M2794.006900 DESIGN FOR MANUFACTURING

Week 2, September 14

Design for Manufacture (DFM): Concept

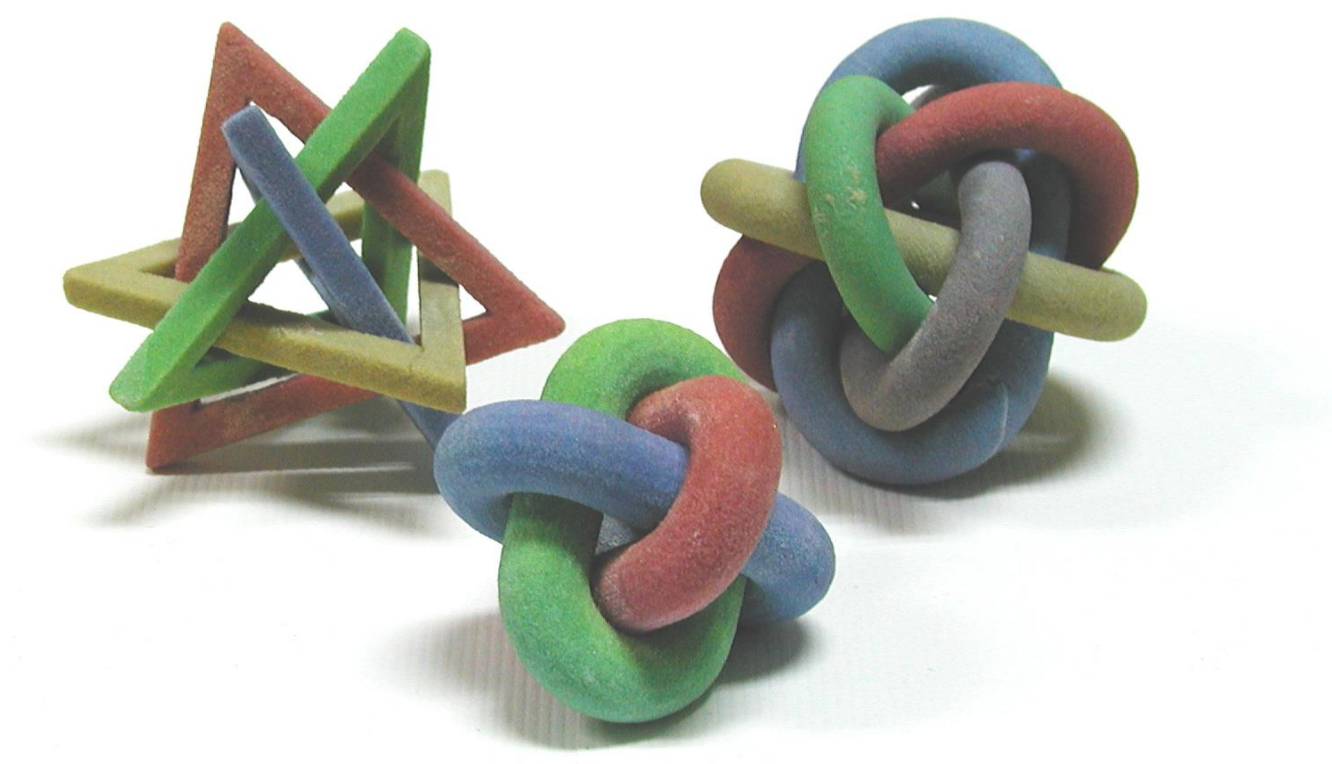
Fall 2017

Professor Sung-Hoon Ahn

Department of Mechanical and Aerospace Engineering

Seoul National University

What is Manufacturability?



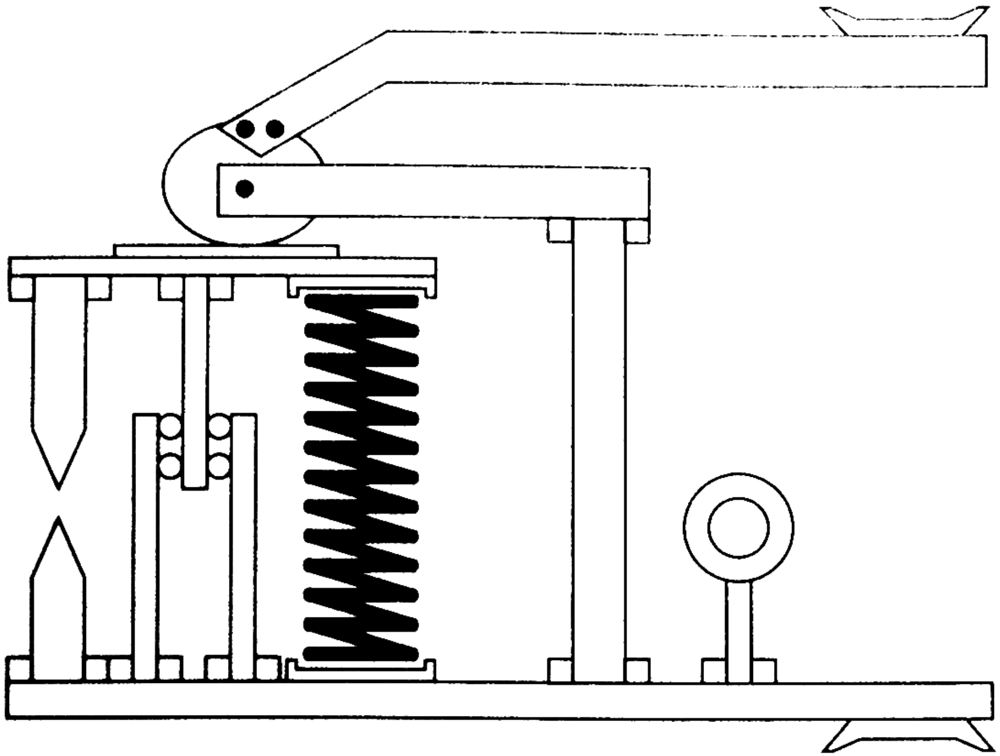
Do you know how to make these parts?

More important questions?

- How much does it cost?
- How long does it take?

- These issues are influenced by:
  - Manufacturing process
  - Availability of machines
  - Material
  - Batch size (how many parts)
  - Etc.

Model for manufacturing??



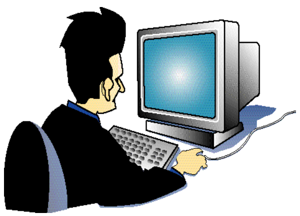
“When we mean to build,
we first survey the plot,
then draw the model”

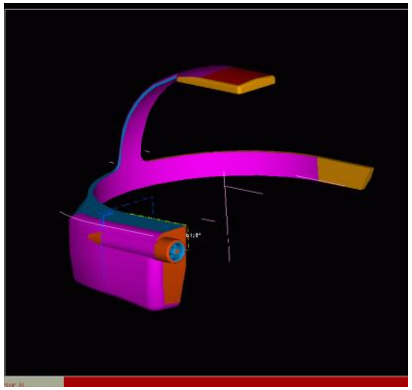
William Shakespeare (1564-1616)

Problems in traditional manufacturing

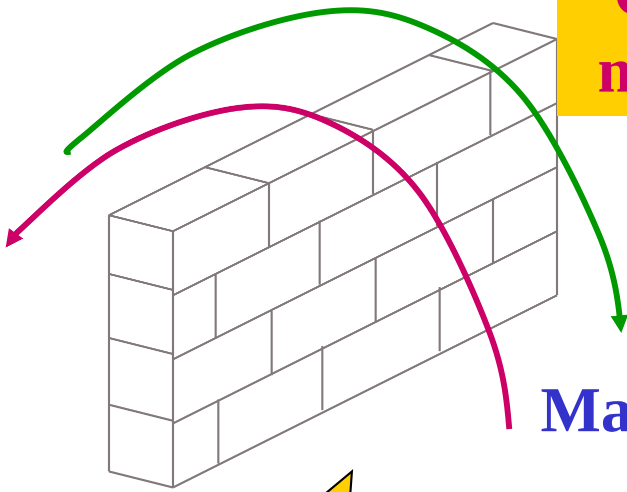
Commercial CAD (CATIA, ProE, I-DEAS, Inventor)

Design





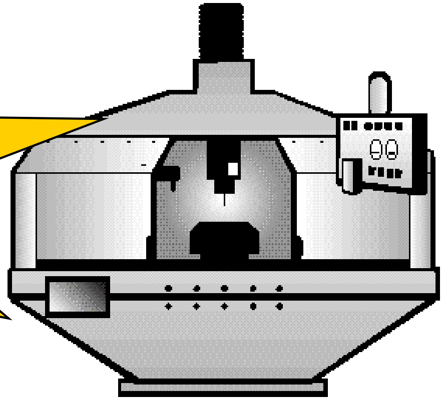
Time lost in redesign



Over-the-wall manufacturing

Manufacturing

Ouch, it's not Machinable



Definition of DFM

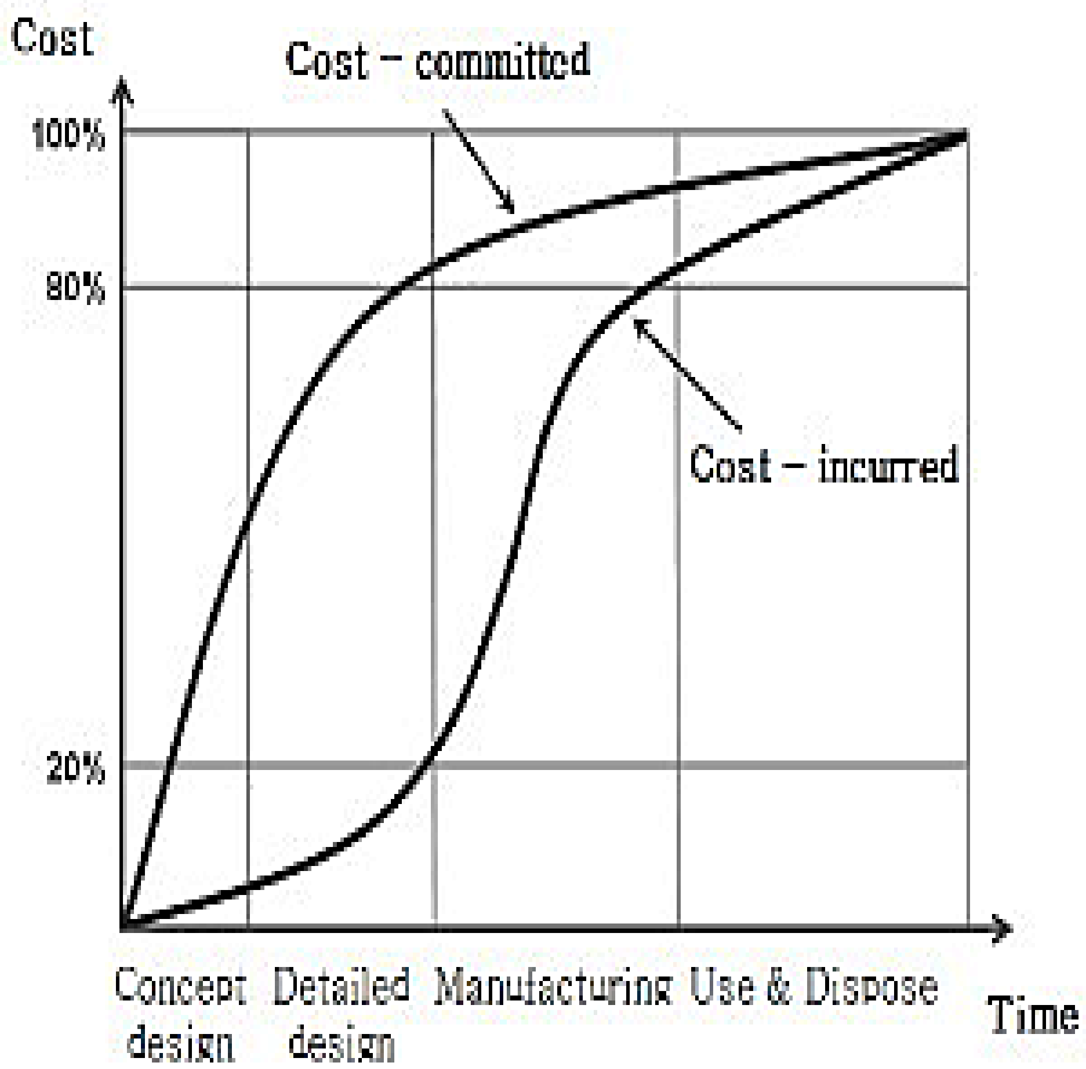
“Process of proactively designing products to:

