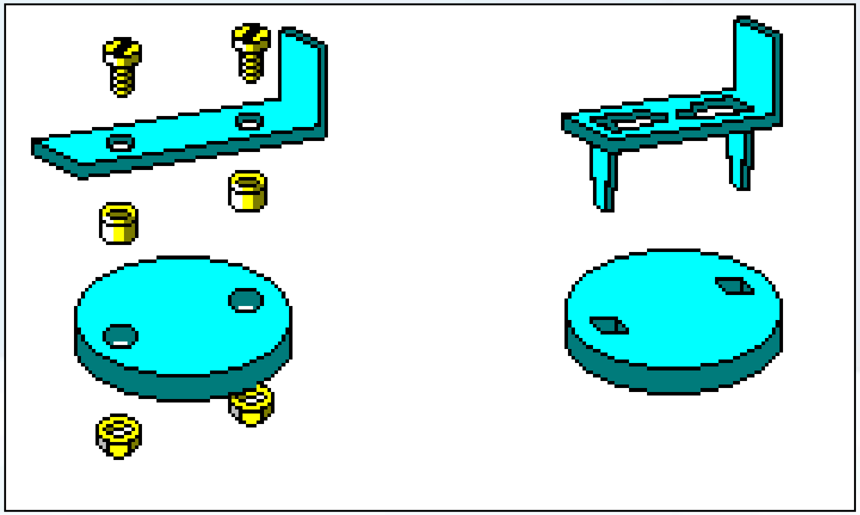
72 Wiring Harness Part Numbers

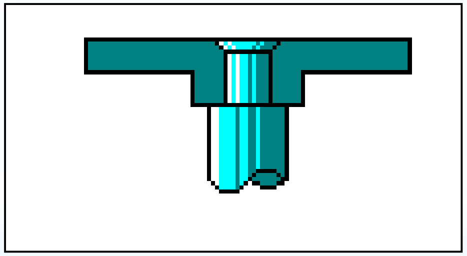
CDC – Rocky Mount, NC

Eliminate Secondary Operations

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



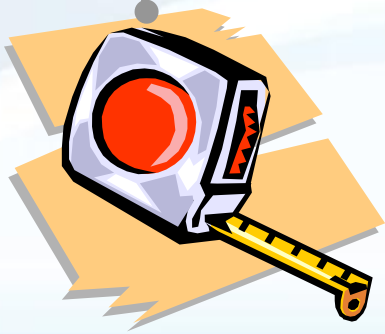


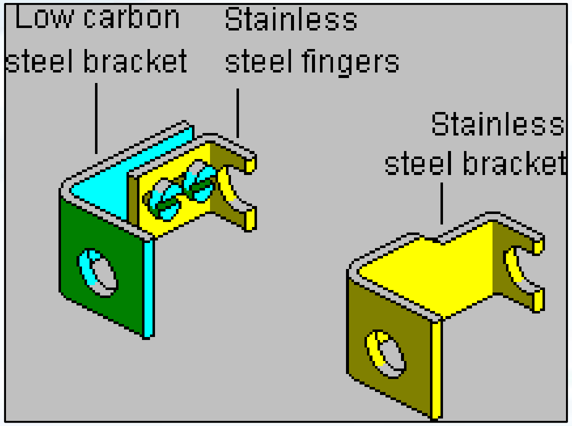


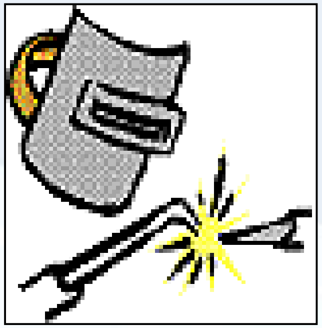
Rivet

Eliminate Secondary Operations

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







Breakout Exercise 7:
Choose the Correct Manufacturing Process

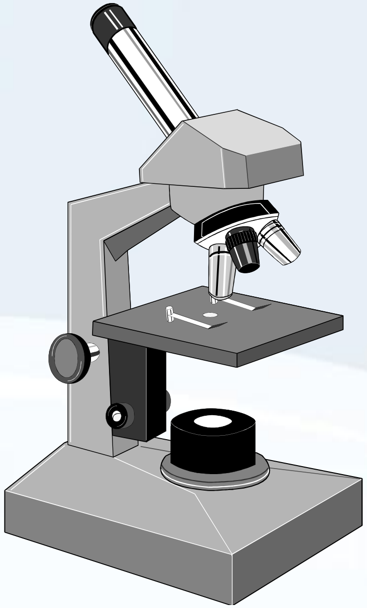
- Study the preliminary process flow from Breakout 6
- What types of design or process changes would you make of your existing process flow?
- Do you feel you are optimized?
- What additional information do you need?

