MG2040 Assembly Technology

Lecture 4: Design for Assembly

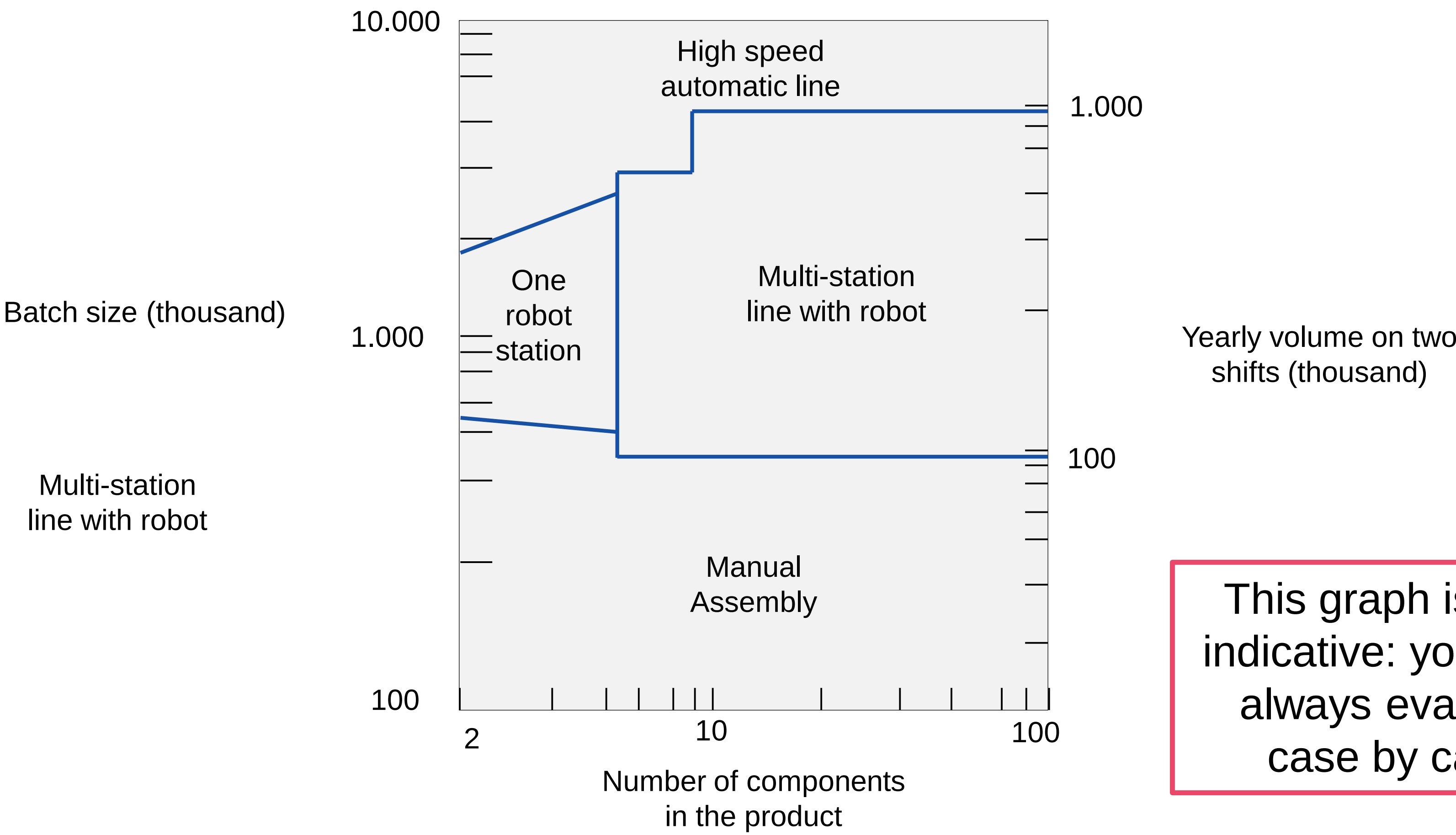
Outline

- Part one
  - Introduction to DFA
  - Design for Manual Assembly: the Boothroyd method
  - DFA uses
  - DFA benefits
  - DFA problems
  - Design Guidelines
- Part two
  - Manual vs automatic assembly
  - Design for automatic assembly
  - The KTH method

Intended Learning Outcomes

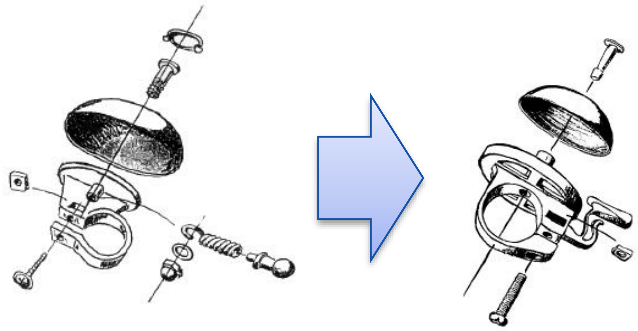
- Describe the purpose of DFA analysis and the main methodologies developed in literature
- Perform a complete DFA analysis with a given set of methods. In detail:
  - Manual assembly: the Boothroyd method for calculation of assembly efficiency
  - Automatic assembly: the Boothroyd method and the method developed at KTH, Stockholm.
- Suggest specific pattern for design improvements on a given product following the results of the DFA evaluation
- Discuss the basic tradeoffs between assembly and manufacturing needs regarding the product design

Assembly approaches



This graph is only indicative: you must always evaluate case by case

Part one



Introduction to DFA

DFA (Design for Assembly) is one of several DFx's, where each «x» is a charateristic of the product, its production or its life cycle that is important to someone in or in some context

Manufacturing ←

Assembly ←

Logistic ←

Design for...

→ Recycling

→ Repair

→ ....

Introduction to DFA

- Each DFx represents a body of knowledge, procedures, analyses, metrics and design recommendation intended to improve the product in the domain «x».
- Therefore, recomandations coming from DFx developped in different domains might conflict!
- The Assembly process, in all its forms, is the target domain of all the methodologies that fall in the DFA category

DFA: definition and purpose

ONE

- Design for assembly (DFA) is a process by which products are designed with ease of assembly in mind. If a product contains fewer parts it will take less time to assemble, thereby reducing assembly costs.

TWO

- Design for Assembly is a method of analyzing components and sub-assemblies in order to:
  - Optimize the assembly process steps
  - Identify part relevance
  - Estimate the cost of assembly –
- The purpose of DFA is to minimize assembly cost by optimizing the assembly process and reducing the number of parts.

The dawn of DFA

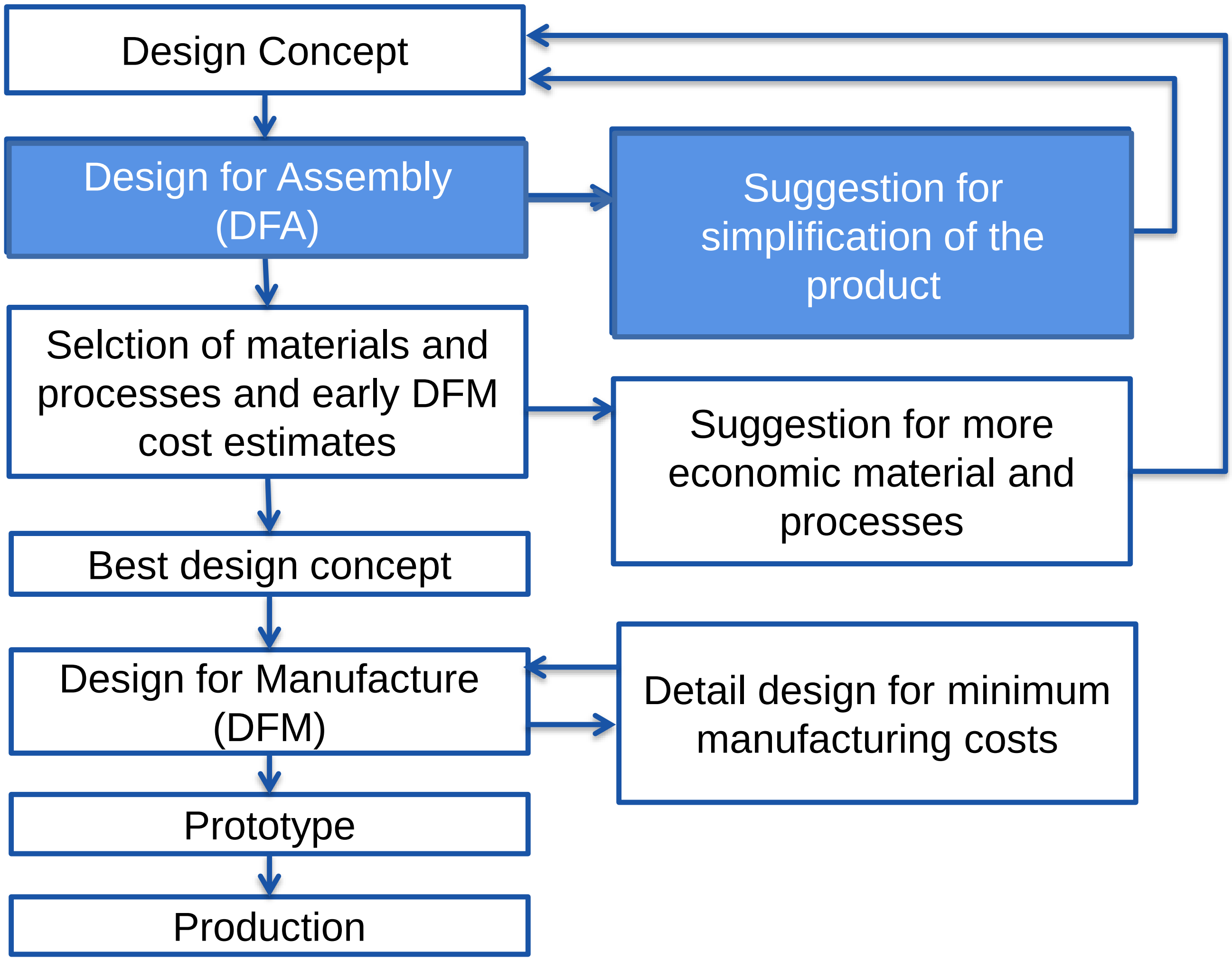
- Although rules for good design in relation with the fabrication processes have been often applied in the past, DFA was first systematized in the 1960s by Geoffrey Boothroyd and his colleagues at the University of Salford, England.
- Large part of this seminar is based on the Boothroyd methodology[1] that still nowadays holds an outstanding position in this domain.
- The empirical studies of this author and his colleagues have been source of inspiration for many scholars and practitioners included the KTH team active in this field.

[1]. Such methodology can be used as a «stand-alone» tool, but as the author suggests it achieves the best result in combination with a Design for Manufacturing analysis.

Some DFA methodologies…

DFA method	Authors	Country of origin
Assemblability Evaluation Method (AEM)	Ohashi Yano	Japan
Boothroyd-Dewhurst DFMA	Boothroyd Dewhurst	USA
A systematic approach to Design For Assembly	Miles Swift	UK
A designers guide to optimise the assemblability of the product design (DGO)	Hock	USA
ASSEMBLY	DeWinter Machiels	Belgium
Assembly Oriented Product Design (AOPD)	Bässler Warnecke	Germany
Assembly SYStem (ASSYST)	Arpino Groppetti	Italy
Assembly view	Sturges	USA
Design for Assembly Cost-effectiveness	Yamagiwa	Japan
Product and System Design for Robot Assembly	Davisson Redford	UK
Product Design Merit	Zorowski	USA
The DFA House	Rampersad	The Netherlands

Ideal use of DFA



Classification of DFA 1

According to the actual embodiment of the method it is possible to classify DFA as:

- Methods that involves calculating timing and related costs for the assembly operations.
- Methods based on a point scale which gives a relative measure of assembly difficulty.
- Hybrids (combination of the ones above)

Underlying principle:

- Too much time or too low a score are indicators that something doesn't work!
- We need to look in detail into the methods' suggested causes for such occurrences!