- optimize the manufacturing functions
  - Fabrication
  - Assembly
  - Test
  - Procurement
  - Service
  - Repair
- assure the best cost, quality, reliability, safety, time-to-market, and custom satisfaction”
  (D. Anderson)

- Also, Design for manufacture, manufacturing, manufacturability

Cost in product development

- 80% of cost is committed at design stage
- Incurred cost for design is less than 10%



Importance of DFM

1. Design decision affects manufacturing cost and productivity
2. Designers play important role not only shaping, but also in manufacturability, cost, life cycle of products

History of DFM (1)

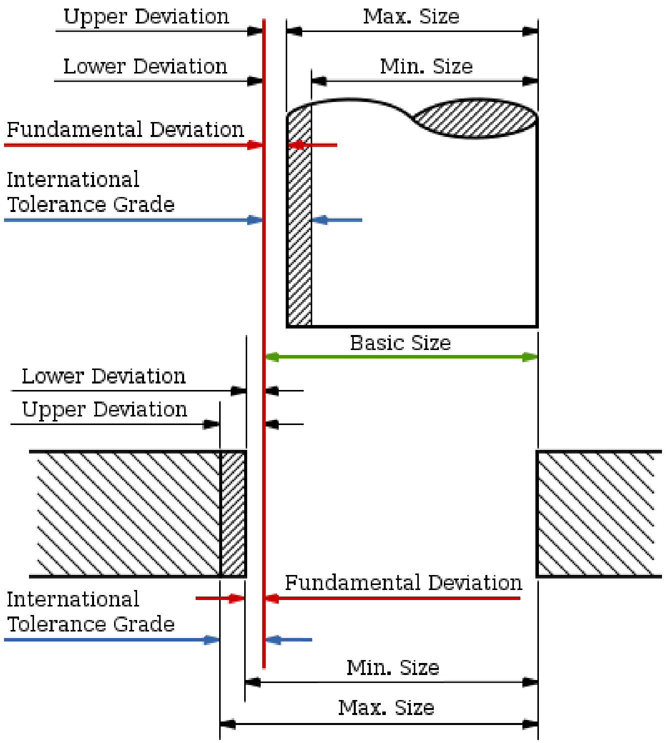
- Eli Whitney (19C)
  - Musket (gun) manufacturer

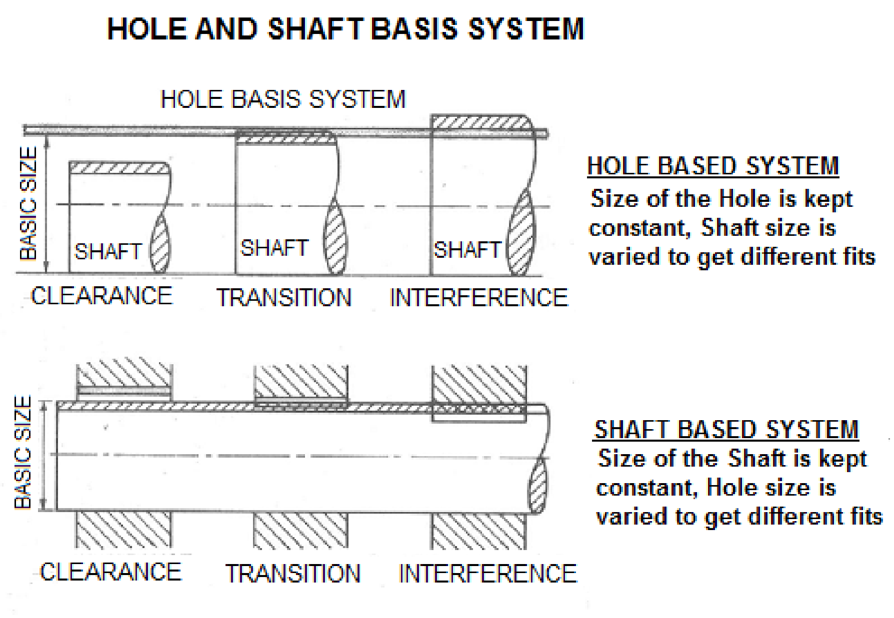
  - Redesigned a limited tolerance*
  - Used fixtures, gauges, and specially developed machines
    - Each part could be made by semi-skilled workers at a faster and cheaper
  - Changed process from sand casting to forging increased accuracy

Tolerance

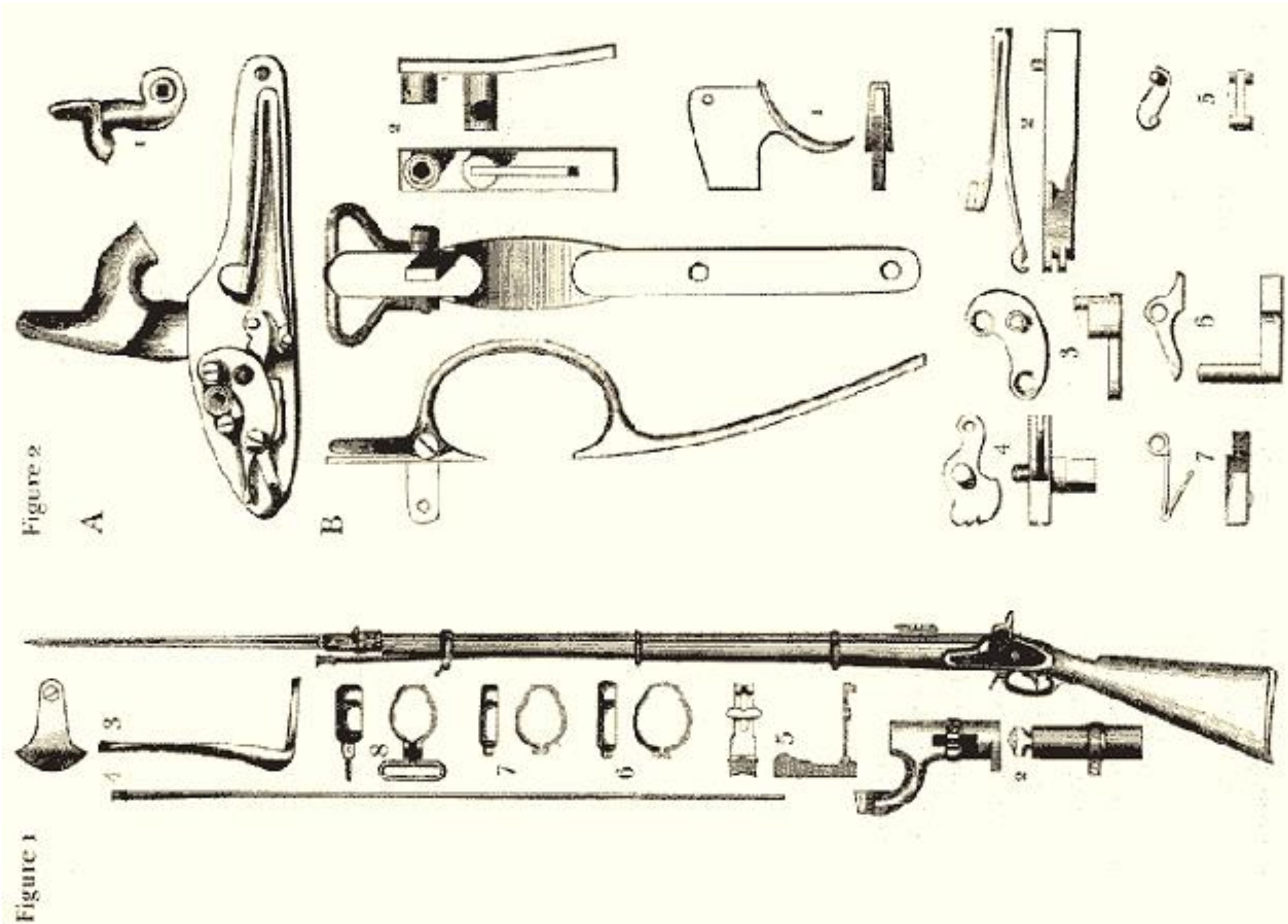
- Engineering tolerance is

  A machine's potential to cope with changes in the following elements of its surroundings and remain functioning





Whitney’s Musket



History of DFM (2)

Henry Ford (1907)

- Standard parts
- Simple design
- Conveyor system
- Price reduction
  - $2000/car -> $350/car
- 1908~1927: 15 million sold

Cadillac, General motors (1909)

Charlie Chaplin – Modern Times; Factory Work

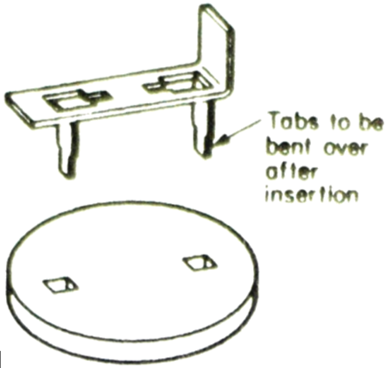
DFM category

1. General rules
2. Process specific rules
3. Product specific rules
4. Design for Assembly (DFA)
5. DFX
   - Environment
   - Recycle
   - Quality
   - Six sigma
   - Etc.

1. General rules of DFM

- Minimum number of parts
- Standard parts
- Modular design
- Multi-functional parts
- The same parts to various products
- Maximum surface roughness and tolerance
- Avoid secondary process
- Use materials easy to manufacture
- Consider number of parts to be manufactured
- Avoid many components
- Minimize handling of parts