Chapter 7

Putting it All Together

Sequence of Analysis

Concept Design	Apply General Design Principles
↓	Optimize Design for Part Count and Assembly
Design for Assembly	Apply DFA Design Rules
↓	Design for Assembly and Choose Assembly Method
Design for Manufacturing	
↓	
Detailed Design	Optimize Design for Production Process

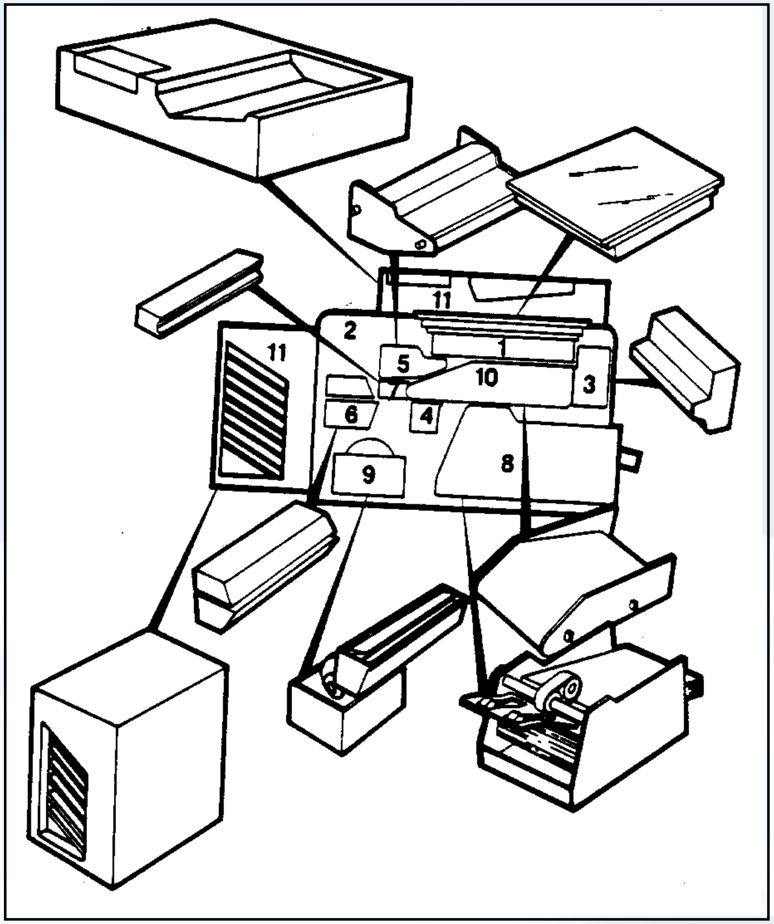


General Design Principles

- **Design Rules are a checklist either enforced by design software or by design rules checklists.**
- **Design Rules are of three kinds for Design for Assembly (DFA)**
  - General Design Principles
  - Design for Assembly Principles
  - Design for Assembly principles for Assembly technique – Manual, Fixed/High Speed and Soft Automation/Robotic
- **Design rules for Design for Manufacturing is process-dependent and should be created**

General Design Principles

- **Modular Assemblies**
  - Imaging
  - Drives
  - Development
  - Transfer/Stripping
  - Cleaning
  - Fusing
  - Charge/Erase
  - Copy Handling
  - Electrical Distribution
  - Photoreceptor
  - Input/Output Devices



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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

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)

DFMA Overall Impact

- Less parts to design, document, revise
- Less Bill of Material (BOM) cost, parts to receive, inspect, store, handle
- Less labor and energy to build product
- Gets into the customer's hands faster
- Less complexity
- More simple assembly instructions
- Higher quality
- Higher profit margin
- More competitive in the marketplace

DFMA Advantages

- Quantitative method to assess design
- Communication tool with other engineering disciplines and other departments (sales, etc.)
- Greater role for other groups while still in the "engineering" phase such as Manufacturing
- Since almost 75% of the product cost is determined in the engineering" phase, it gives a tool to attach hidden waste area before committing to a design.