Classification of DFA 2

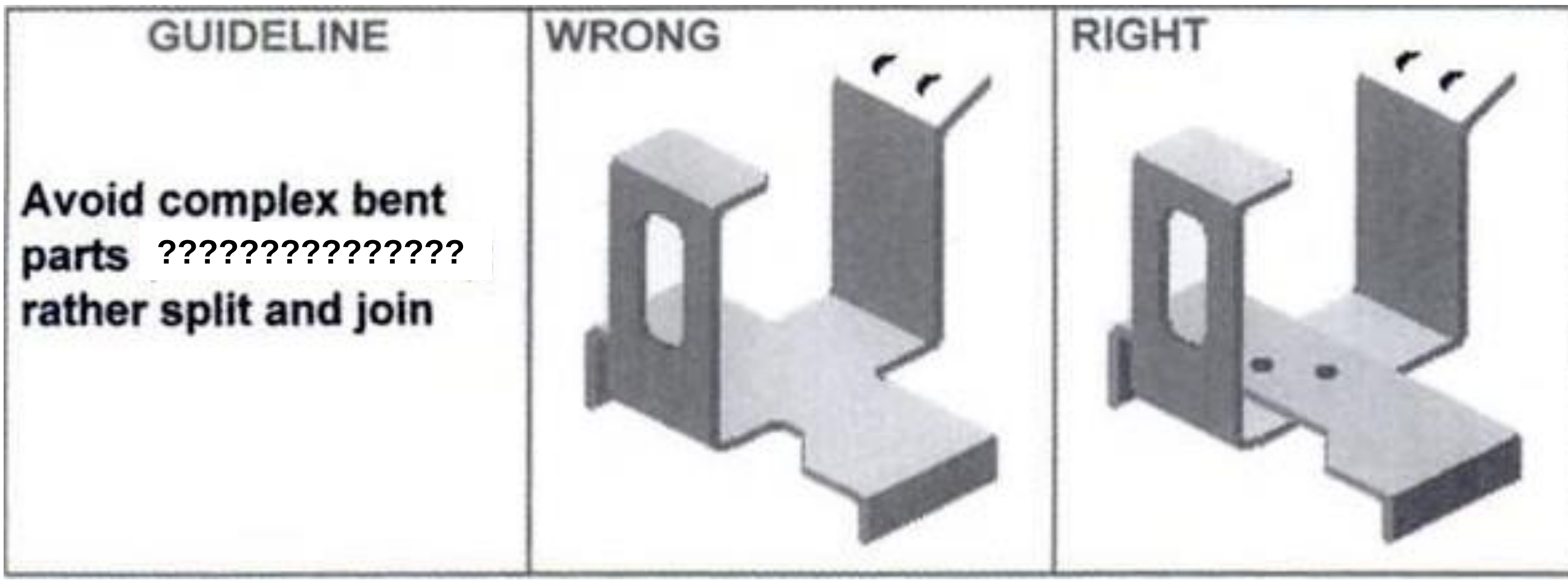
Assembly can be seen as a two level problem, thus DFA can be classified as:

- DFA in the Small: methods or process steps that can be applied to one part at the time by an engineer working alone
- DFA in the Large: methods or process steps that involve consideration of all the parts in an assembly at once and that may need many people with different skills to interact

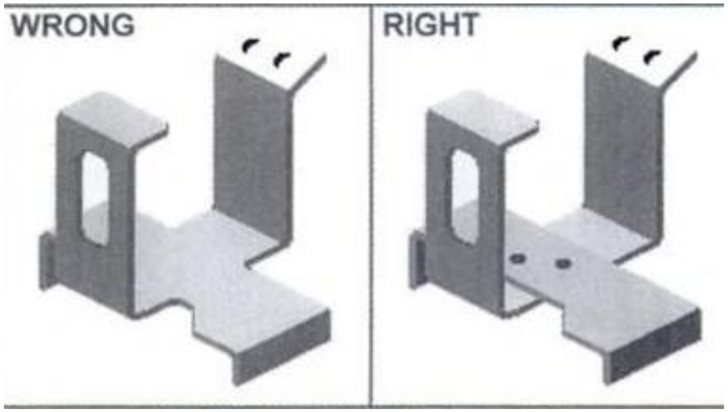
[1]. Most of the actual methodologies includes both levels

The dawn of DFA

Good design… back in the 60-70's



The dawn of DFA



The “right” one is not so right!!!

	Wrong	Right
Setup	0.015	0.023
Process	0.535	0.683
Material	0.036	0.025
Pierce part	0.586	0.731
Tooling	0.092	0.119
Total manufacture	0.678	0.850
Assembly	0.000	0.200
Total	0.678	1.050

DFA

- The basic input to any DFA method are:
  - A model, drawing or prototype of the assembly
  - A proposed assembly sequence.
- The DFA analysis depends largely on whether the product has to be assembled manually, with special-purpose automation, with general-purpose automation (robot) or with combinations of them.
- The cost of the different solution should be evaluated and compared in order to select the suitable one

Design for Manual Assembly

The focus of this first part of the seminar is manual assembly. Two are the main areas in the process of manual assembly:

1. Part Handling (acquiring, orienting, moving)
2. Part Insertion and Fastening

A relevant part of any manual assembly process are the non-value added process steps such as quality check, replenishing the components in the shelves and so on. We will leave these out from our analysis

The DFA index

This index is also called assembly efficiency and it is used to give a synthetic evaluation on a given design. Two are the factors that influence this index:

1. The number of parts in a product
2. The ease of handling, insertion and fastening of the part

DFA Index

The index is obtained by dividing the theoretical minimum assembly time by the actual assembly time. The equation for calculating the DFA index is as follows:

$$E_{ma} = \frac{N_{min} t_a}{t_{ma}}$$

Where:

N_{min} = theoretical minimum number of parts required

t_a = basic assembly time for one part

t_{ma} = estimated time to complete the assembly of the product

Theoretical minimum number of parts required N_{min}

- The main issue in order to produce a good design for assembly is to *keep the number of components as low as possible*.
- Therefore each part in a conceptual design has to be evaluated against the following criteria:

1. During operation of the product, does the part move relative to all other parts already assembled. Only gross motion should be considered- small motions that can be accommodated by integral elastic element, for example are not sufficient for a positive answer.
2. Must the part be of a different material than or be isolated (insulation, electrical isolation, vibration damping…) from all other parts already assembled? Only fundamental reasons concerned with material properties are acceptable.
3. Must the part be separate from all other parts already assembled because otherwise necessary assembly or disassembly of other separate parts would be impossible.

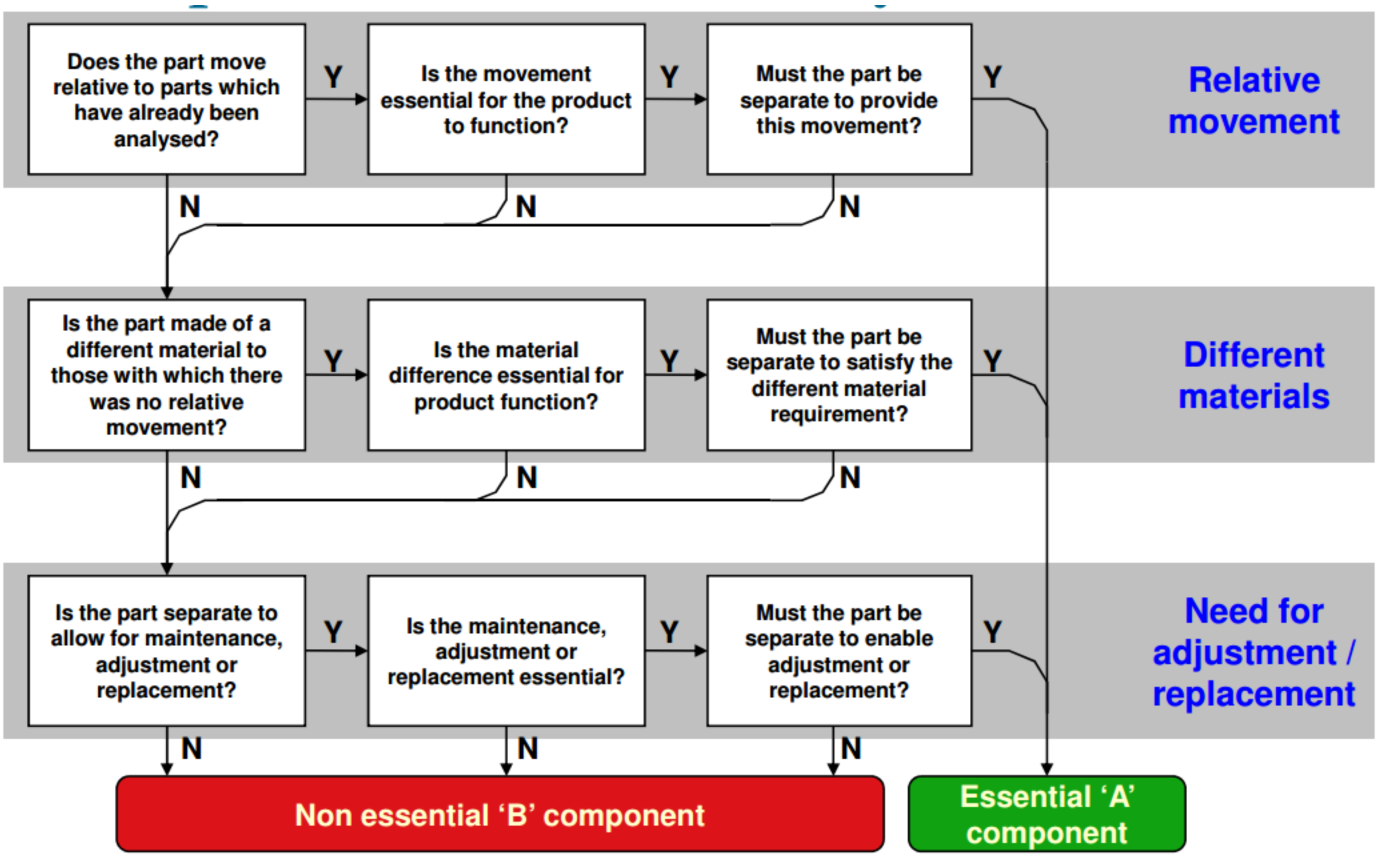
MOST IMPORTANT CONCEPT TODAY!!!

N_{min} alternative set of question

These questions cover the same aspects than the previous but are formulated differently:

- 1) Is the component/sub-assembly used only for fastening or securing other items? If yes, try to eliminate.
- 2) Is the component/sub-assembly used only for connecting other items (for example, wiring harnesses, belts, chains)? If yes, try to eliminate.
- 3) During operation, does the component move relative to all other parts already assembled? If no, skip question #4
- 4) Must the part be made of a different material than, or isolated from all other parts already assembled? Only fundamental reasons concerned with material properties are acceptable. If no, go to question #5
- 5) Must the part be separate from all other parts already assembled because of any necessary assembly or disassembly of the other parts would otherwise be impossible? If no to questions #3-5, part is theoretically unnecessary.
- 6) If this is a part in a sub-assembly, can any part be combined with another part in the parent assembly?

A flow chart for the process



Theoretical minimum number of parts required N_{min}

Remember to exclude from this count all the ***fasteners***!