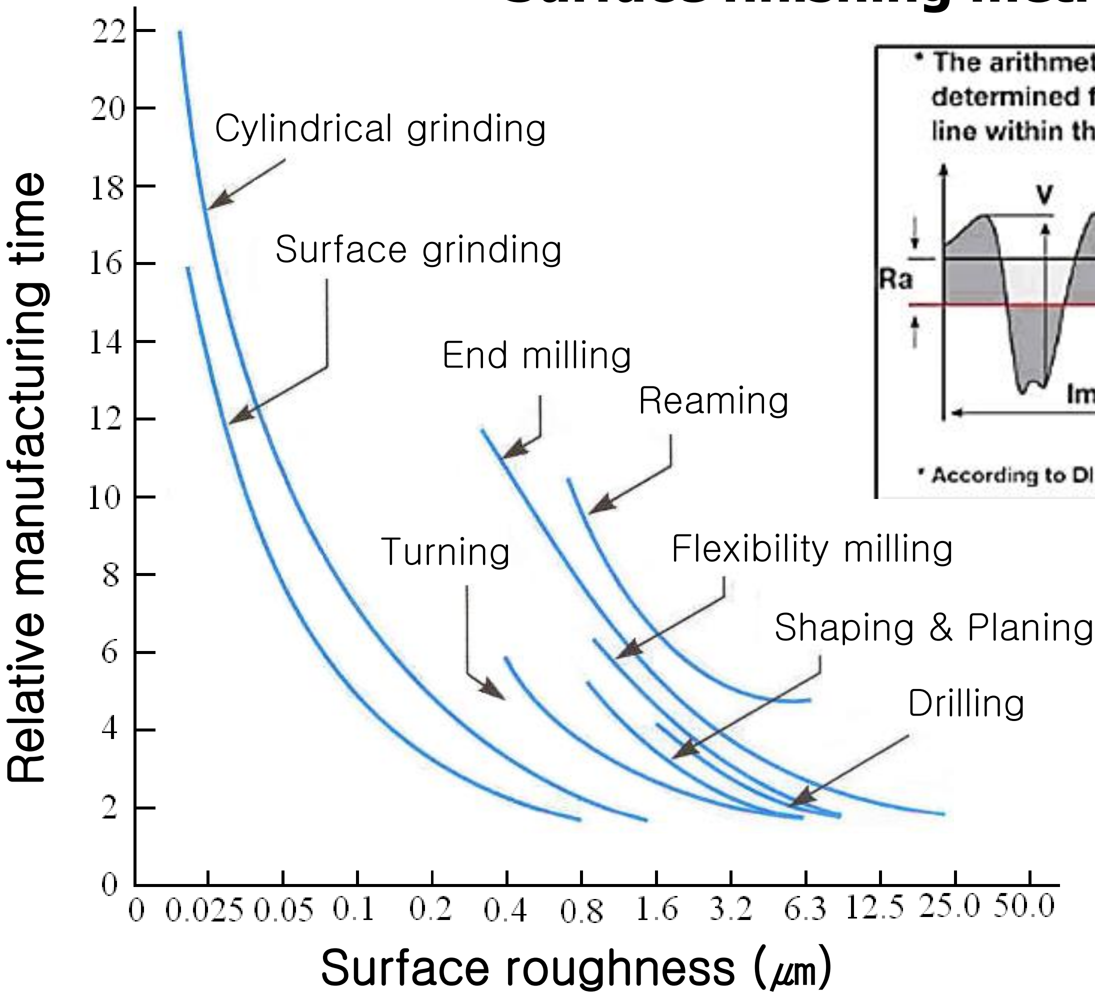
Feasible

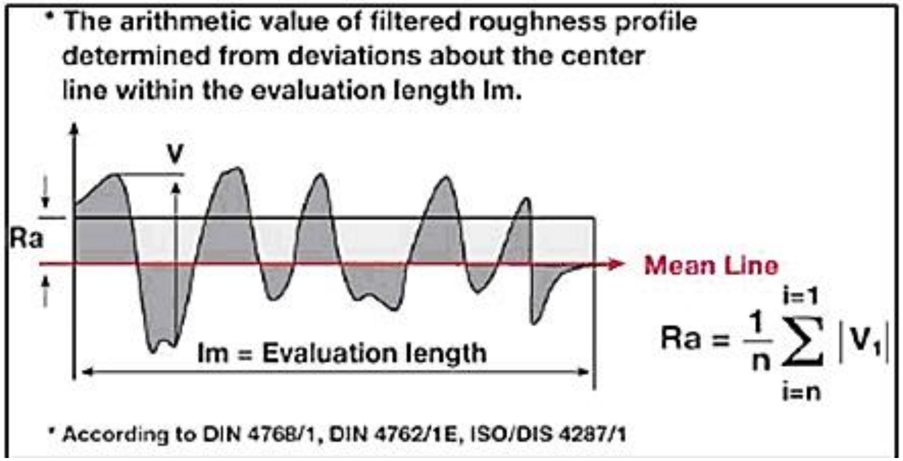


Better

Manufacturing Time vs. Surface Roughness

Surface roughness vs. Relative manufacturing time depend on Surface finishing method





Tolerances

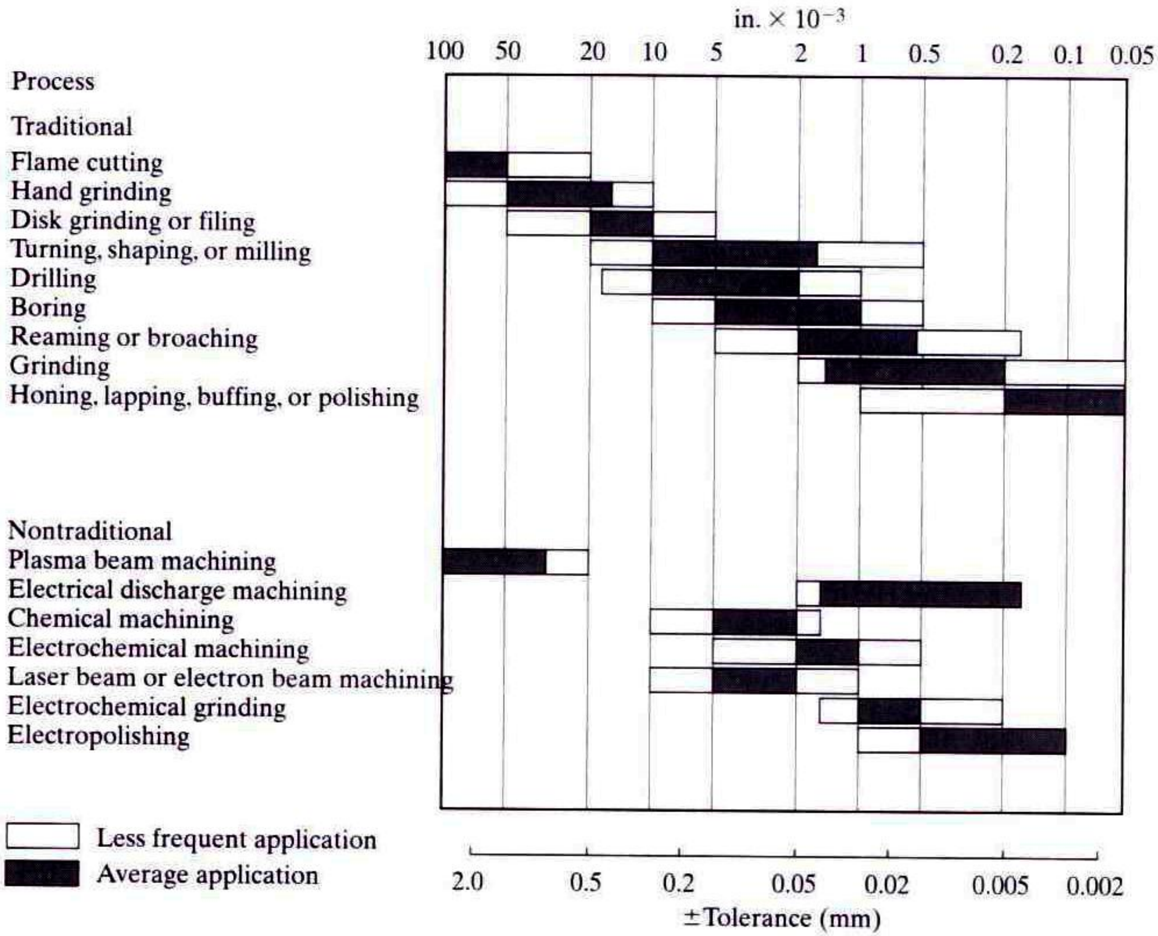
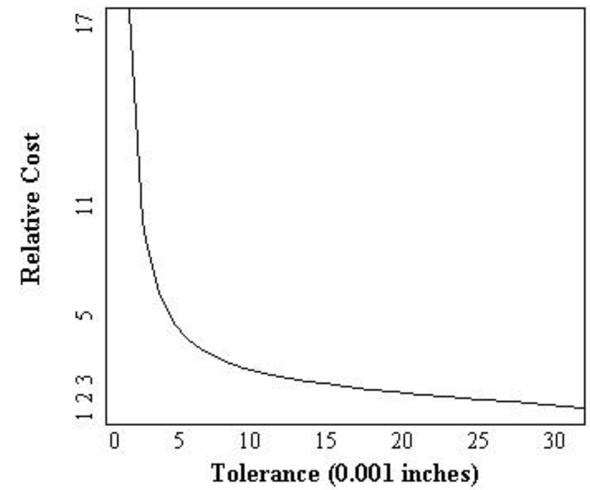


Figure 2.8 Natural tolerances (NT) = the darker bands, for a variety of common mechanical manufacturing processes. Variations = the lighter bands (from *Manufacturing Processes for Engineering Materials* by Kalpakjian, © 1997. Reprinted by permission of Prentice-Hall, Inc., Upper Saddle River, NJ).

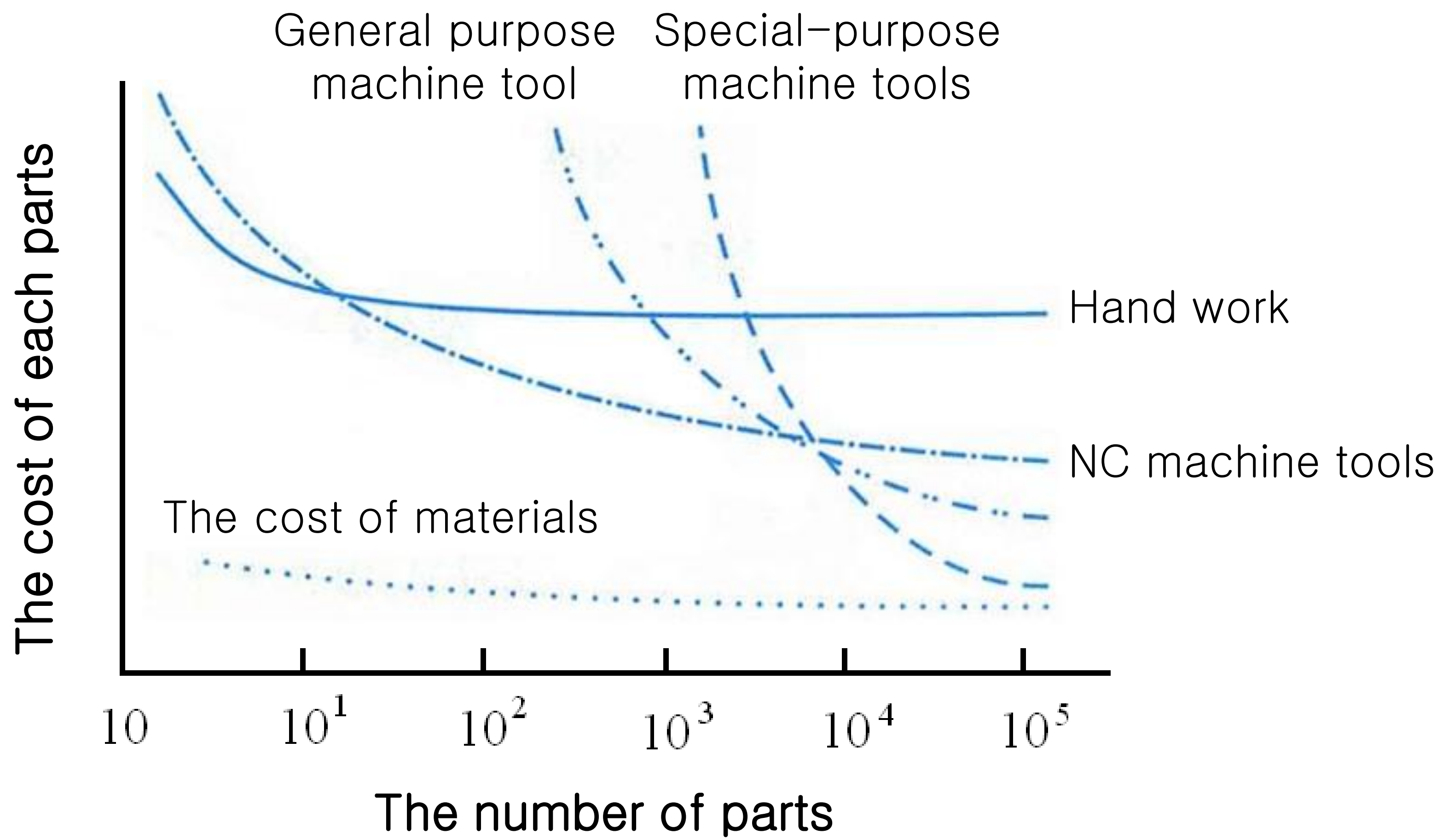


Relationship between relative machining cost and tolerance.

Source: S. Kalpakjian, Manufacturing Engineering and Technology, 3rd ed. Addison-Wesley, 1995

Per Part Cost

The relation among an output, selection of machine tools, and economical efficiency of production making.