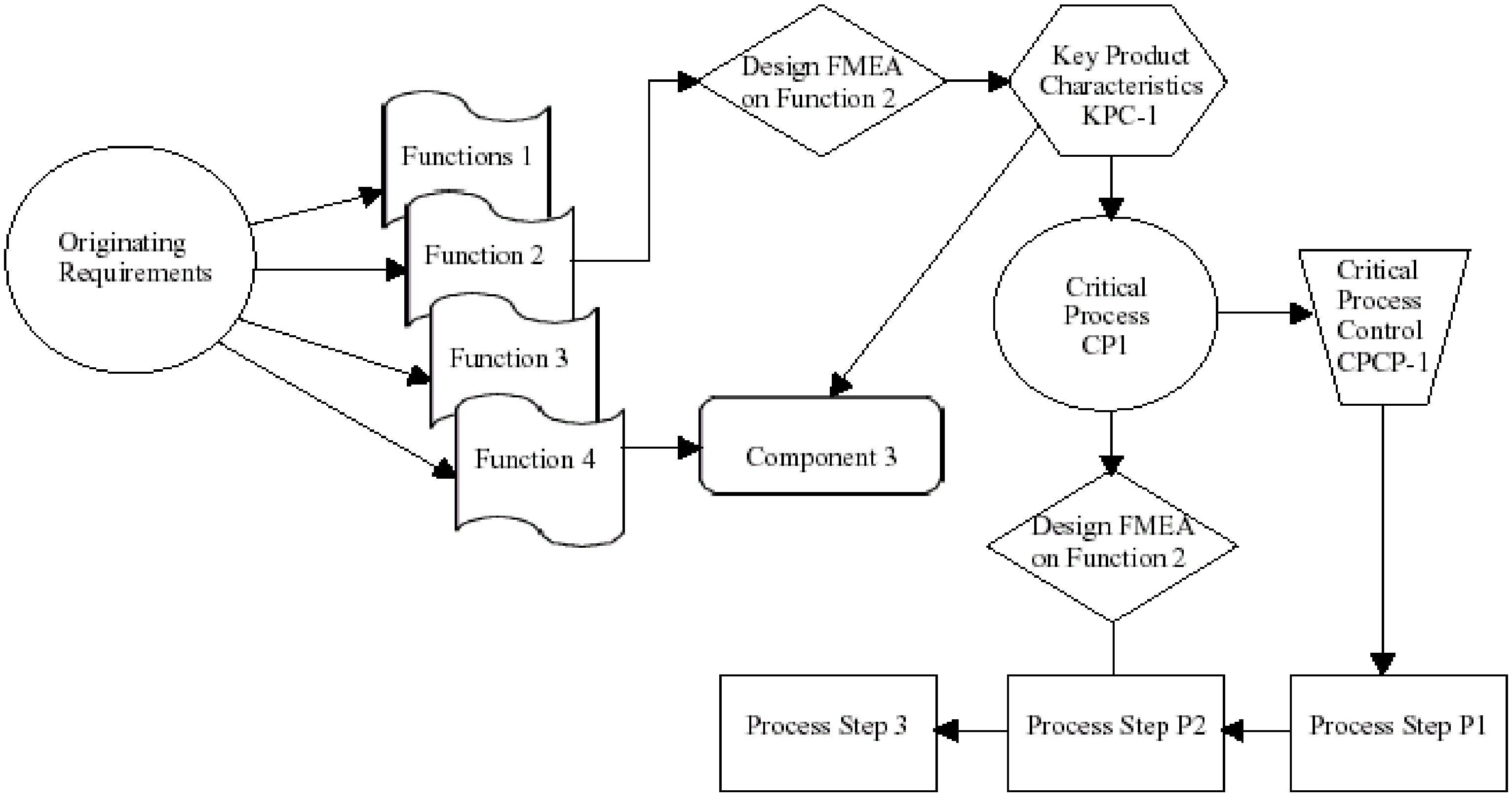
DFMA – Design Guidelines

- Design for top down assembly
- Make parts self locating
- Try to design parts with symmetry
- If symmetry is not possible, then make it obvious that the part needs a specific orientation

DFMA – Design Guidelines

- **Prevent stacked parts from getting stuck together or tangled using features**
- **Avoid parts that are difficult to handle, i.e. too small, sharp, fragile, etc.**
- **Avoid parts that only connect. Try and bring the other parts together to eliminate the connection**
- **Avoid adjustments. In general, adjustments compensate for poor design.**