More facts… the Ford/GM multiplier effect

- For every product part, there are about 1000 manufacturing equipment parts
- Or, for every toleranced dimension or feature on a product part, there are about 1000 toleranced dimensions or features on manufacturing equipment
- Such “equipment” includes fixtures, transporters, dies, clamps, robots, machine tool elements, etc

The basic assembly time t_a

- Average time for a part that presents no handling, insertion or fastening difficulties (**ideal part**)
- Usually the value is set to 3s

Estimated time for product assembly t_{ma}

- It is the time necessary to assemble a given product in its current design.
- Includes all the necessary handling, insertion and fastening operation
- It is calculated following specific tables elaborated through empirical studies

Estimated time for product assembly t_{ma}

Example of table[1] for calculation of the t_{ma}:

MANUAL HANDLING-ESTIMATED TIMES (s)

Key: One hand

Parts can be grasped and manipulated by one hand without the aid of grasping tools

		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
		0	1	2	3	4	5	6	7	8	9
(α+β) < 360°	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
360° ≤ (α+β) < 540°	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
540° ≤ (α+β) < 720°	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
(α+β) = 720°	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

[1]. For the complete set of tables refer to the handouts

Estimated time for product assembly t_{ma}

Each operation should be classified with a numer consisting of two digits:

1. ID of the the raw
2. ID of the column

The intersection provide the given time for the operation

MANUAL HANDLING-ESTIMATED TIMES (s)

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
			0	1	2	3	4	5	6	7	8	9
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	360° ≤ (α+β) < 540°	1	1.5	1.8	2.25	2.06	[illegible]	2.25	2.57	3.06	3	3.38
	540° ≤ (α+β) < 720°	2	1.8	2.1	2.55	[illegible]	2.85	2.57	2.9	3.38	3.18	3.7
	(α+β) = 720°	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

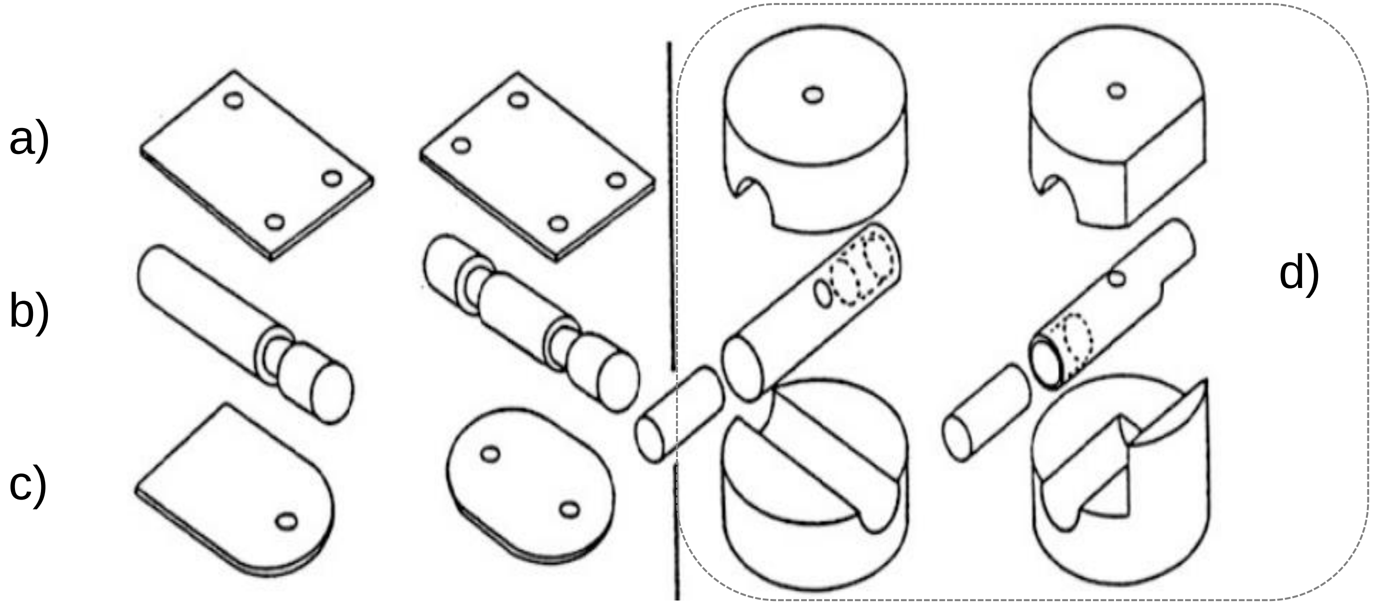
Estimated time for product assembly t_{ma}

The final sum of the required times for each operation gives an indication of the needed operator time for such assembly

$$\sum$$

Quiz

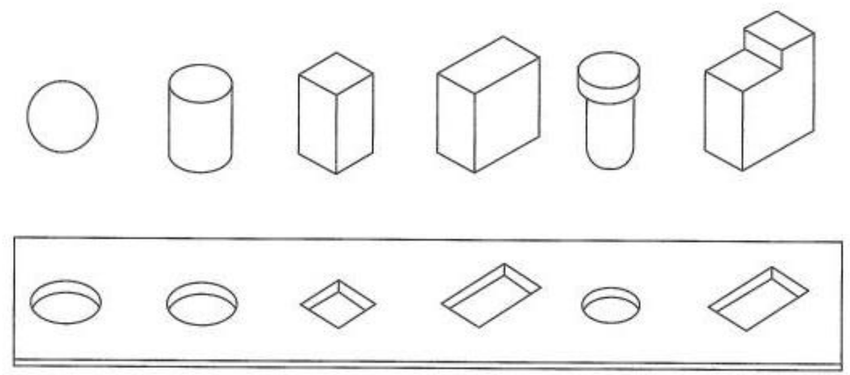
- Question: which one are the best among the couples of part of the one down here and why?
- Think about it alone or with one of your colleague for some minutes and then I will ask to some of you.



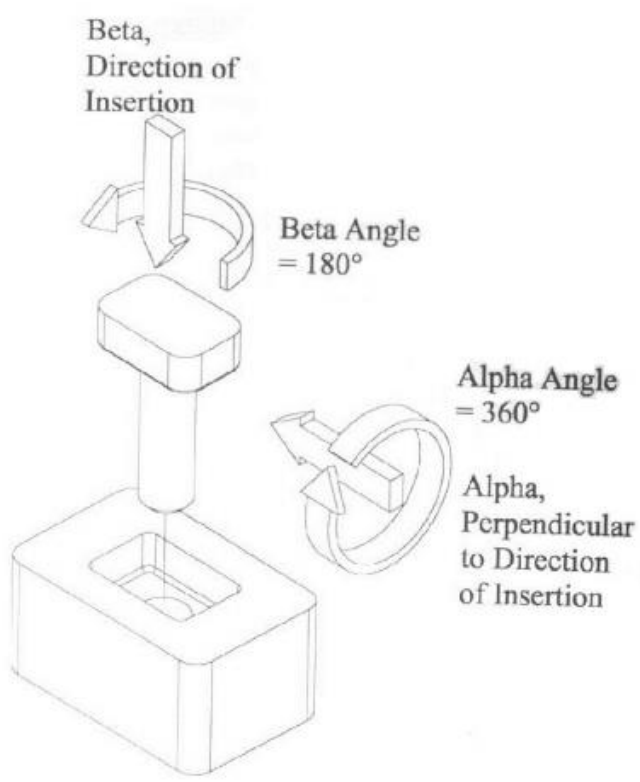
Definition for the handling tables

Alpha is the rotational symmetry of a part about an axis perpendicular to its axis of insertion

Beta is the rotational symmetry of a part about its axis of insertion

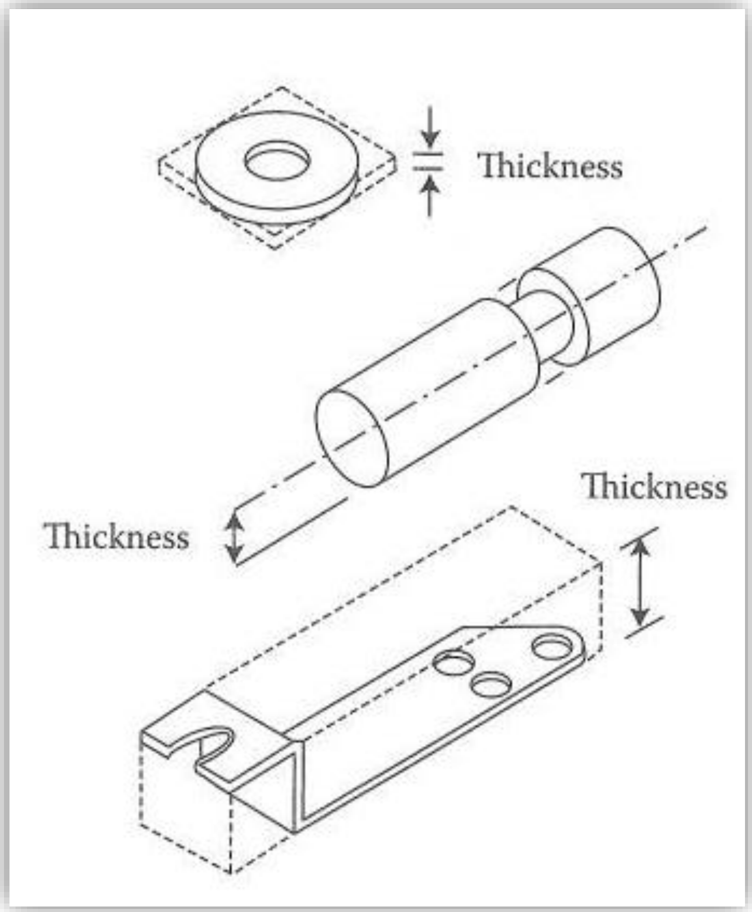


α	0	180	180	90	360	360
β	0	0	90	180	0	360

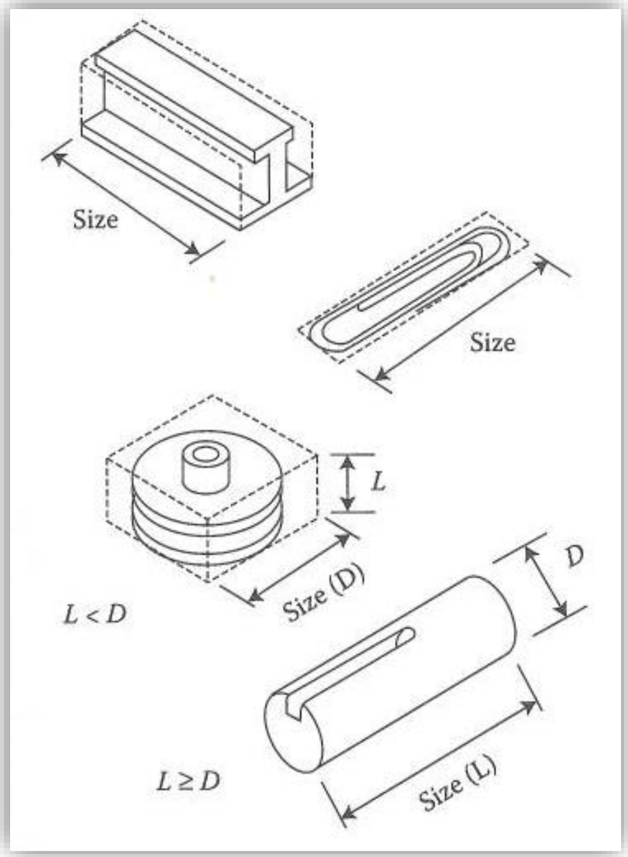


Definition for the handling tables

Thickness: is the leght of the shortest side of the smallest rectangular prism that encloses the part. However if the part is cylindrical, or has a regular poligonal cross-section with five or more sides and the diameter is less than the lenght, then thickness is defined as the radius of the smallest cylinder that can enclose the part



Definition for the handling tables



Size: is the leght of the longest side of the smallest rectangular prism that encloses the part.

Definition for the insertion tables

Holding down required: the partrequireg gripping, realignment, or holding down before it is finally secured.