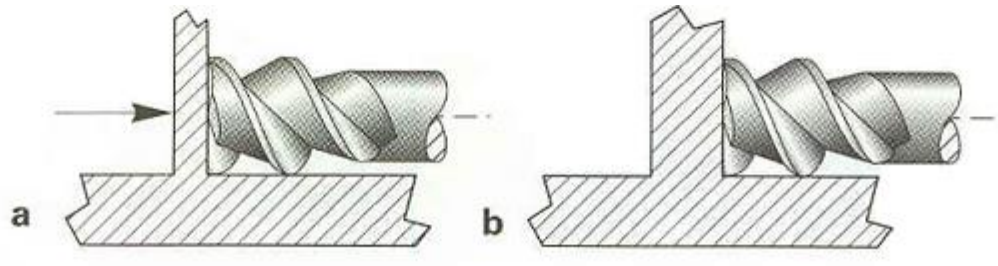


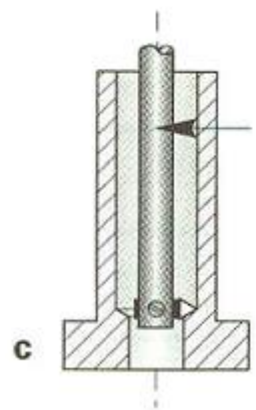
Product Development Time

	Stanley Tools Jobmaster Screwdriver	Rollerblade In-Line Skate	Hewlett-Packard DeskJet Printer	Volkswagen New Beetle Automobile	Boeing 777 Airplane
Annual production volume	100,000 units/year	100,000 units/year	4 million units/year	100,000 units/year	50 units/year
Sales lifetime	40 years	3 years	2 years	6 years	30 years
Sales price	$3	$200	$300	$17,000	$130 million
Number of unique parts (part numbers)	3 parts	35 parts	200 parts	10,000 parts	130,000 parts
Development time	1 year	2 years	1.5 years	3.5 years	4.5 years
Internal development team (peak size)	3 people	5 people	100 people	800 people	6,800 people
External development team (peak size)	3 people	10 people	75 people	800 people	10,000 people
Development cost	$150,000	$750,000	$50 million	$400 million	$3 billion
Production investment	$150,000	$1 million	$25 million	$500 million	$3 billion

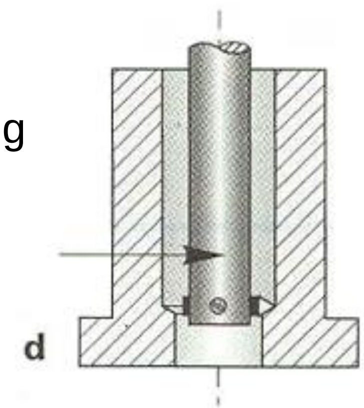
2. Process specific rules: Machining

Avoid thin wall





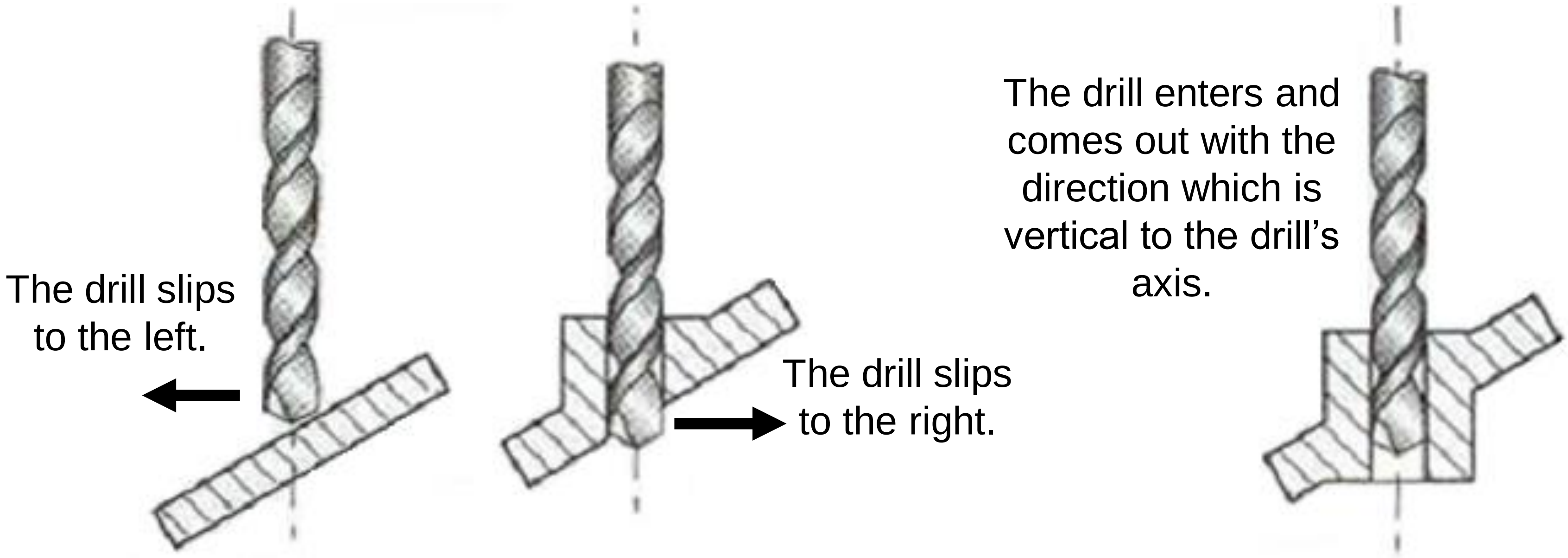
Avoid thin and long boring beam



Avoid turing processing of thin and long component.

Short and firm component does not require tailstock.

Process specific DFM: Drilling



Worst **Bad** **Good**

3. The Assembly from Heaven

- 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

(Dr. Peter Will, ISI)

Snap-fit principle

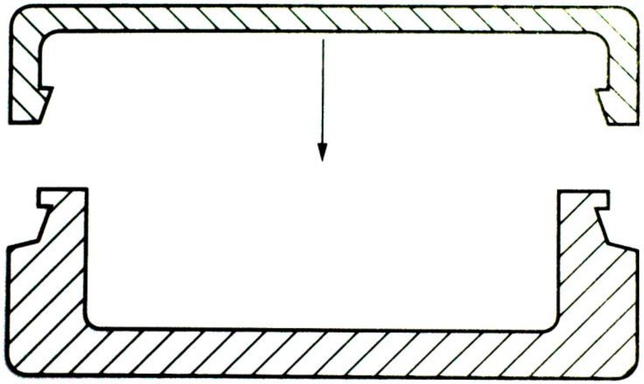


FIGURE 7.1.3 This product illustrates the snap-fit principal to attach the cover, eliminating the need for screw fasteners. (*From James G. Bralla,* Design for Excellence, *McGraw-Hill, New York, 1996.*)

The Assembly from Hell - iPhone 4

- The opposite in each case from the previous slide

VS

Assembly components of iPhone 4

- Number of screws: 52*
- Number of components : 14*

Assembly components of Galaxy S3

- Number of screws: 11*
- Number of components : 8*

* Number of screws and components are assumed values.

Assembly Issue of iPhone

"**The iPhone 5 is the most difficult device that Foxconn has ever assembled.** To make it light and thin, the design is very complicated," said an official at the company who declined to be named. "It takes time to learn how to make this new device. Practice makes perfect. Our productivity has been improving day by day."

- *The Wall Street Journal, October 17, 2012*

Assembly of iPhone 4

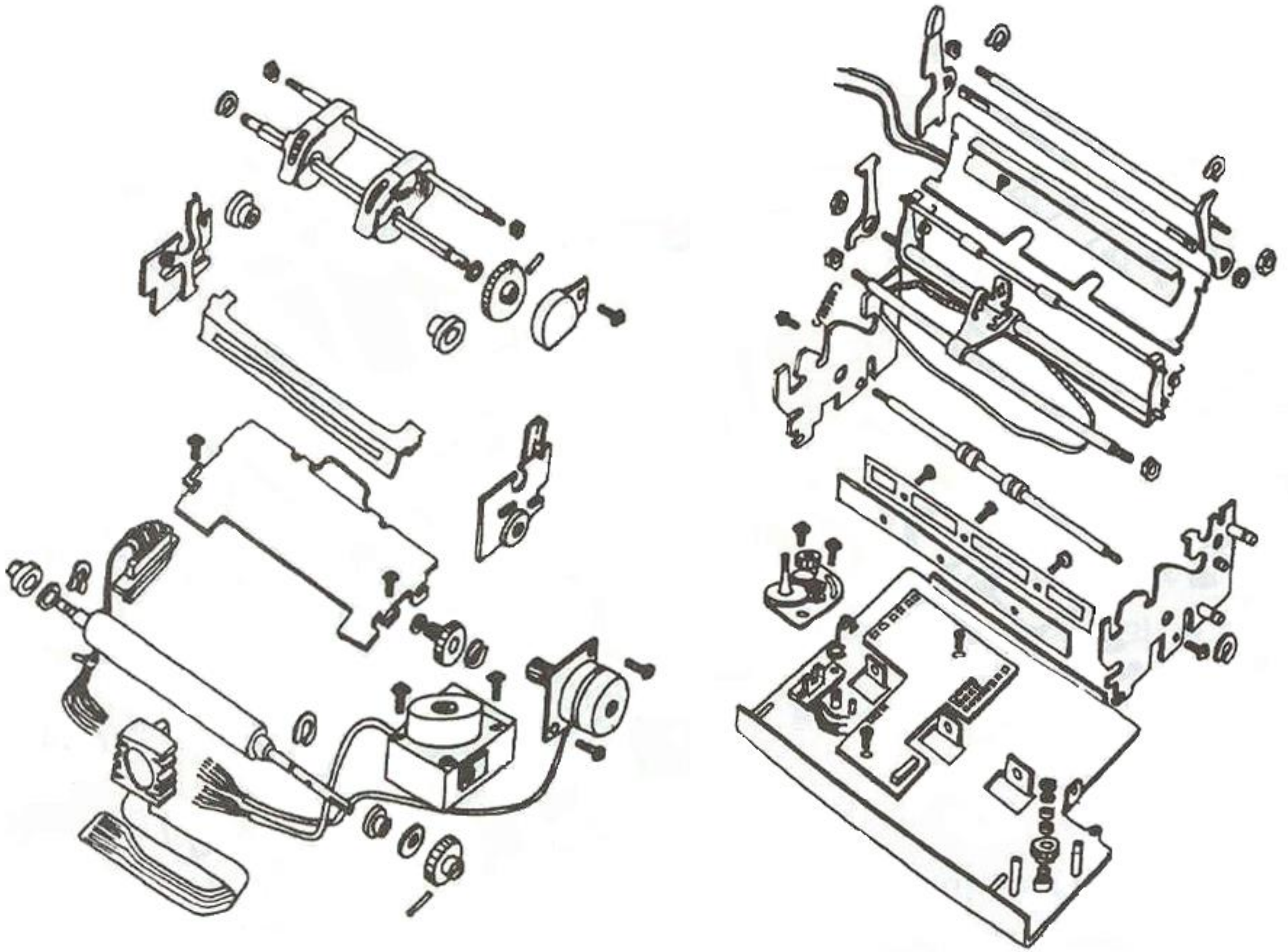
http://www.youtube.com/watch?v=Q67gLwbpQao

Assembly of Galaxy S3

http://www.youtube.com/watch?v=efXxYbz8DXs

Design for Assembly-bad design

A main assembly for the Epson printer.