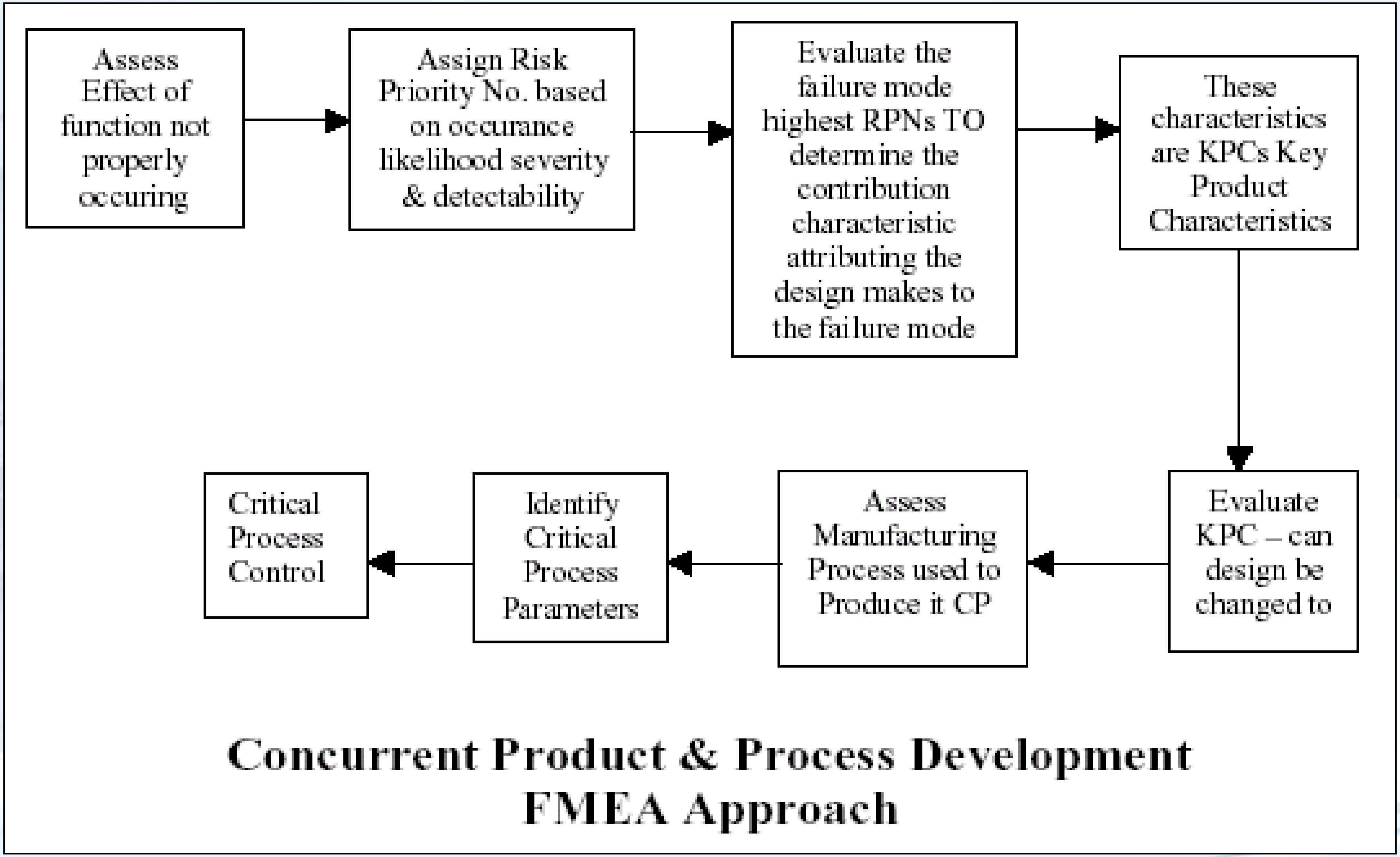
FMEA Process Flow



Typical Process Flow – Concurrent Product & Process Development

FMEA

FMEA Process Flow



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Activities to Achieve Stable Design Knowledge

- **Limit design challenge**
- **Demonstrate design meets requirements**
- **Complete critical design reviews**
- **Stake holders agree drawings complete and producible**
- **Review to begin initial manufacturing**

Activities to Achieve MFG. Knowledge

- **Identify key system charecteristics and critical mfg. Processes**
- **Determine processes in control and capable**
- **Conduct failure mode and effects analysis**
- **Set reliabilty growth plan and goals**
- **Conduct reliability growth testing**
- **Review to begin production**

Your Turn

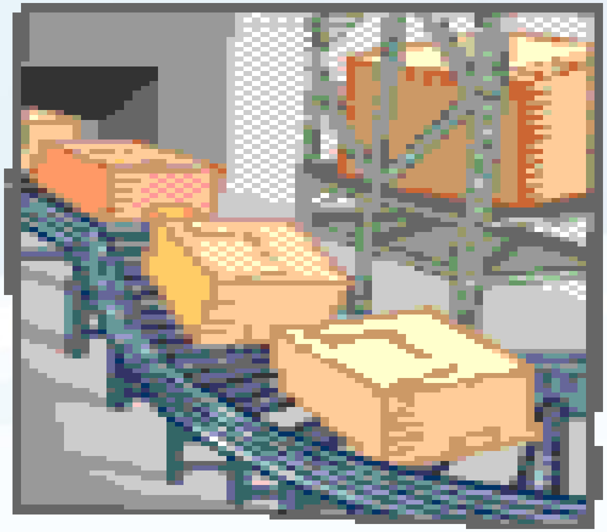
Putting it all Together

Final Exercise: Putting It All Together

Select a product within your company to apply the DFMA guidelines to simplify the design to improve quality, cost, and reduce manufacturing variability.