Easy to alignand position: the insertion is facilitated by well-designed chamfers or similar features

Obstructed access: the space available for the operation causes a significant increase in the assembly time

Restricted vision: the operator has to rely mainly on tactile sensing during the assembly process

DFA uses

1. As the basis for concurrent engineering studies to provide guidance to the design team in simplifying the product structure, to reduce assembly costs, and quantify the improvements: the sooner in the design phase such method is applied the better results are likely to be achieved
2. As a benchmarking tool to study competitors' products and quantify assembly difficulties
3. As a should-cost tool to help negotiate suppliers contracts.

DFA benefits

Beside the expected cost reduction in assembly, a correct DFA implementation brings a set of secondary benefits that often outweigh the direct ones:

- Improved quality and reliability
- Reduction in production equipment and part inventory
- Given the integrative power of assembly DFA can stimulate discussion about all the other aspects of design and manufacturing

DFA problems

- DFA is that it focuses on part reduction. This often results in multi-functional parts with very high complexity, which increases manufacturing costs. It is necessary to find the balance between assembly costs and manufacturing costs
- DFA recommendation can conflict also with recommendations from other DFx methodologies (i.e., design for recycling)
- Design time can be prolonged by the pursuit of the desired level of DFA index.
- Eliminating and consolidating parts can deprive the assembly process of needed adjustment opportunities

Design guidelines for manual assembly

As a result of experience in applying DFA, it has been possible to develop general design guidelines that attempt to consolidate manufacturing knowledge and present them to the designer in the form of simple rules to be followed when creating a design.

Once again, two are the macro areas addressed by such guidelines:

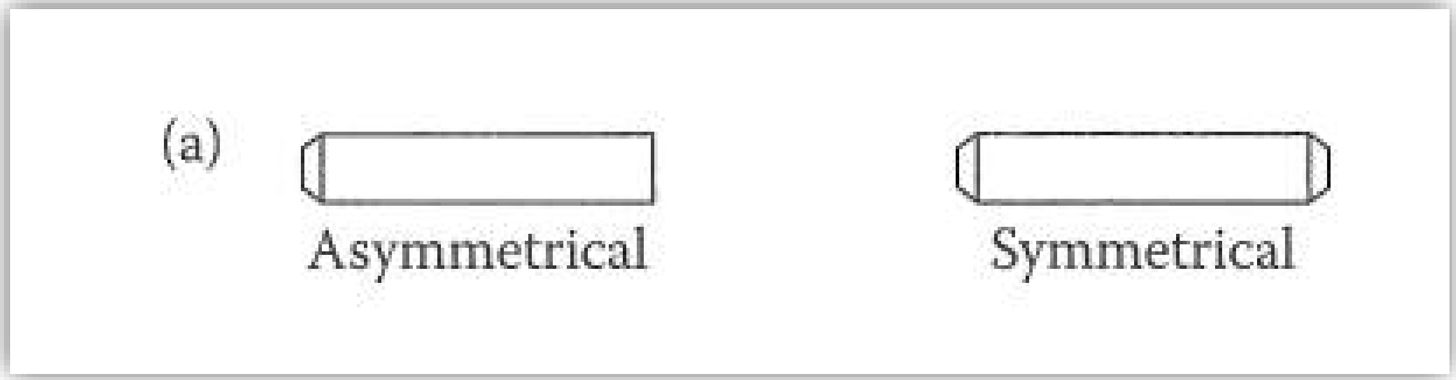
Handling:

- Acquiring
- Orienting
- Moving

Insertion and Fastening

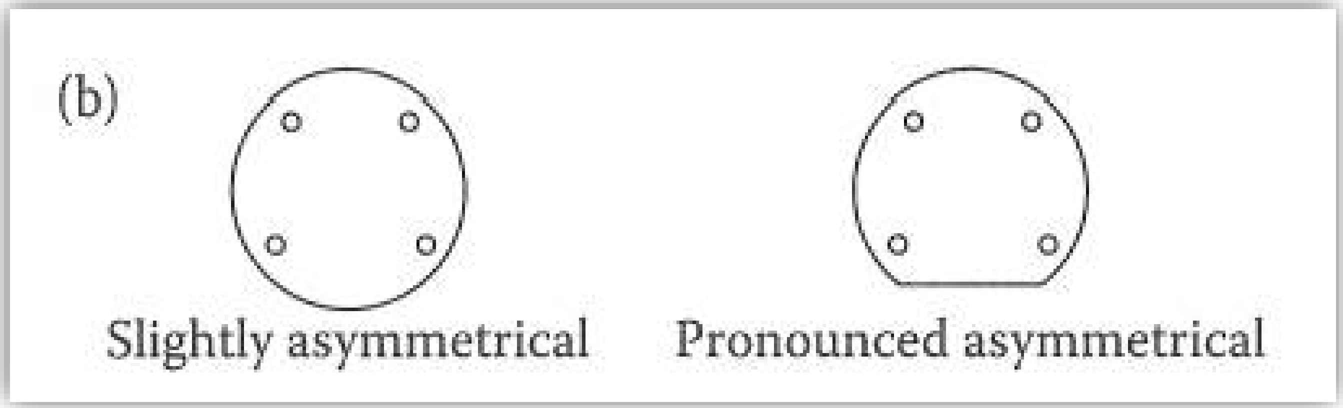
Design guidelines for manual handling 1

Design parts that have an end-to-end symmetry and rotational symmetry about the axis of insertion. If this cannot be achieved, try to design parts that have the maximum possible symmetry



Design guidelines for manual handling 2

Design parts that, in those instances where the part cannot be made symmetric, are obviously asymmetric

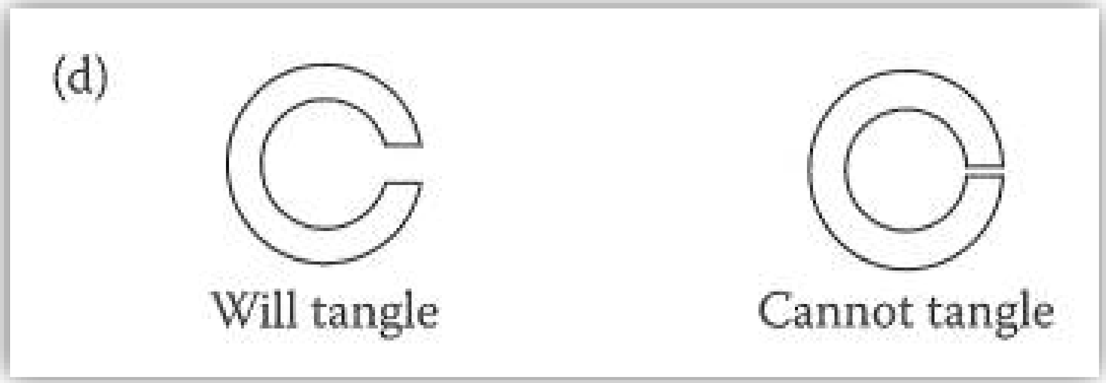


Design guidelines for manual handling 3

Provide features that prevent jamming of parts that tend to nest or stack when stored in bulk

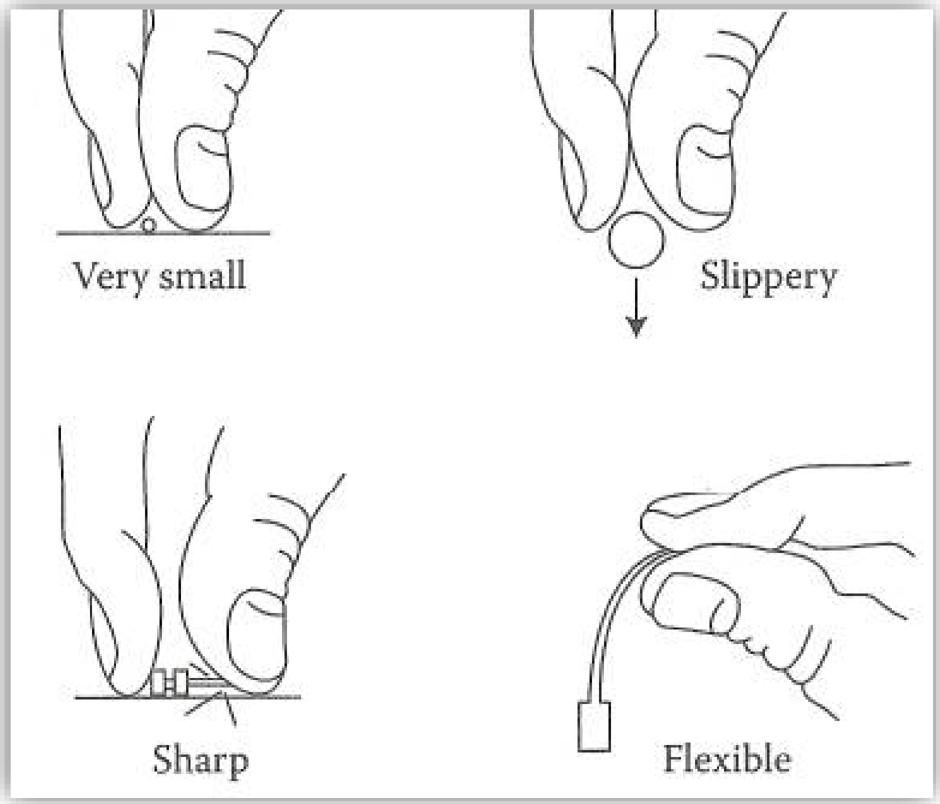
Design guidelines for manual handling 4

Avoid features that allow tangling of parts when stored in bulk



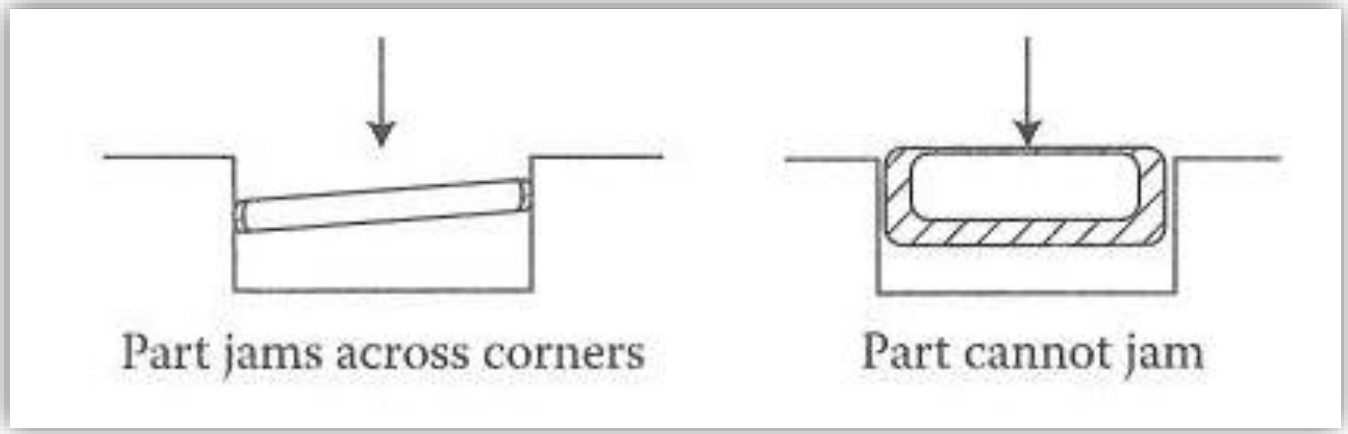
Design guidelines for manual handling 5

Avoid parts that stick together or are slippery, delicate, flexible, very small or very large, or that are hazardous to the handler (i.e., parts that are sharp)