The No. of parts:

49 parts

Assembly work:

57 time

Assembly time:

552 sec

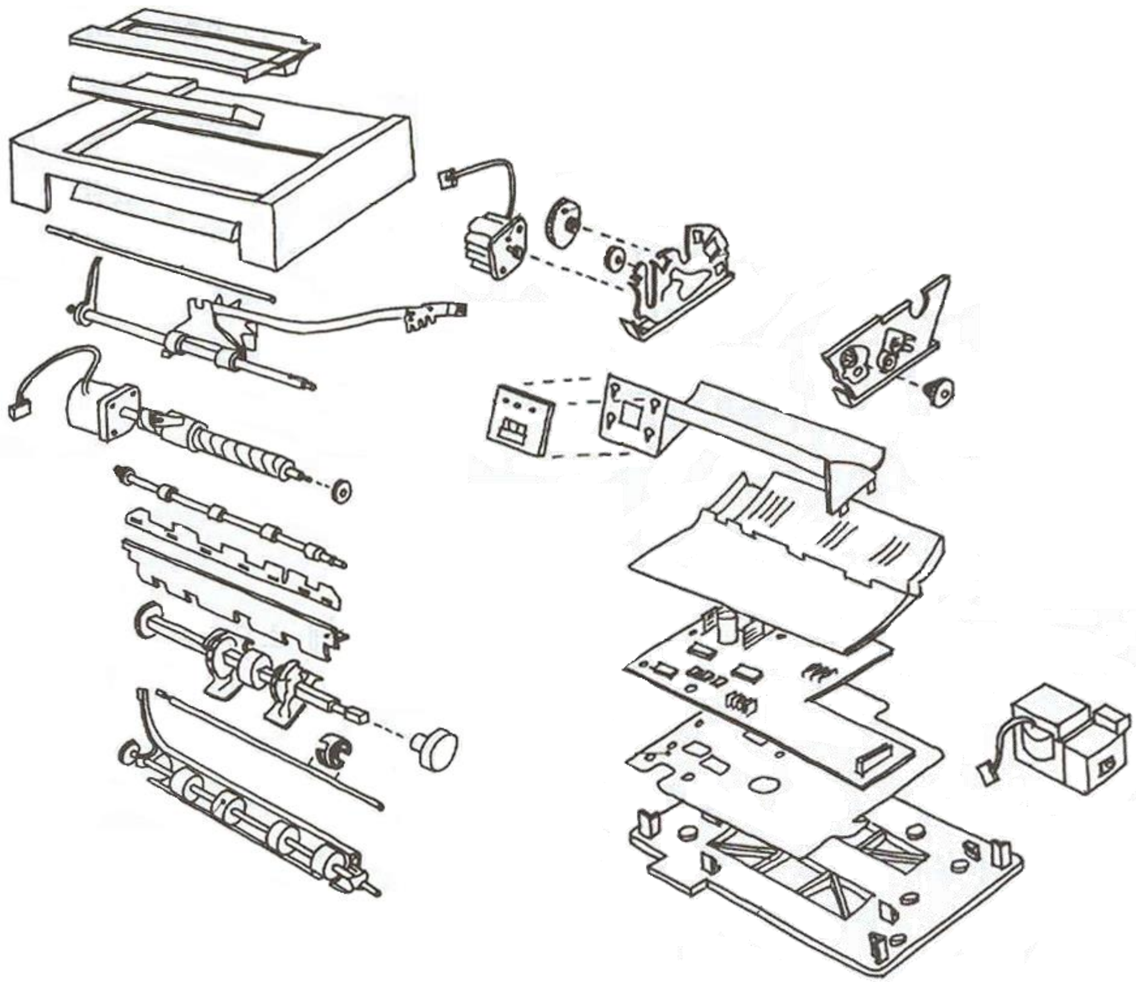
The labor costs:

$3.83

(Ref.: Assembly Engineering. January 1987)

Design for Assembly-good design

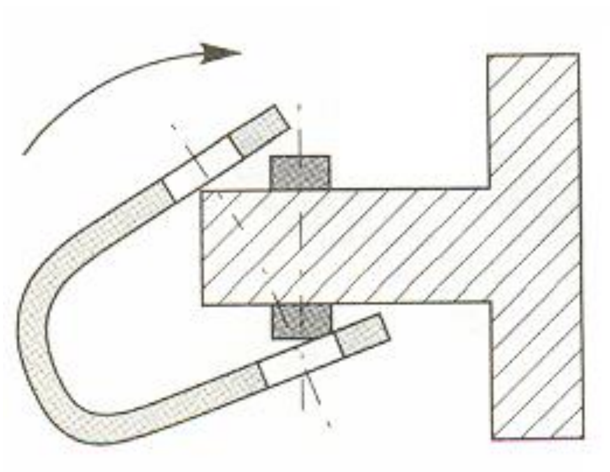
A main assembly for IBM printer.



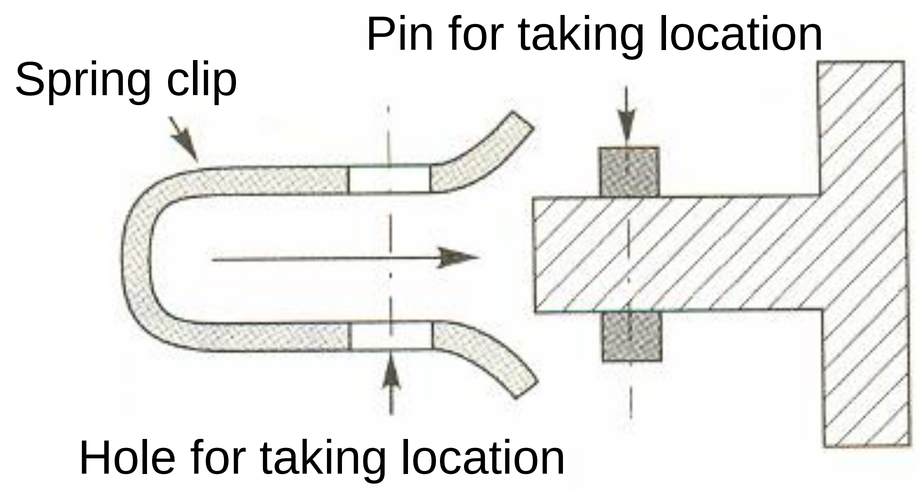
The No. of parts: IBM printer	The No. of parts: Epson printer
32 parts	49 parts
Assembly work: 32 time	Assembly work: 57 time
Assembly time: 170 sec	Assembly time: 552 sec
The labor costs: **$1.18**	The labor costs: **$3.83**

(Ref.: Assembly Engineering. January 1987)

Straight Movement



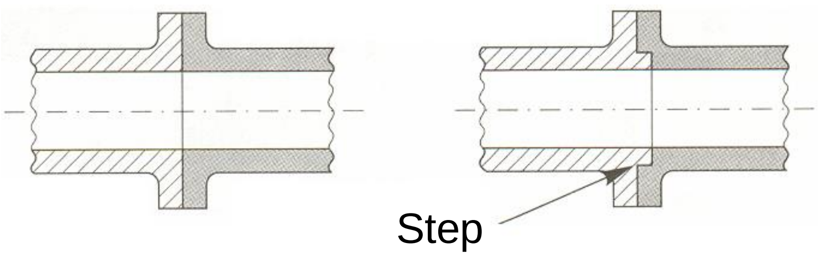
Bad



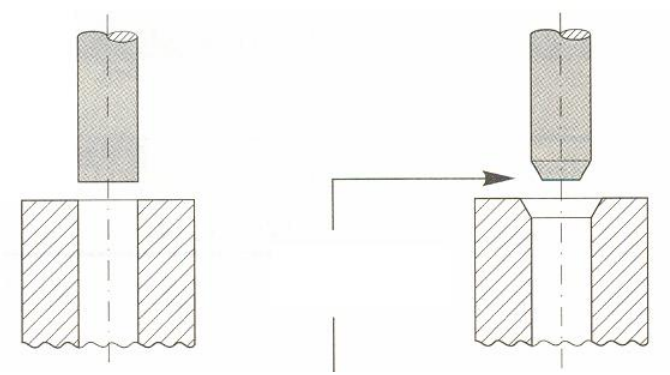
Good

Self Location

The pipe is connected to flange.



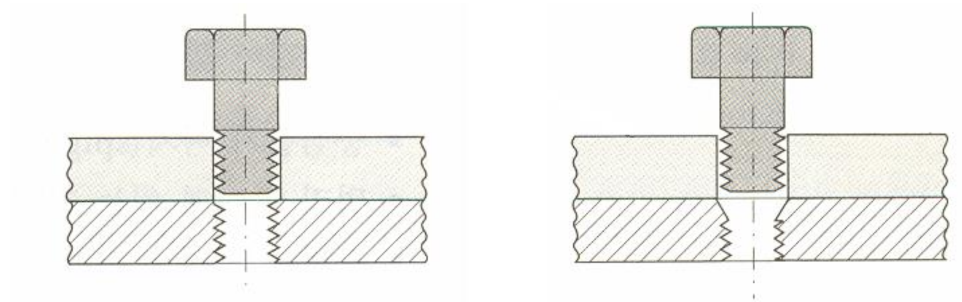
Bad **Good**

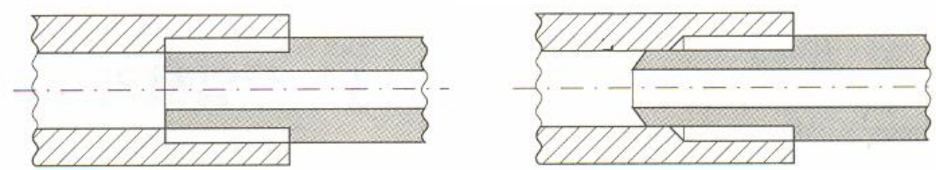


The cylinder inserts at the hole.

There is the chamfering at the edge.

One part is connected at the other part using bolt





The cylinder having step inserts at the hole.

Design for no-assembly

Comparison of number of parts in a conventional stapler with a one-piece compliant stapler. [Ananthasuresh, Saggere, & Kota 1994]

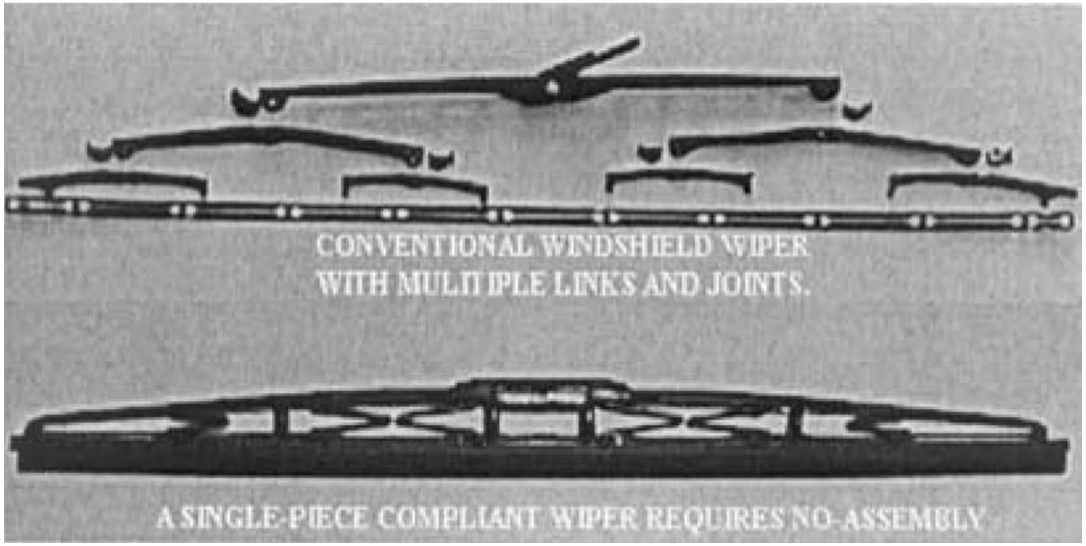
Design-for-No-Assembly:

- Compliant mechanisms are single-piece flexible structures that generate motions through elastic deformation as opposed to the rigid body rotations and translations.
- Consideration of compliance in design treats elastic deformation as a preferred effect in mechanical design to achieve controlled motion and force transmissions.
- Compliant mechanism is best suited for devices with small range of motion.

Highlights and Advantages of Compliant Mechanisms:

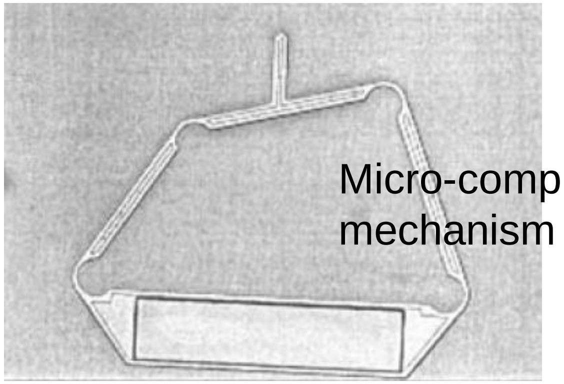
- No assembly, no joints and ease of manufacture.
- Less friction, less wear and noise, and no backlash.
- Reduced cost of production.
- Elimination of additional accessories such as springs.
- Provision for non-mechanical actuation.
- A variety of short-range motions.
- Compliance in design = simplicity in manufacture.