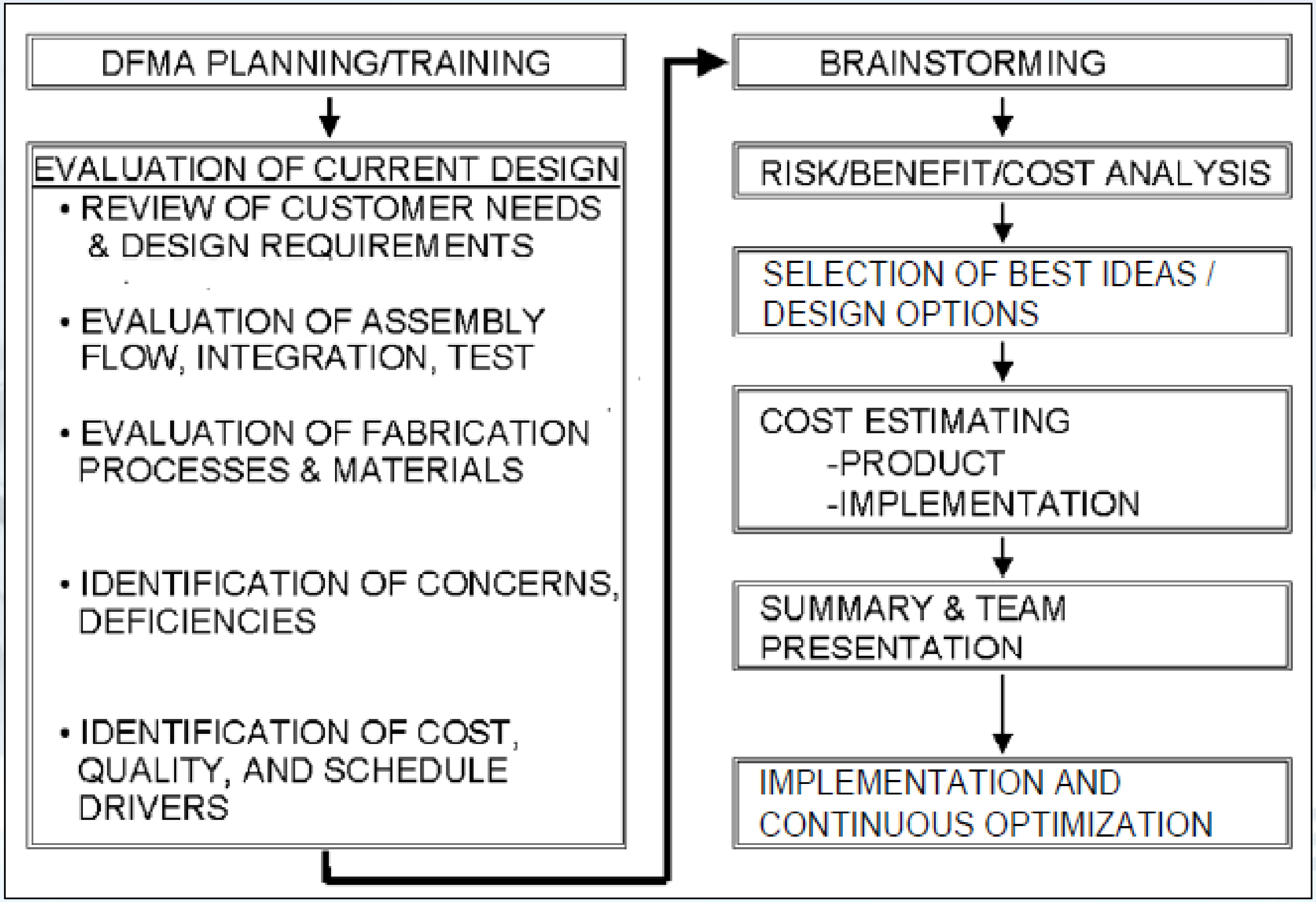
Determine …..

1. Existing total part count
2. Assembly method
3. Manufacturing process



Explain rationale to Design Recommendations

Helpful Hint : DFMA Methodology



Exercise Debrief

Decision Criteria

- **Cost (Implementation)**
- **Cost (Recurring)**
- **Schedule**
- **Risk (Technical, schedule, cost)**
- **Performance**

Appendix A

Assembly Data Tables

Automatic Insertion Assembly Data

AUTOMATIC INSERTION-RELATIVE WORKHEAD COST, WC

Key: PART ADDED but NOT SECURED

		after assembly no holding down required to maintain orientation and location (5)				holding down required during subsequent process(es) to maintain orientation and location (5)			
		easy to align and position (6)		not easy to align or position (no features provided for the purpose)		easy to align and position (6)		not easy to align or position (no features provided for the purpose)	
		no resistance to insertion	resistance to insertion (7)	no resistance to insertion	resistance to insertion (7)	no resistance to insertion	resistance to insertion (7)	no resistance to insertion	resistance to insertion (7)
		0	1	2	3	6	7	8	9
addition of any part (1) where no final securing is taking place (2) — straight line insertion — from vertically above	0	1	1.5	1.5	2.3	1.3	2	2	3
addition of any part (1) where no final securing is taking place (2) — straight line insertion — not from vertically above (3)	1	1.2	1.6	1.6	2.5	1.6	2.1	2.1	3.3
addition of any part (1) where no final securing is taking place (2) — insertion not straight line motion (4)	2	2	3	3	4.6	2.7	4	4	6.1