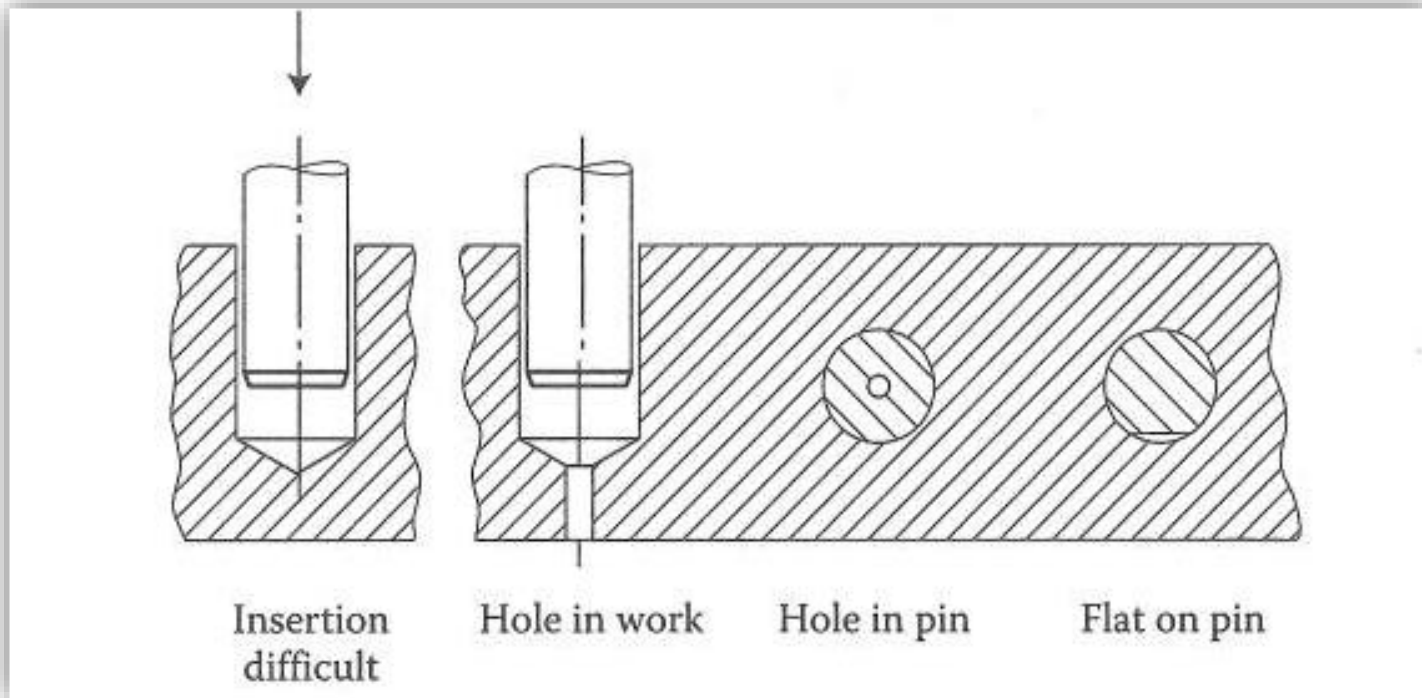
Design guidelines for manual insertion and fastening 1

Design so that there is little or no resistance to insertion and provide chamfers to guide the insertion of two mating parts. Generous clearance should be provided, but care must be taken to avoid clearances that result in a tendency for parts to jam or hang-up during insertion



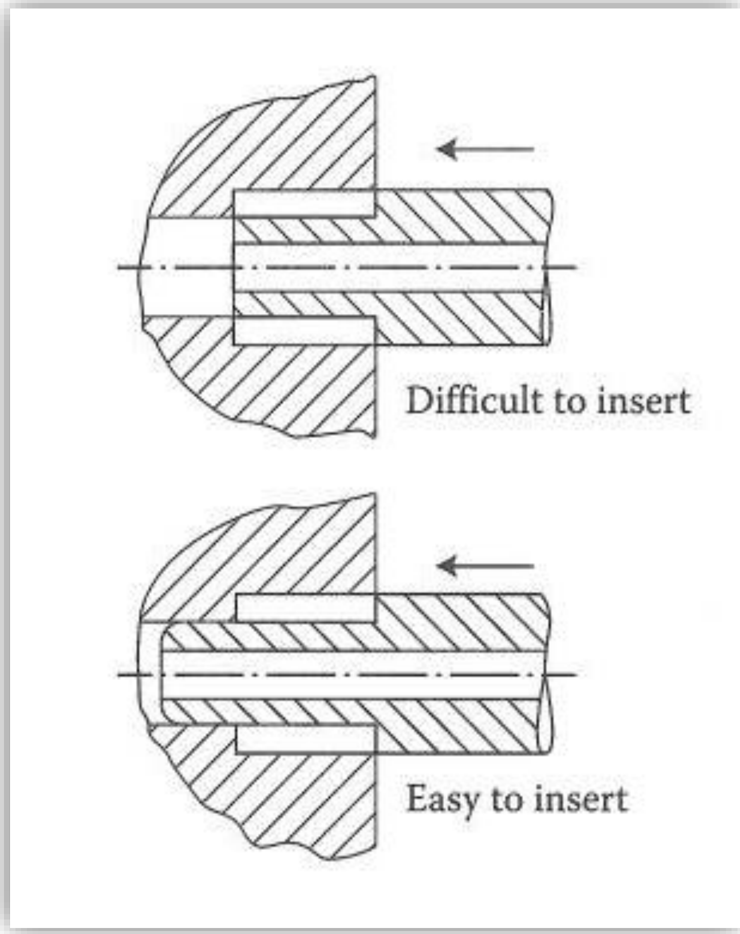
Incorrect geometry can allow a part to jam during insertion

Design guidelines for manual insertion and fastening 1



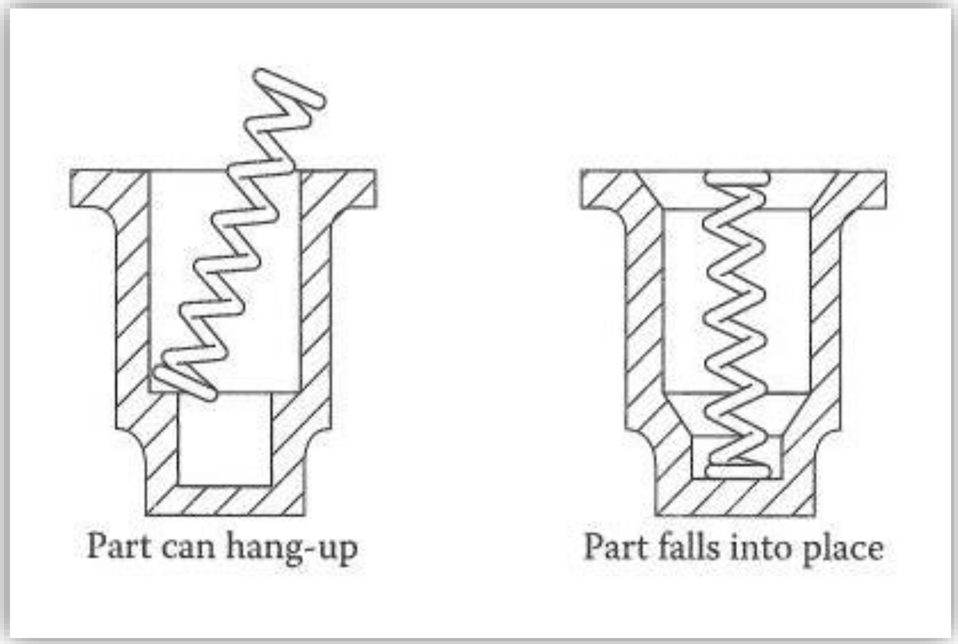
Provision of air-relief passages to improve insertion into blind holes

Design guidelines for manual insertion and fastening 1



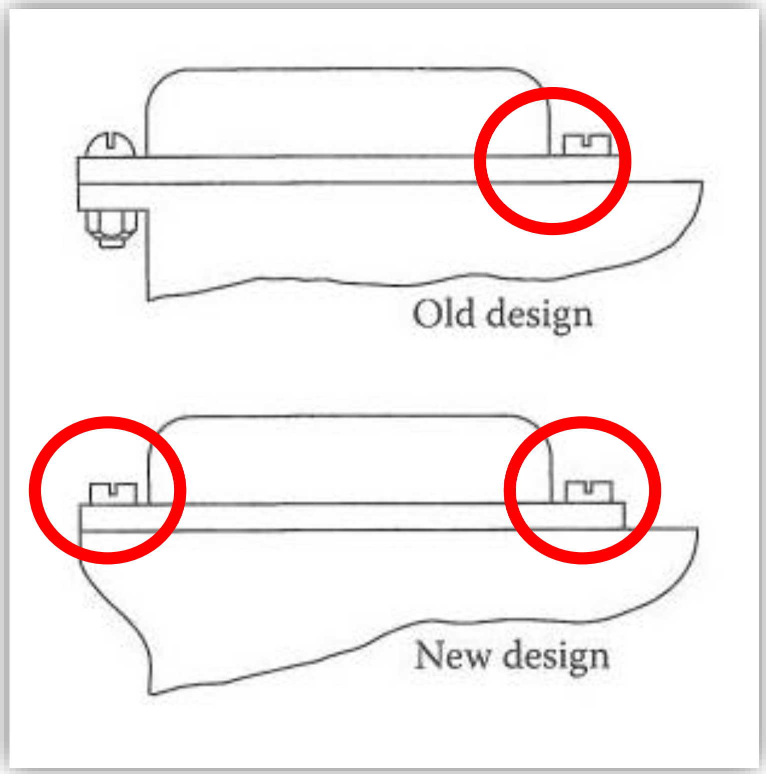
Design for ease of insertion – assembly of long-stepped bushing into counterbored hole

Design guidelines for manual insertion and fastening 1



Provision of chamfers to allow easy insertion

Design guidelines for manual insertion and fastening 2

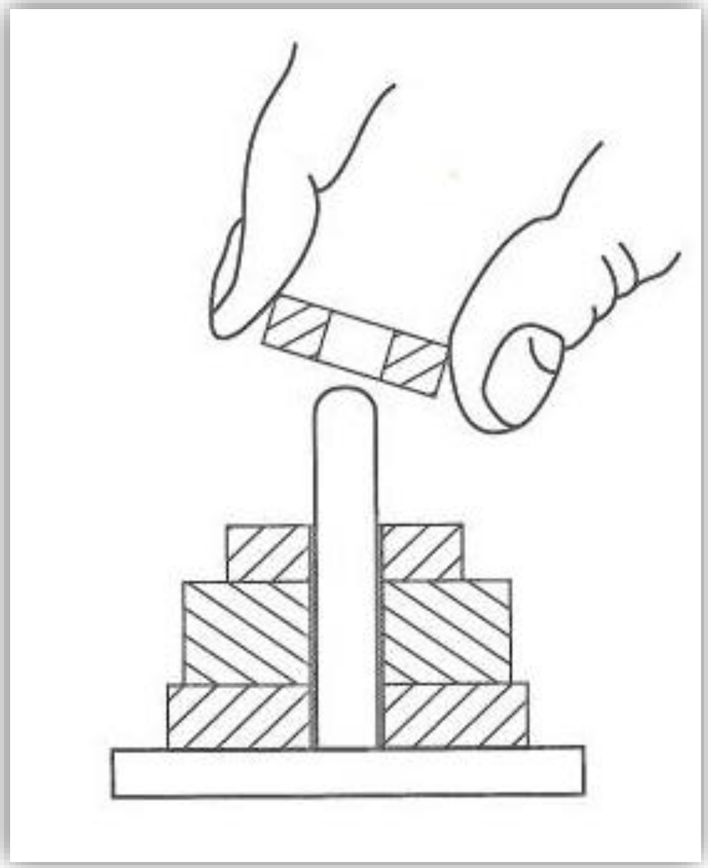


Standardize parts

Standardize by using common parts, processes, and methods across all models and even across product lines to permit the use of higher volume processes that normally result in lower product cost