Design for no-assembly

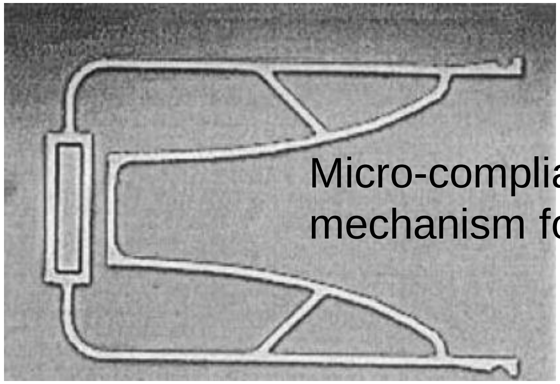


Windshield Wiper

Manufactured in one single step, drastically reducing manufacturing costs



Micro-compliant compliant mechanism for four-bar

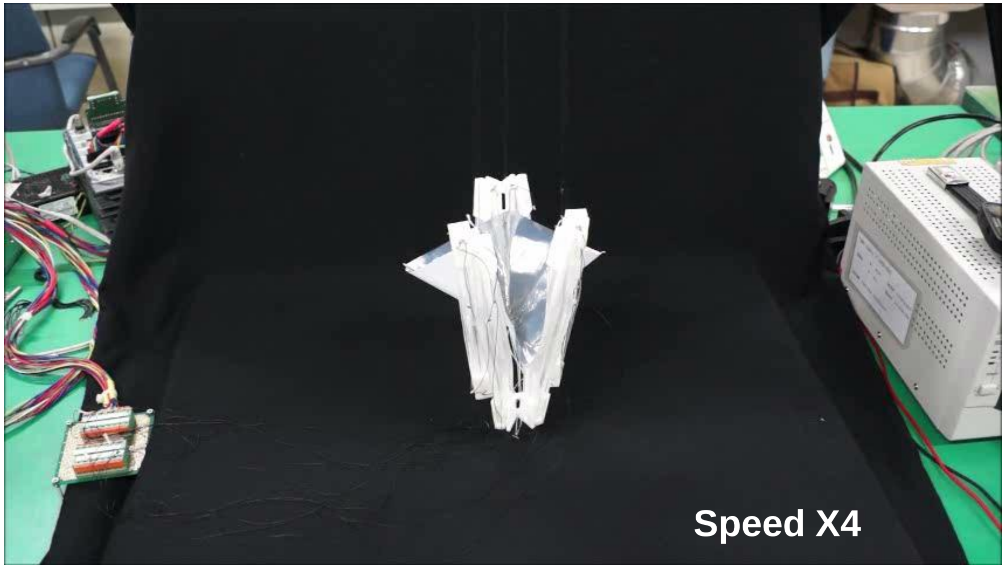


Micro-compliant compliant mechanism for crimping

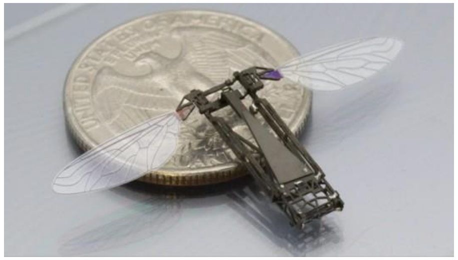
Analog Integrated Circuits and signal processing 29 7 7-15 2001

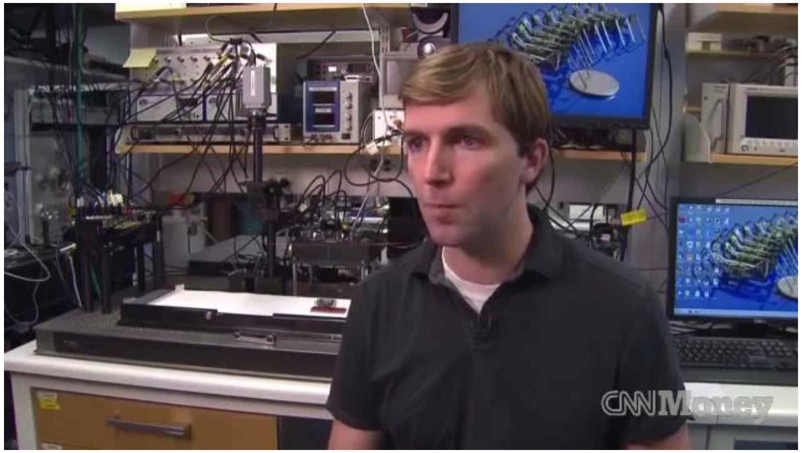
Design for no-assembly

- **4D printing**



Folding-unfolding process of the prototype of deployable mirror
(Wei Wang, IDIM, SNU)



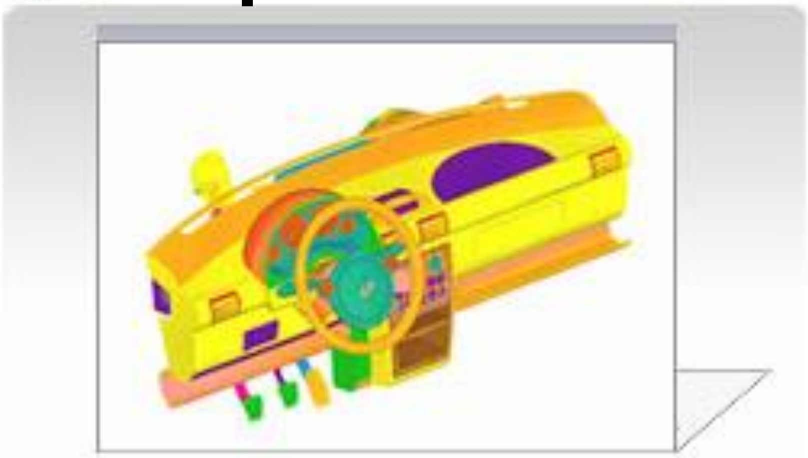


Robotic bees take flight
(Harvard U.)

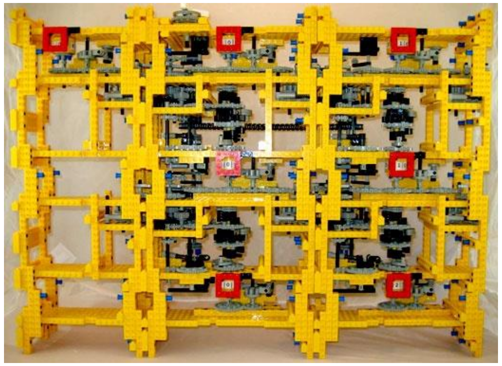
DFA - Modular Design

- **Existing mode**

- **Cockpit module**

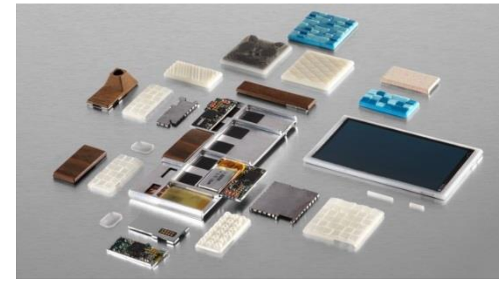


- Example: Lego –building block



Modular Design: example

- Google's modular smartphone

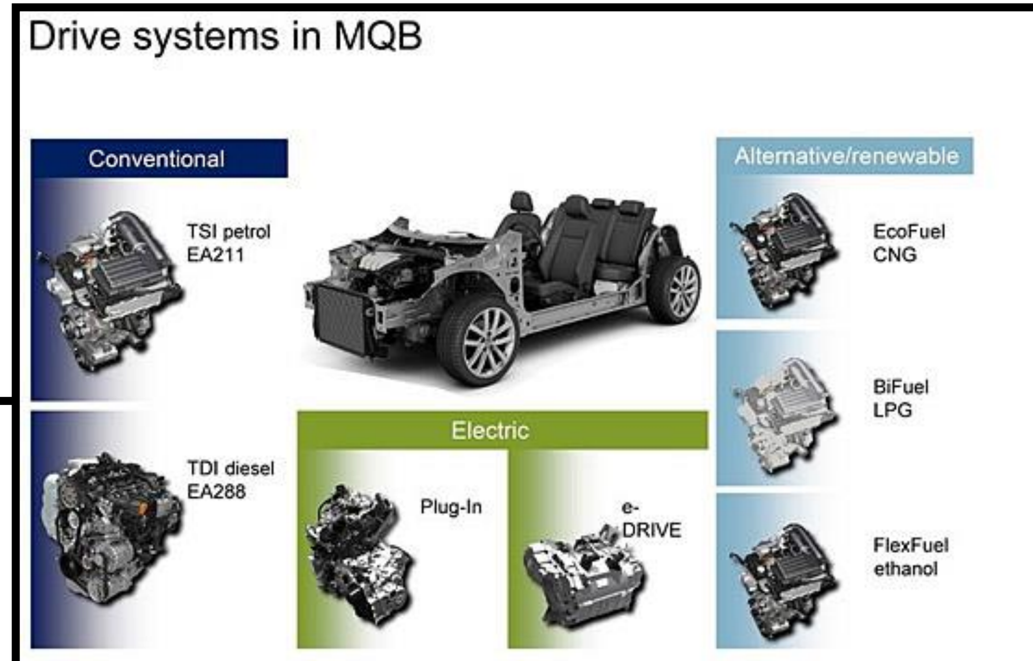


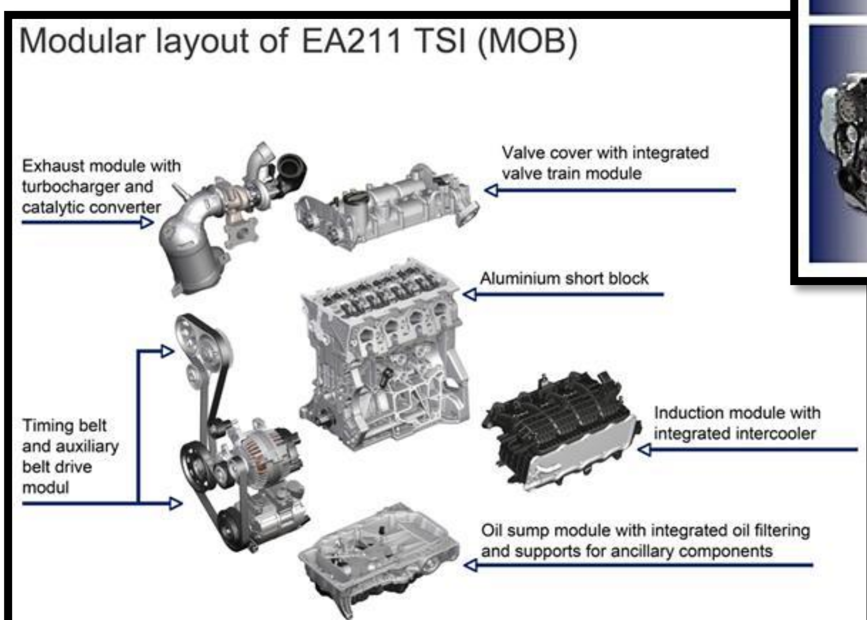
http://www.youtube.com/watch?v=fEC6myN2mXg