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Automatic Insertion Assembly Data

PART SECURED IMMEDIATELY

Addition of any part (1) where final securing is taking place:

			0	1	2	3	4	5	6	7	8	9
			no screwing operation or plastic deformation immediately after insertion (snap or press fits, etc.): easy to align and position (6) no resistance to insertion	no screwing operation or plastic deformation immediately after insertion (snap or press fits, etc.): not easy to align or position and/or resistance to insertion	plastic deformation immediately after insertion – plastic bending: easy to align and position (6)	plastic deformation immediately after insertion – plastic bending – not easy to align or position (no features provided for the purpose): no resistance to insertion	plastic deformation immediately after insertion – plastic bending – not easy to align or position (no features provided for the purpose): resistance to insertion (7)	plastic deformation immediately after insertion – rivetting or similar plastic deformation: easy to align and position (6)	plastic deformation immediately after insertion – rivetting or similar plastic deformation – not easy to align or position (no features provided for the purpose): no resistance to insertion	plastic deformation immediately after insertion – rivetting or similar plastic deformation – not easy to align or position (no features provided for the purpose): resistance to insertion (7)	screwing immediately after insertion: easy to align and position (6) no resistance to screwing	screwing immediately after insertion: not easy to align or position and/or resistance to screwing (7)
straight line insertion	from vertically above	3	1.2	1.9	1.6	2.4	3.6	0.9	1.4	2.1	0.8	1.8
straight line insertion	not from vertically above (3)	4	1.3	2.1	2.1	3.2	4.8	1	1.5	2.3	1.3	2
insertion not straight line motion (4)		5	2.4	3.8	3.2	4.8	7.2	1.8	2.8	4.2	1.6	3.6

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Automatic Insertion Assembly Data

		mechanical fastening processes (parts already in place)				non-mechanical fastening processes (parts already in place)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	riveting or similar processes	screwing or other processes	snap fit, snap clip, press fit, etc.	no addition of material (friction or resistance welding, etc.)	soldering processes	welding or brazing	chemical processes (adhesive bonding etc.)	manipulation of parts or sub-assembly (orienting, fitting, adjustment etc.)	other processes (liquid insertion etc.)
		0	1	2	3	4	5	6	7	8	9
assembly process where all solid parts are in place or non-solids added or parts are manipulated	9	1.6	0.9	0.8	1.6	1.2	1.1	1.1	0.8	1.5	

SEPARATE OPERATION

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Robot Assembly Data for Single-Station System

AR	TP
AG	TG

TP — relative affective basi[c]
operation time

AR — relative robot cost

AG — relative additional gri[pper]
or tool cost

TG — relative time penalty
gripper or tool chang[e]

			part can be gripped and inserted using standard gripper or gripper used for previous part				part requires change to special gripper			
			no holding down		part requires temporary holding or clamping		no holding down		part requires temporary holding or clamping	
			self-aligning	not easy to align	self aligning	not easy to align	self-aligning	not easy to align	self-aligning	not easy to align
			0	1	2	3	4	5	6	7
part added but not finally secured	using motion along or about the vertical axis	AR TP	1.0 0.55	1.0 0.6	1.5 0.85	1.5 0.9	1.0 0.6	1.0 0.6	1.5 0.85	1.5 0.9
		AG TG	0 0	0 0	0 0	0 0	1.5 0.7	1.5 0.7	1.5 0.7	1.5 0.7
	using motion along or about a non-vertical axis	AR TP	1.5 0.55	1.5 0.6	1.5 0.85	1.5 0.9	1.5 0.6	1.5 0.6	1.5 0.85	1.5 0.9
		AG TG	0 0	0 0	0 0	0 0	1.5 0.7	1.5 0.7	1.5 0.7	1.5 0.7
	involving motion along or about more than one axis	AR TP	1.5 1.05	1.5 1.1	1.5 1.3	1.5 1.4	1.5 1.05	1.5 1.1	1.5 1.3	1.5 1.4
		AG TG	0 0	0 0	0 0	0 0	1.5 0.7	1.5 0.7	1.5 0.7	1.5 0.7

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Robot Assembly Data for Single-Station System