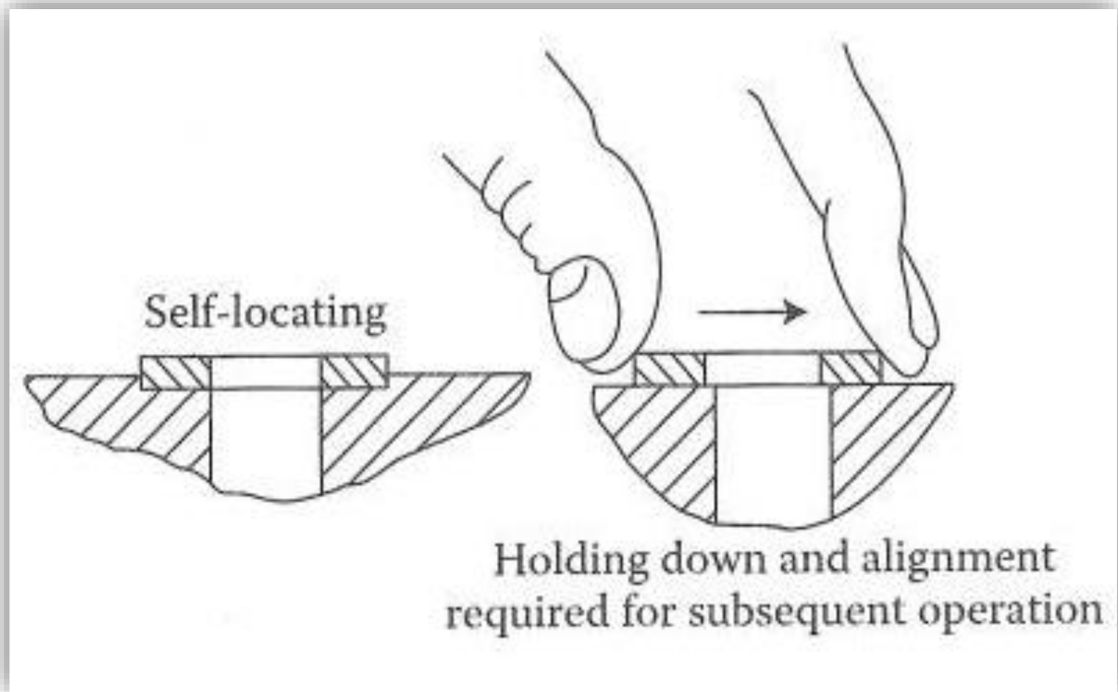
Design guidelines for manual insertion and fastening 3

Use pyramid assembly – provide for progressive assembly about one axis of reference. In general it is better to assemble from the above



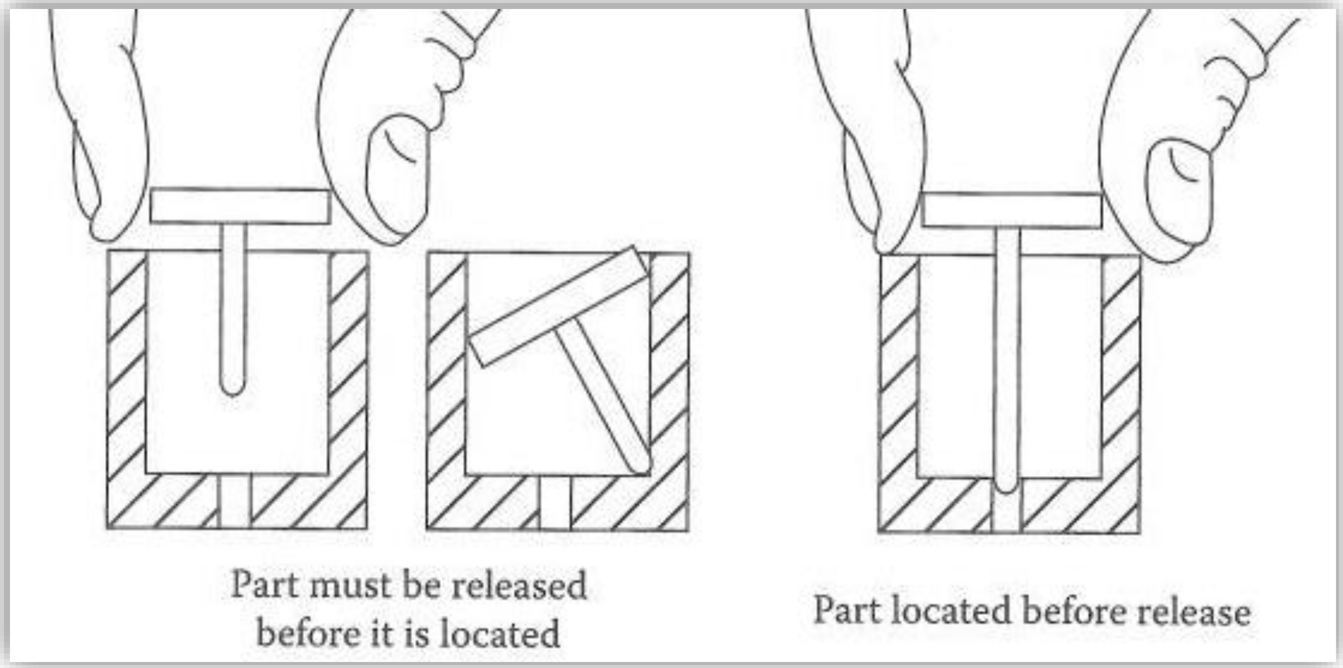
Design guidelines for manual insertion and fastening 4

Avoid the necessity of holding parts down to mantain their orientation during manipulation of the subassembly or during the placement of another part. If holding down is required, then try to design so that the part is secured as soon as possible after it has been inserted



Design guidelines for manual insertion and fastening 5

Design so that a part is located before it is released.



Design guidelines for manual insertion and fastening 6

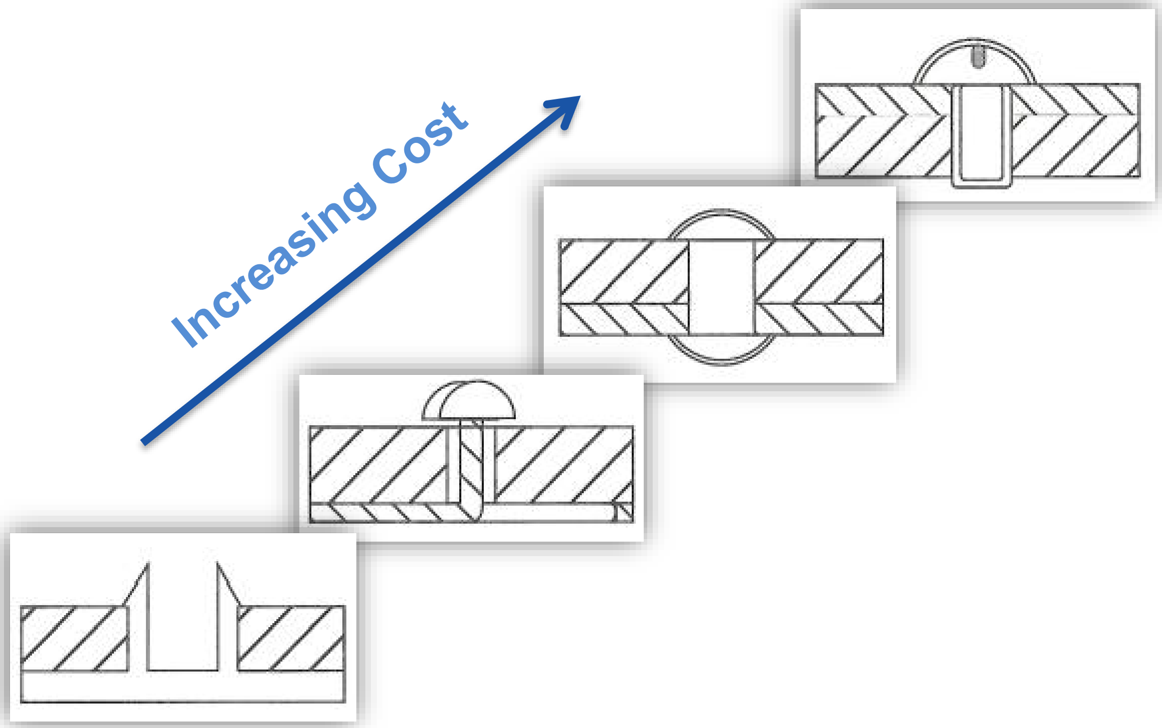
When common mechanical fasteners are used, the following sequence indicates the relative cost of different fastening processes.

Screw Fastening

Plastic Bending

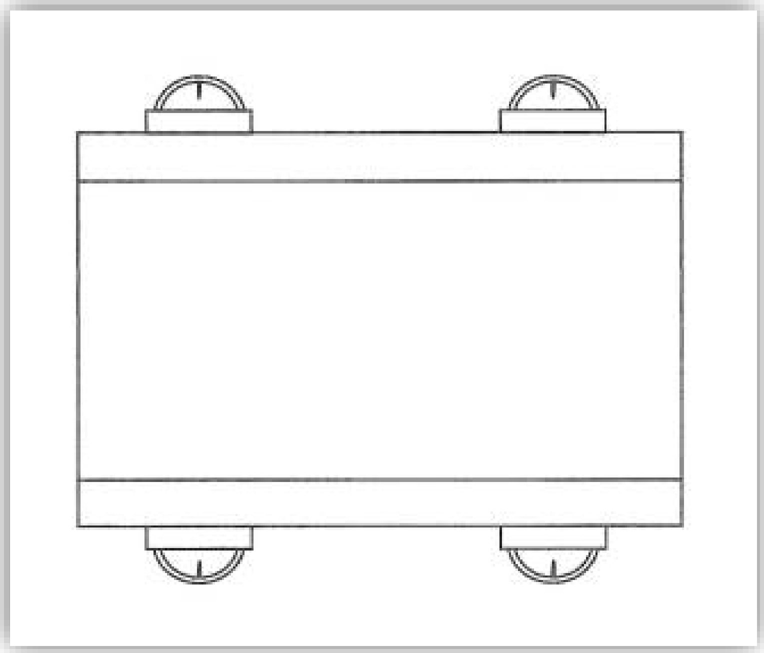
Riveting

Snap Fitting



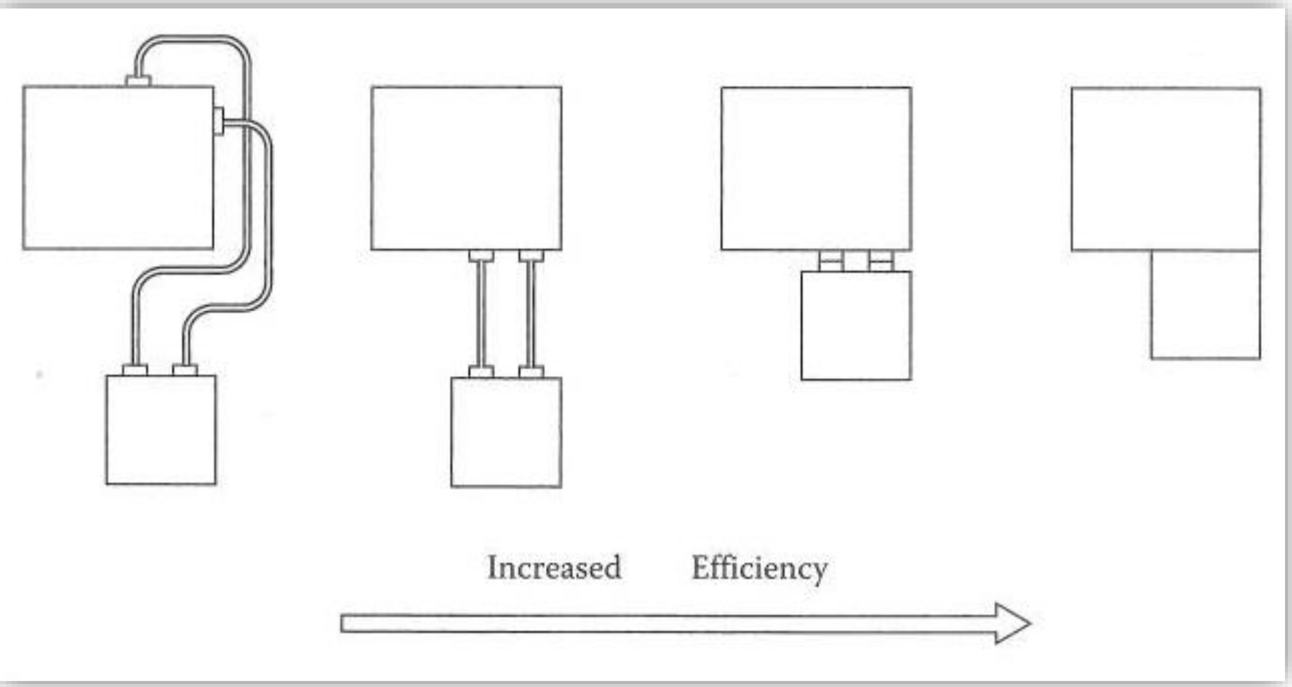
Design guidelines for manual insertion and fastening 7