Modular Design: example

- Volkswagen modular platform

  MQB(Modulen Quer Baukasten): Modular Transverse Matrix

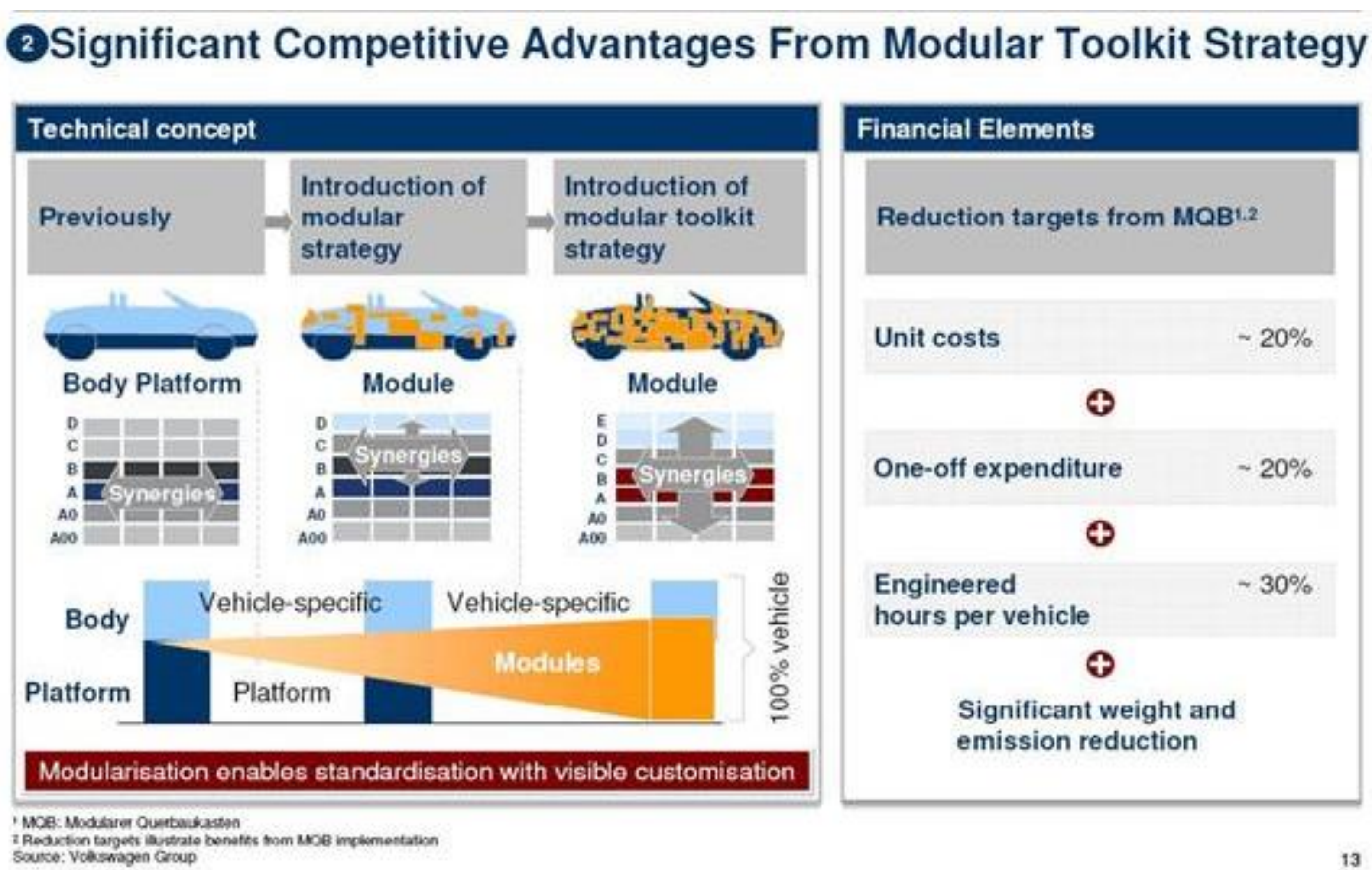




Modular Design: example

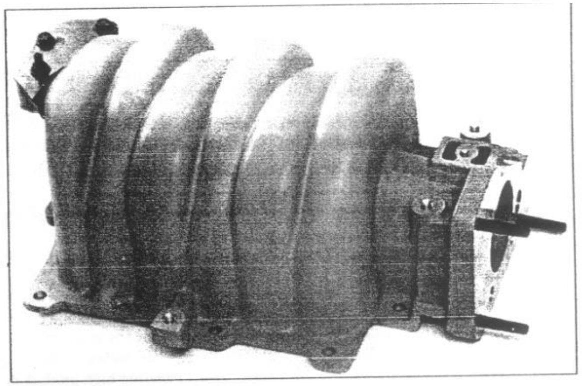
- Volkswagen modular platform

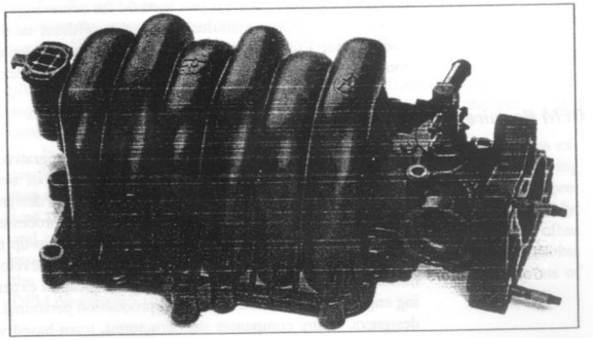
  MQB(Modulen Quer Baukasten): Modular Transverse Matrix



4. Product specific rules: DFM

- Air intake manifolds
  - Original : Cast Al
  - Redesigned : molded thermoplastic composite





Example: GM 3.8 liter V6 engine

K T Ulrich & S D Eppinger, Product design and development 2nd edition

Manufacturing cost

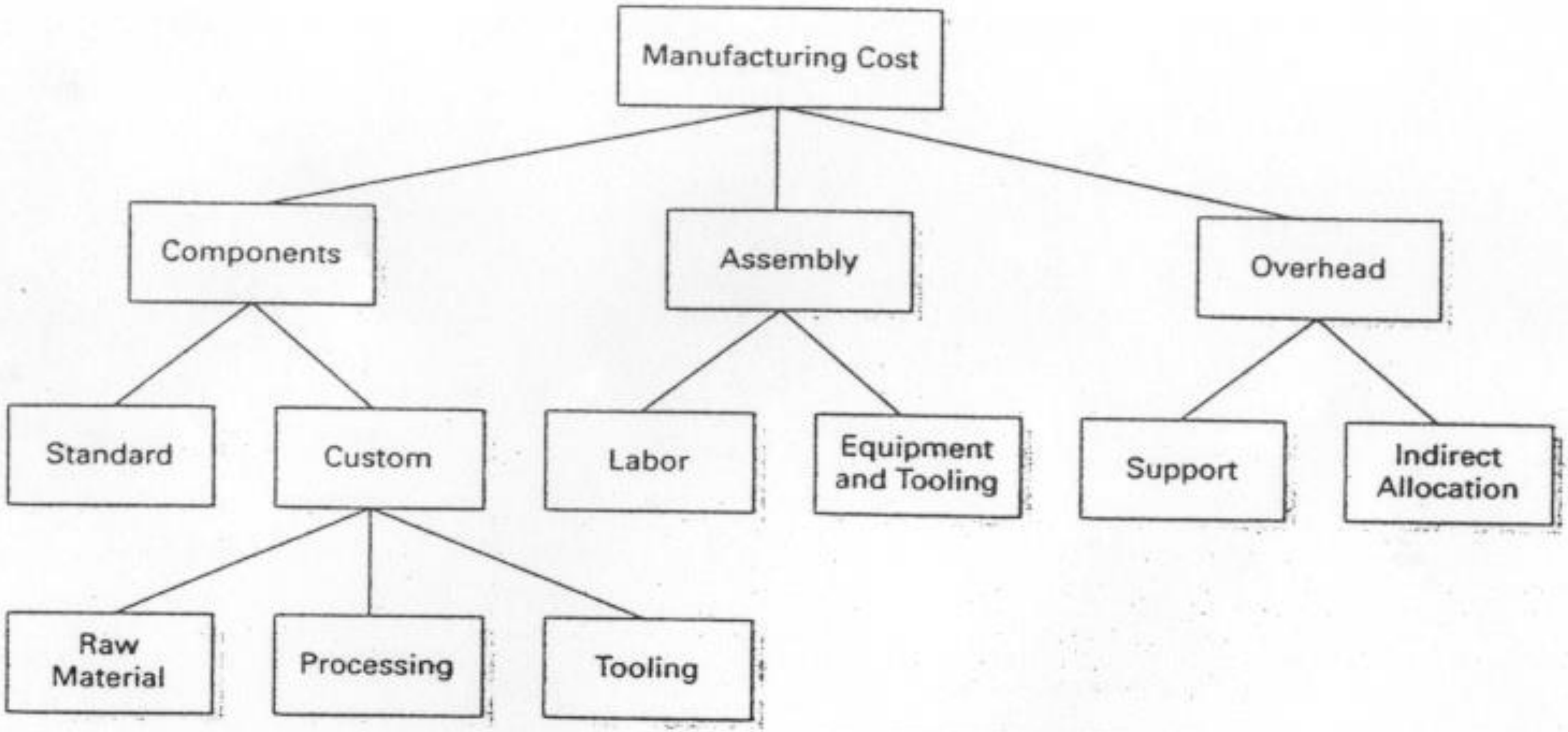


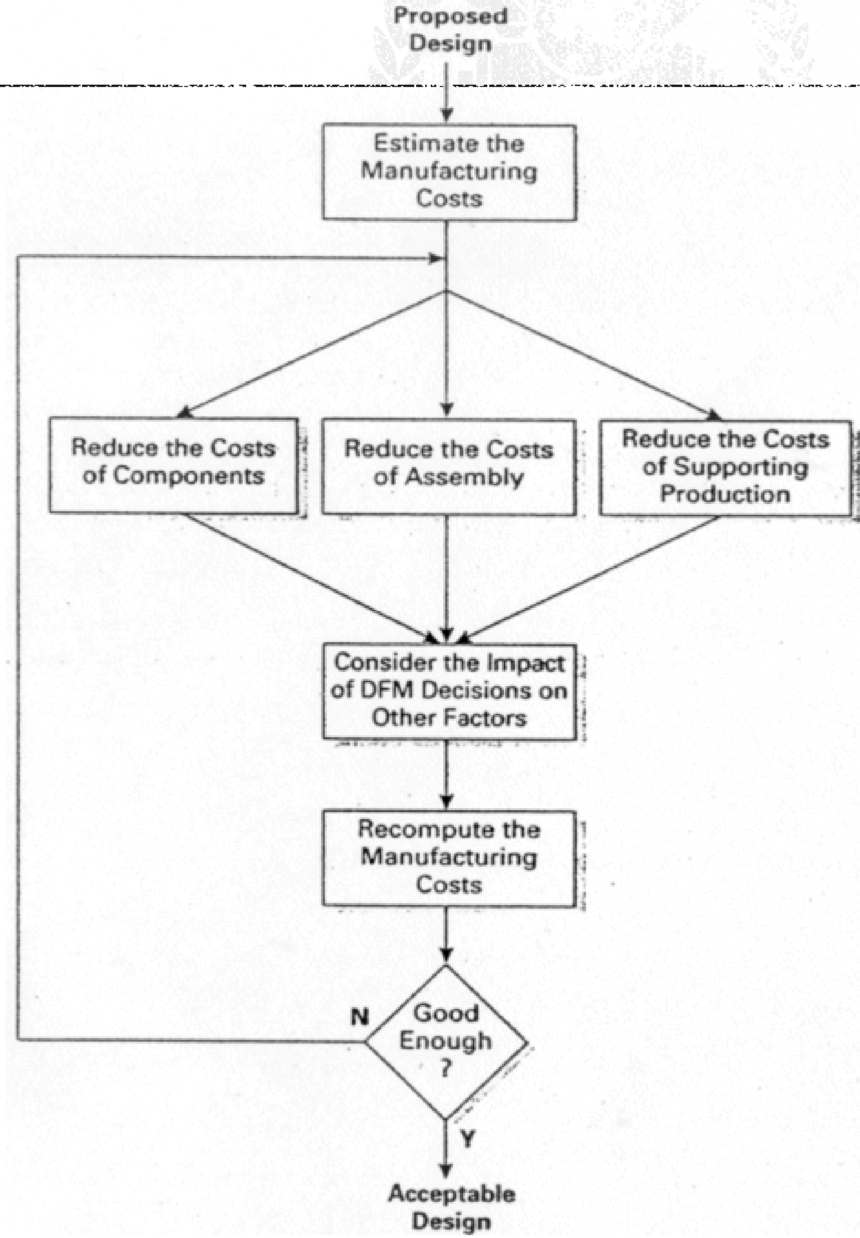
EXHIBIT 11–5

Elements of the manufacturing cost of a product.