AR	TP
AG	TG

TP— relative affective basic operation time

AR— relative robot cost

AG— relative additional gripper or tool cost

TG— relative time penalty for gripper or tool change

		part can be gripped and inserted using standard gripper or gripper used for previous part				part requires change to special gripper			
		no holding down		part requires temporary holding or clamping		no holding down		part requires temporary holding or clamping	
		self-aligning	not easy to align	self aligning	not easy to align	self-aligning	not easy to align	self-aligning	not easy to align
		0	1	2	3	4	5	6	7
part added but not finally secured: using motion along or about the vertical axis	0	1.0 0.55 0 0	1.0 0.6 0 0	1.5 0.85 0 0	1.5 0.9 0 0	1.0 0.6 1.5 0.7	1.0 0.6 1.5 0.7	1.5 0.85 1.5 0.7	1.5 0.9 1.5 0.7
part added but not finally secured: using motion along or about a non-vertical axis	1	1.5 0.55 0 0	1.5 0.6 0 0	1.5 0.85 0 0	1.5 0.9 0 0	1.5 0.6 1.5 0.7	1.5 0.6 1.5 0.7	1.5 0.85 1.5 0.7	1.5 0.9 1.5 0.7
part added but not finally secured: involving motion along or about more than one axis	2	1.5 1.05 0 0	1.5 1.1 0 0	1.5 1.3 0 0	1.5 1.4 0 0	1.5 1.05 1.5 0.7	1.5 1.1 1.5 0.7	1.5 1.3 1.5 0.7	1.5 1.4 1.5 0.7

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Robot Assembly Data for Single-Station System

			force or torque levels within robot capability								
			part can be gripped and inserted using standard gripper or gripper used for previous part				part requires change to special gripper				special workhead operation
			snap or push fit		push and twist or other simple manipulation		snap or push fit or simple manipulation		screw fastening or nut running		robot positions part
			self-aligning	not easy to align	self aligning	not easy to align	self-aligning	not easy to align	self-aligning	not easy to align	
			0	1	2	3	4	5	6	7	8
part added and secured immediately	using motion along or about the vertical axis	3	1.0 0.55 0 0	1.0 0.6 0 0	1.0 0.7 0 0	1.0 0.75 0 0	1.0 0.6 1.5 0.7	1.0 0.65 1.5 0.7	1.0 0.7 1.5 0.7	1.0 0.8 1.5 0.7	1.0 1.15 4.0 0.7
	using motion along or about a non-vertical axis	4	1.5 0.55 0 0	1.5 0.6 0 0	1.5 0.7 0 0	1.5 0.75 0 0	1.5 0.6 1.5 0.7	1.5 0.65 1.5 0.7	1.5 0.7 1.5 0.7	1.5 0.8 1.5 0.7	1.5 1.15 4.0 0.7
	involving motion along or about more than one axis	5	1.5 1.05 0 0	1.5 1.1 0 0	1.5 1.15 0 0	1.5 1.2 0 0	1.5 1.05 1.5 0.7	1.5 1.1 1.5 0.7			1.5 1.6 4.0 0.7

Robot Assembly Data for Single-Station System

			operation can be carried out using standard gripper or gripper used for previous operation			operation requires change to special gripper or tool					special workhead operation
			snap or push fit	push and twist or simple manipulation	reorient or unload assembly	snap or push fit	screw or nut tighten	solder	apply liquid or adhesive	reorient or unload assembly	robot positions assembly
			0	1	2	3	4	5	6	7	8
separate securing operation or manipulation, or reorientation, or addition of non-solid	using motion along or about the vertical axis	6	1.0 0.45 0 0	1.0 0.5 0 0	1.0 0.6 0 0	1.0 0.45 1.5 0.7	1.0 0.5 1.5 0.7	1.0 0.55 1.5 0.7	1.0 0.7 1.5 0.7	1.0 0.6 1.5 0.7	1.0 1.15 4.5 0.7
	using motion along or about a non-vertical axis	7	1.5 0.45 0 0	1.5 0.5 0 0	1.5 0.6 0 0	1.5 0.45 1.5 0.7	1.5 0.5 1.5 0.7	1,5 0.55 1.5 0.7	1.5 0.7 1.5 0.7	1.5 0.6 1.5 0.7	1.5 1.15 4.5 0.7
	involving motion along or about more than one axis	8	1.5 0.8 0 0	1.5 0.9 0 0	1.5 1.05 0 0	1.5 0.8 1.5 0.7	1.5 0.85 1.5 0.7	1.5 1.0 1.5 0.7	1.5 1.15 1.5 0.7	1.5 1.05 1.5 0.7	1.5 1.8 4.5 0.7

Robot Assembly Data for Multi-Station System

AR	TP
AG	

TP— relative affective basic operation time

AR— relative robot cost

AG— relative additional gripper or tool cost

		part can be gripped and inserted using standard gripper or gripper used for previous part				part requires change to special gripper			
		no holding down		part requires temporary holding or clamping		no holding down		part requires temporary holding or clamping	
		self-aligning	not easy to align	self aligning	not easy to align	self-aligning	not easy to align	self-aligning	not easy to align
		0	1	2	3	4	5	6	7
part added but not finally secured	0 using motion along or about the vertical axis	1.0 1.0 0	1.0 1.1 0	1.0 1.05 1.0	1.0 1.15 1.0	1.0 1.0 0.5	1.0 1.1 0.5	1.0 1.05 1.5	1.0 1.15 1.5
	1 using motion along or about a non-vertical axis	1.5 1.0 0	1.5 1.1 0	1.5 1.05 1.0	1.5 1.15 1.0	1.5 1.0 0.5	1.5 1.1 0.5	1.5 1.05 1.5	1.5 1.15 1.5
	2 involving motion along or about more than one axis	1.5 1.8 0	1.5 1.9 0	1.5 1.85 1.0	1.5 1.95 1.0	1.5 1.8 0.5	1.5 1.9 0.5	1.5 1.85 1.5	1.5 1.95 1.5