Avoid the need to reposition the partially completed assembly in the fixture



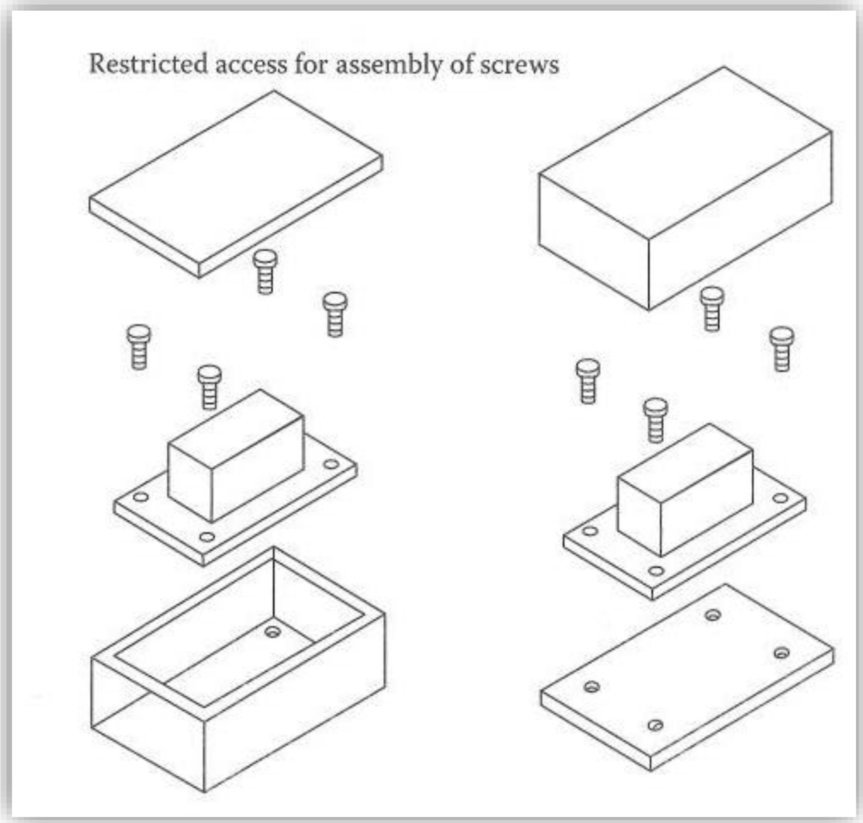
Further Guidelines 1

Avoid connections



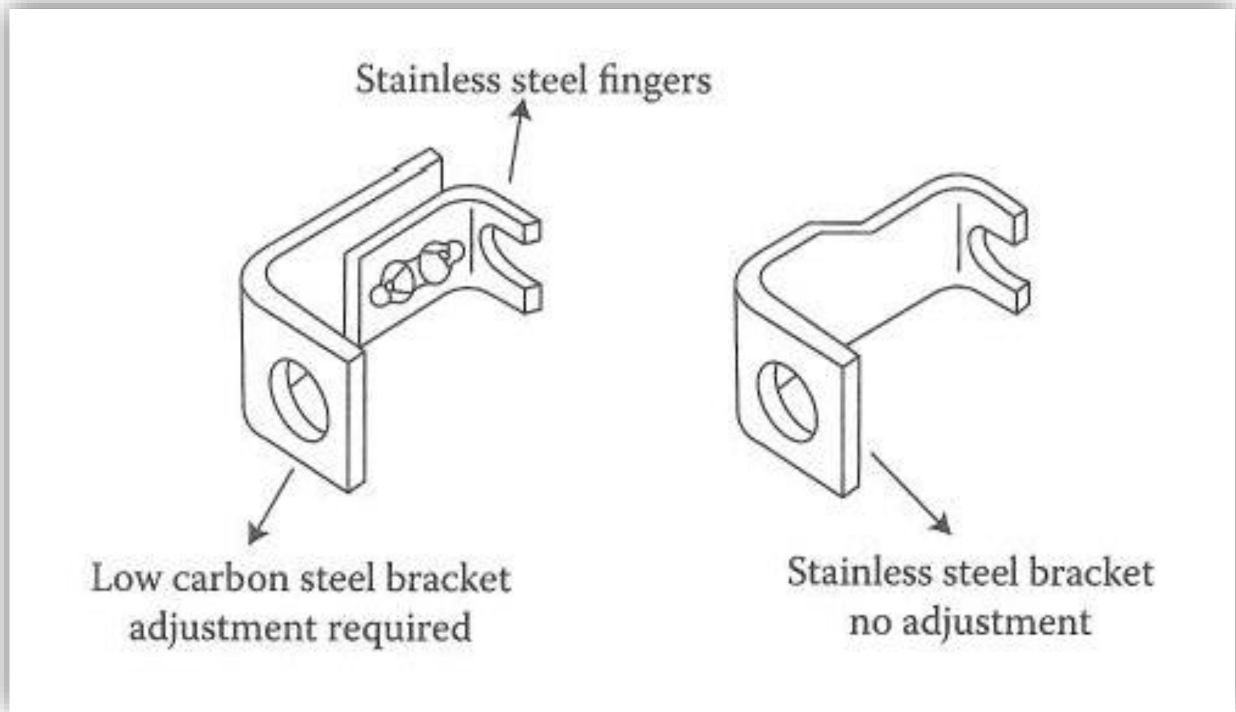
Further Guidelines 2

Design so that access for assembly operations is not restricted



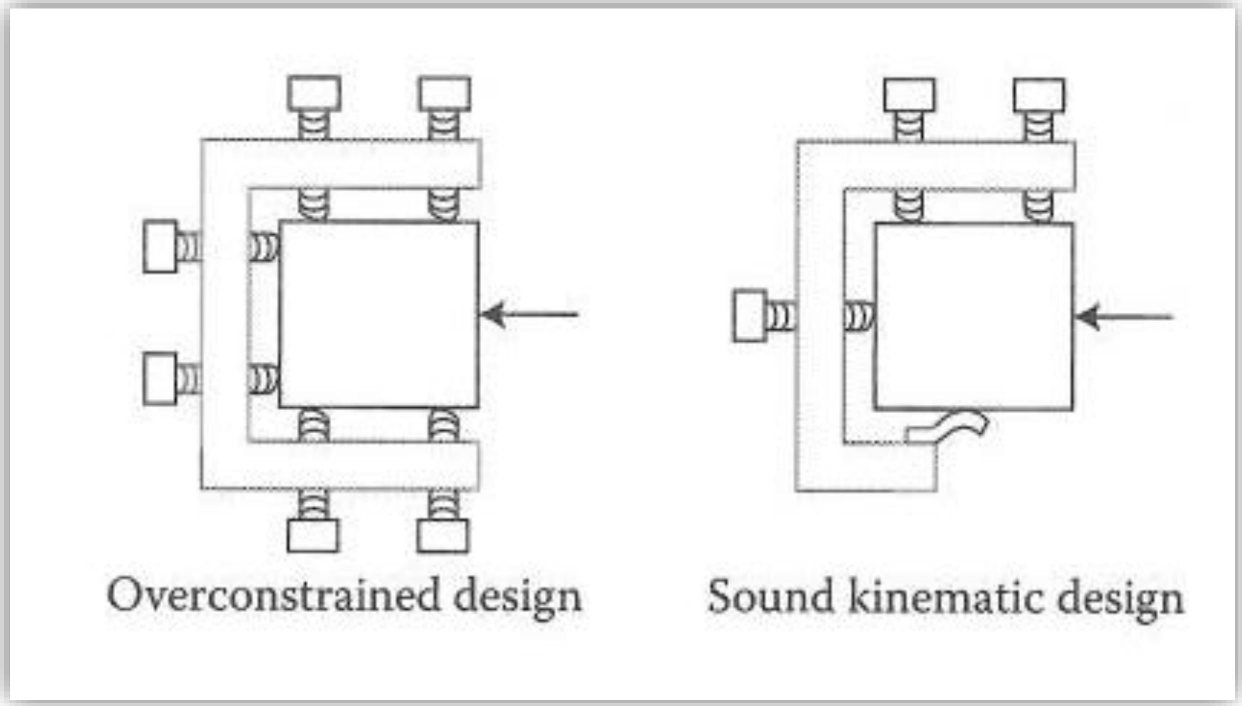
Further Guidelines 3

Avoid adjustments

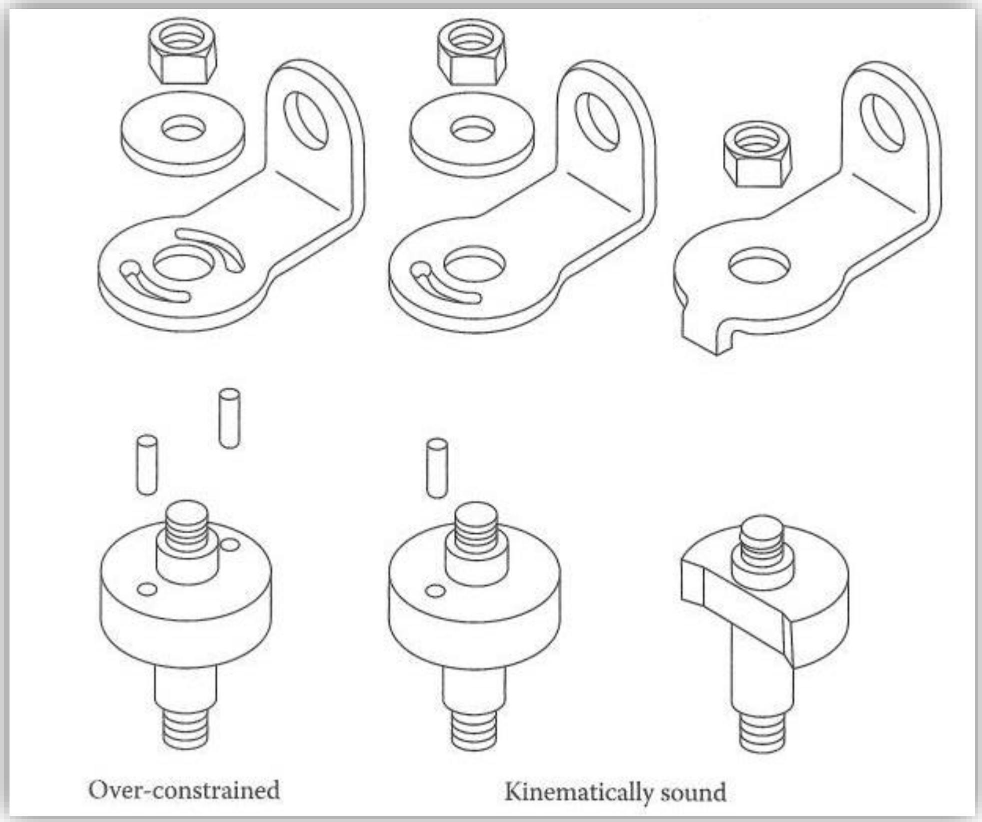


Further Guidelines 4

Use kinematic design principles

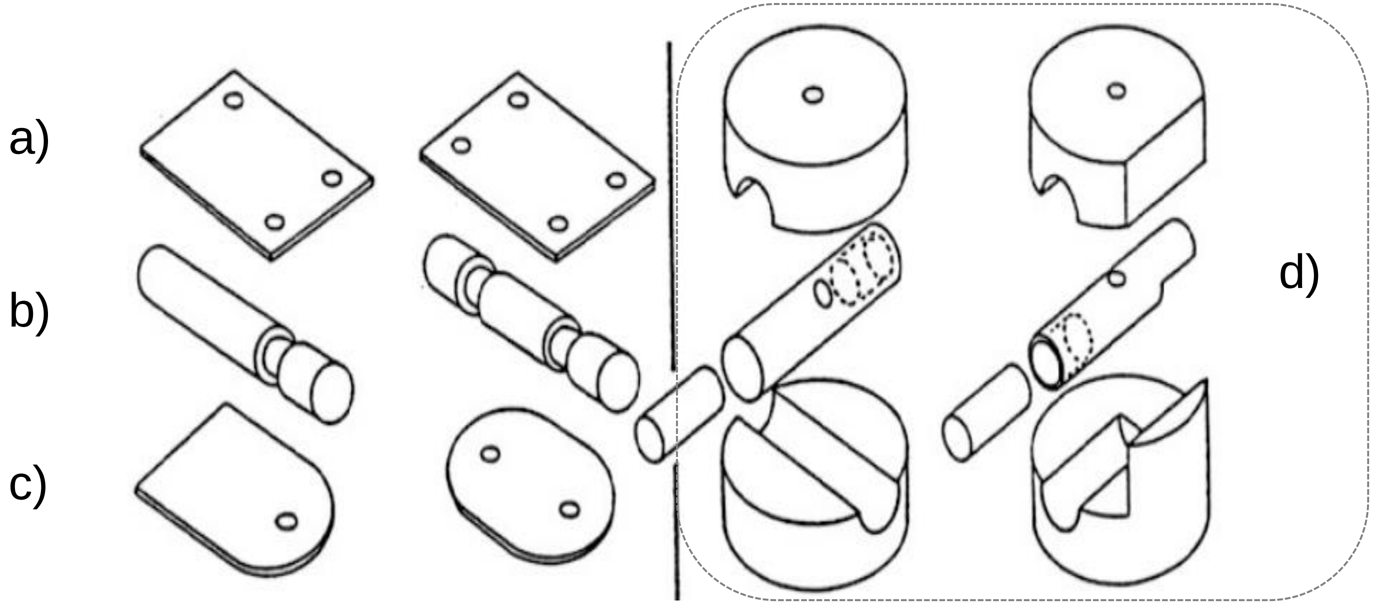


Further Guidelines 4



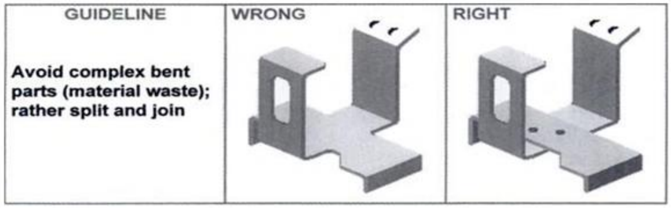
Quiz... again

- Question: which one are the best among the couples of part of the one down here and why?
- Think about it alone or with one of your colleague for some minutes and then I will ask to some of you.



Questions for the formative assessment

1. Explain why the right design in the following guideline is not so right

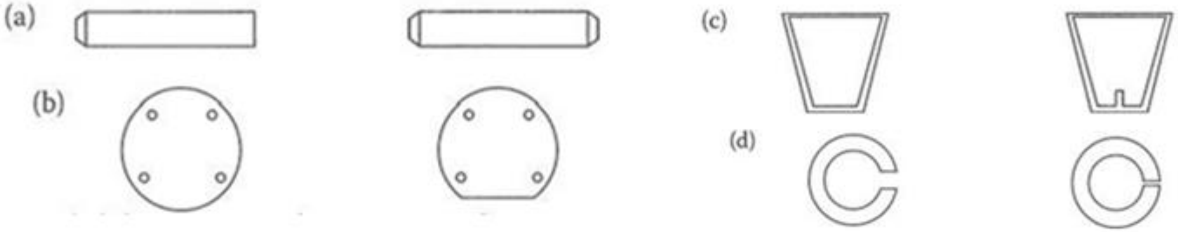


2. Report and discuss the rationale behind the three questions that allows to calculate the Nmin of part in Boothroyd methodology.

3. Define all the term of the following equation:

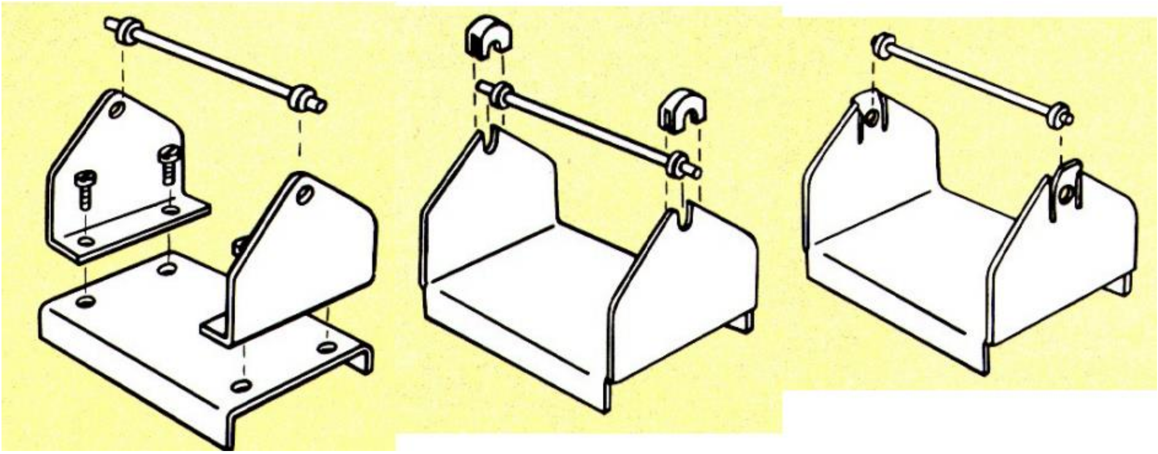
$$E_{ma} = \frac{N_{min} t_a}{t_{ma}}$$

4. Discuss the following design guidelines: which column is best for assembly and why do such solutions improve the assembly efficiency?



Questions for the formative assessment

5. List and describe the possible uses of DFA
6. List and describe the benefit of applying DFA
7. List and describe the problems connected with the use of DFA