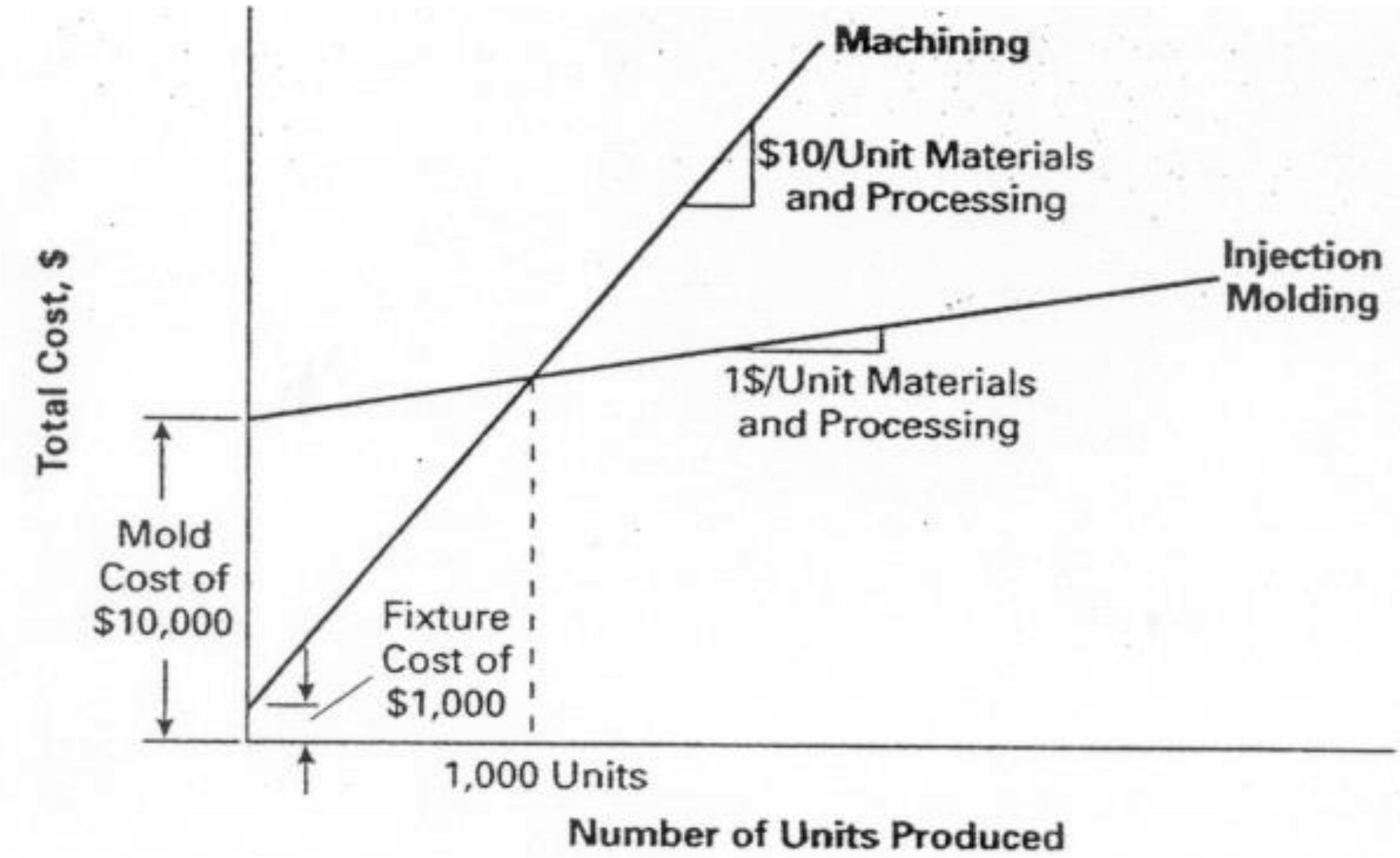
DFM process

5 steps of DFM Process

1. Estimate the manufacturing cost
2. Reduce the cost of components
3. Reduce the cost of assembly
4. Reduce the cost of supporting production
5. Consider the impact of DFM decision on other factors



Effect of process change



Cost of original intake manifold

Component	Purchased Materials	Processing (Machine + Labor)	Assembly (Labor)	Total Unit Variable Cost	Tooling and Other NRE, K$	Tooling Lifetime, K units	Total Unit Fixed Cost	Total Cost
Manifold								
machined casting	12.83	5.23		18.06	1960	500+	0.50	18.56
EGR return pipe	1.30		0.15	1.45				1.45
PCV assembly								
Valve	1.35		0.14	1.49				1.49
Gasket	0.05		0.13	0.18				0.18
Cover	0.76		0.13	0.89				0.89
Screws (3)	0.06		0.15	0.21				0.21
Vacuum source block assembly								
Block	0.95		0.13	1.08				1.08
Gasket	0.03		0.05	0.08				0.08
Screw	0.02		0.09	0.11				0.11
Total Direct Costs	17.35	5.23	0.95	23.53	1960		0.50	24.03
Overhead Charges	2.60	9.42	1.71				0.75	14.48
Total Cost								38.51

Cost comparison

Variable Cost		
Materials	5.7 kg aluminum at $2.25/kg	$12.83
Processing (casting)	150 units/hr. at $530/hr.	3.53
Processing (machining)	200 units/hr. at $340/hr.	1.70
Fixed Cost		
Tooling for casting	$160,000/tool at 500K units/tool (lifetime)	0.32
Machine tools and fixtures	$1,800,000/line at 10M units (lifetime)	0.18
Total Direct Cost		**$18.56**
Overhead charges		$12.09
Total Unit Cost		**$30.65**

Custom component for the original intake manifold

Component	Quantity	Handling Time	Insertion Time	Total Time
Valve	1	1.50	1.50	3.00
O-rings	2	2.25	4.00	12.50
Spring	1	2.25	6.00	8.25
Cover	1	1.95	6.00	7.95
Total Time (seconds)				31.70
Assembly Cost at $45/hour				$0.40

Assembly cost estimation For the PCV valve assy. of the redesigned intake manifold

Redesigned intake manifold

Component	Purchased Materials	Processing (Machine + Labor)	Assembly (Labor)	Total Unit Variable Cost	Tooling and Other NRE, K$	Tooling Lifetime, K units	Total Unit Fixed Cost	Total Cost
Manifold housing	3.85	1.56		5.41	350	1500	0.23	5.65
Intake runner insert	0.83	1.10	0.13	2.05	150	1500	0.10	2.15
Steel inserts (16)	0.32		1.00	1.32				1.32
ERG adapter	1.70		0.13	1.83				1.83
PCV valve								
Valve	0.85		0.04	0.89				0.89
O-rings(2)	0.02		0.16	0.18				0.18
Spring	0.08		0.10	0.18				0.18
Cover	0.02		0.10	0.12				0.12
Vacuum source block	0.04		0.06	0.10				0.10
Total Direct Costs	7.71	2.66	1.71	12.08	500		0.33	12.41
Overhead Charges	1.16	4.79	3.08				0.50	9.52
Total Cost								21.93

EXHIBIT 11–16

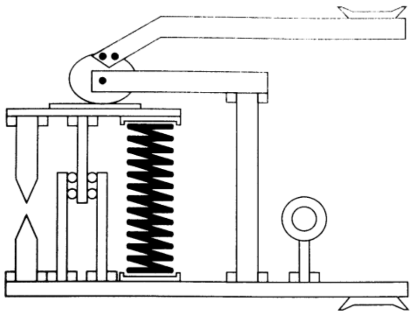
Cost estimate for the redesigned intake manifold.

These were:
24.03
14.48
38.51

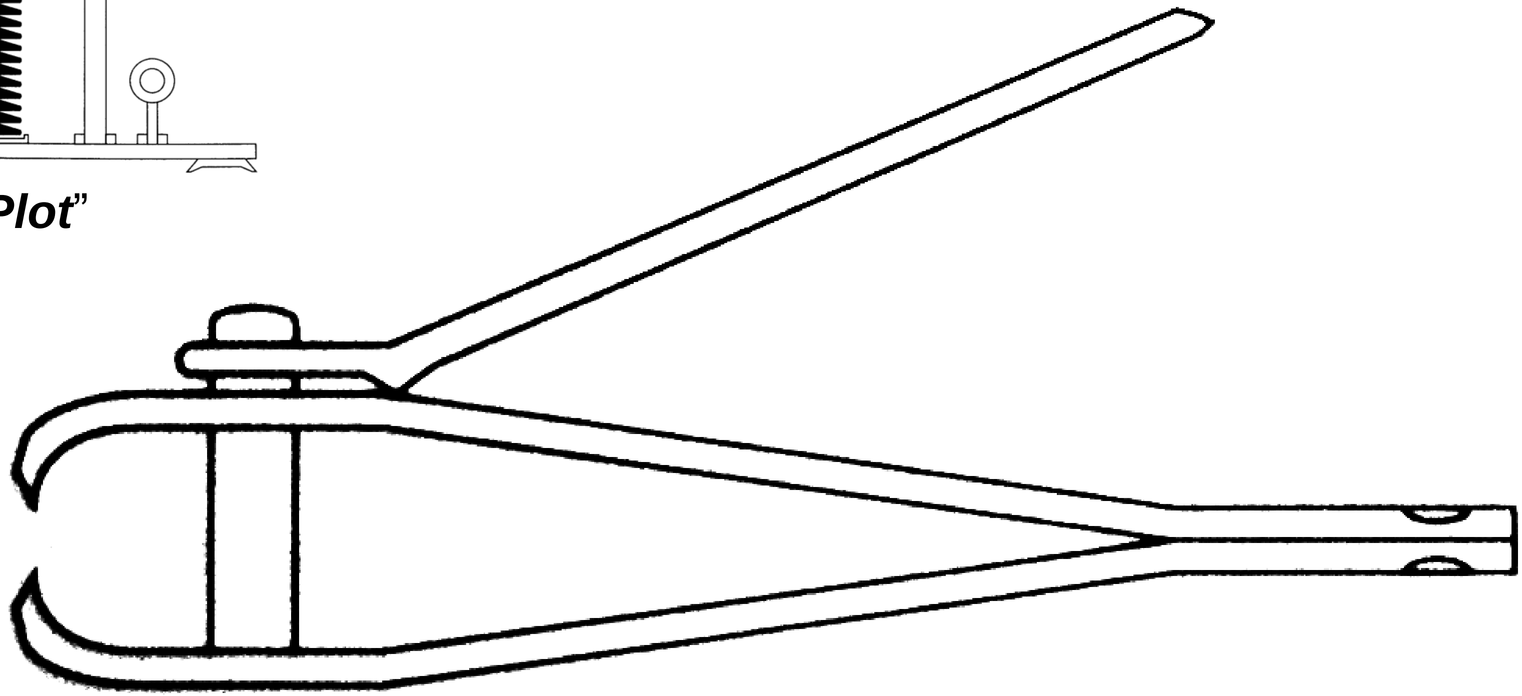
If they sell 1 million cars, cost saving can be $ 16.58 million just from the manifold

43% reduction of cost

“*Design*” applying the DFM principle



“***Plot***”



“***Design***” applying the DFM principle

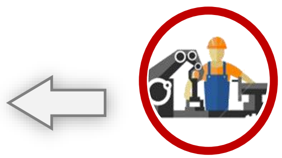
DFM vs MFD

Design for Manufacturing, DFM

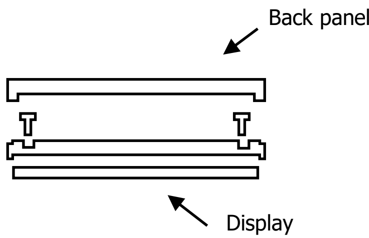
Paradigm in 1990s
Cost reduction

Design

Manufacturing



Reduction of degree of freedom for design by limitation of manufacturing processes



Flat cellphone

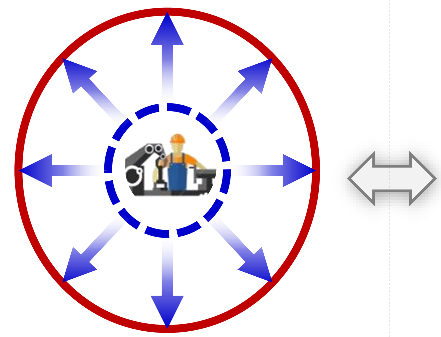
Simple design with consideration of assembly

Demand for new paradigm

Manufacturing for Design, MFD

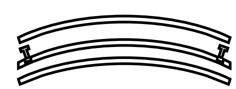
(Design Realizing Manufacturing, DRM)
Emerging paradigm
High added-value

Manufacturing



Design

Increasing degree of freedom for design by expansion of manufacturing processes



Curved display design

Edge (Glass process)

Curved display

Problems

- Design and manufacturing processes focused on cost and productivity
- Limitation of material and its property

High added-value

How?
Hybrid processes

Expanding Manufacturing Domain