Robot Assembly Data for Multi-Station System

AR	TP
AG	

TP — relative affective basic operation time

AR — relative robot cost

AG — relative additional gripper or tool cost

part added but not finally secured		part can be gripped and inserted using standard gripper or gripper used for previous part				part requires change to special gripper			
		no holding down		part requires temporary holding or clamping		no holding down		part requires temporary holding or clamping	
		self-aligning	not easy to align	self aligning	not easy to align	self-aligning	not easy to align	self-aligning	not easy to align
		0	1	2	3	4	5	6	7
using motion along or about the vertical axis	0	1.0 1.0 0	1.0 1.1 0	1.0 1.05 1.0	1.0 1.15 1.0	1.0 1.0 0.5	1.0 1.1 0.5	1.0 1.05 1.5	1.0 1.15 1.5
using motion along or about a non-vertical axis	1	1.5 1.0 0	1.5 1.1 0	1.5 1.05 1.0	1.5 1.15 1.0	1.5 1.0 0.5	1.5 1.1 0.5	1.5 1.05 1.5	1.5 1.15 1.5
involving motion along or about more than one axis	2	1.5 1.8 0	1.5 1.9 0	1.5 1.85 1.0	1.5 1.95 1.0	1.5 1.8 0.5	1.5 1.9 0.5	1.5 1.85 1.5	1.5 1.95 1.5

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Robot Assembly Data for Multi-Station System

AR	TP
AG	

TP— relative affective basic operation time

AR— relative robot cost

AG— relative additional gripper or tool cost

		part can be gripped and inserted using standard gripper or gripper used for previous part				part requires change to special gripper			
		no holding down		part requires temporary holding or clamping		no holding down		part requires temporary holding or clamping	
		self-aligning	not easy to align	self aligning	not easy to align	self-aligning	not easy to align	self-aligning	not easy to align
		0	1	2	3	4	5	6	7
part added but not finally secured: using motion along or about the vertical axis	0	1.0 1.0 0	1.0 1.1 0	1.0 1.05 1.0	1.0 1.15 1.0	1.0 1.0 0.5	1.0 1.1 0.5	1.0 1.05 1.5	1.0 1.15 1.5
part added but not finally secured: using motion along or about a non-vertical axis	1	1.5 1.0 0	1.5 1.1 0	1.5 1.05 1.0	1.5 1.15 1.0	1.5 1.0 0.5	1.5 1.1 0.5	1.5 1.05 1.5	1.5 1.15 1.5
part added but not finally secured: involving motion along or about more than one axis	2	1.5 1.8 0	1.5 1.9 0	1.5 1.85 1.0	1.5 1.95 1.0	1.5 1.8 0.5	1.5 1.9 0.5	1.5 1.85 1.5	1.5 1.95 1.5

Robot Assembly Data for Multi-Station System

		force or torque levels within robot capability								special workhead operation
		part can be gripped and inserted using standard gripper or gripper used for previous part				part requires change to special gripper				
		snap or push fit		push and twist or other simple manipulation		snap or push fit or simple manipulation		screw fastening or nut running		
		self-aligning	not easy to align	self aligning	not easy to align	self-aligning	not easy to align	self-aligning	not easy to align	
		0	1	2	3	4	5	6	7	8
part added and secured immediately: using motion along or about the vertical axis										
part added and secured immediately: using motion along or about a non-vertical axis	3	1.0 1.0 0	1.0 1.1 0	1.0 1.1 0	1.0 1.2 0	1.0 1.0 0.5	1.0 1.1 0.5	1.0 1.25 0.5	1.0 1.3 0.5	0 1.0 4.0
part added and secured immediately: involving motion along or about more than one axis	4	1.5 1.0 0	1.5 1.1 0	1.5 1.1 0	1.5 1.2 0	1.5 1.0 0.5	1.5 1.1 0.5	1.5 1.25 0.5	1.5 1.3 0.5	0 1.0 5.0
	5	1.5 1.8 0	1.5 1.9 0	1.5 2.0 0	1.5 2.0 0	1.5 1.8 0.5	1.5 1.9 0.5			0 1.5 6.0

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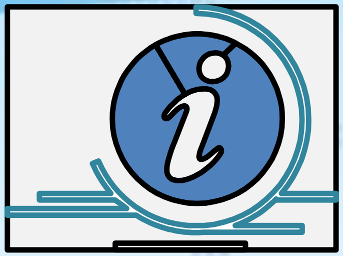
THANK YOU

Are there any Questions?



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