8. Which one of the following design solution is better from the assembly perspective and why.



Tutorial 1 and exercise:

Boothroyd method for Design for manual assembly

Manual Vs. Automatic

Human are flexible and sensitive:

- Turning the assembly over
- Determining if a part is suitable for use

Machines are quick and reliable:

- Picking up little parts
- Handling hazardous parts
- Placing integrated circuits with a few μm tolerance at a rate of 6 per second
- Tighting fasteners at an exact torque everytime

Automatic Assembly

- Automatic handling is usually the bigger problem in applying automation for the assembly process: design must focus on feeding and orienting components rather than simply inserting
- Automation forces to product redesign: savings resulting from product redesign often outweigh those resulting from automation

DFA and Automatic Assembly 1

DFA is vital in the domain of automatic assembly

- In manual Assembly DFA targets timing of the basic operation.
- In automatic assembly the time taken to complete the assembly does not control the cost. Rather, it is the cycle rate of the assembly system.

Relevant parameters for the overall analysis:

- Cost of the equipment
- Personnel cost (directly connected with the system)
- Nominal assembly rate of the system (included down-time)

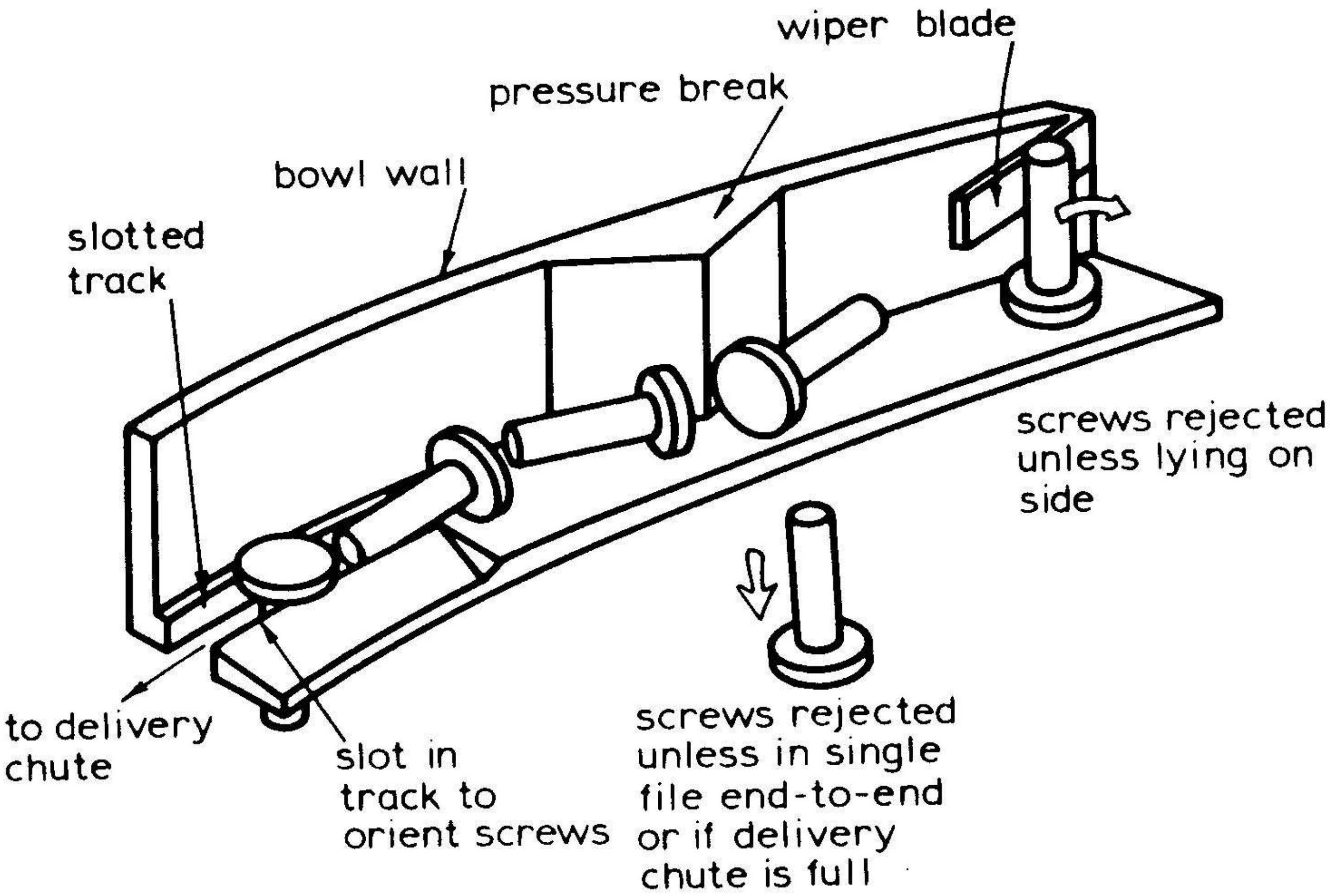
DFA and Automatic Assembly 2

Relevant parameters for the punctual analysis on single parts:

Cost of feeding
Cost of orienting
→ **Industrial Feeders**

Cost of insertion
→ **Workheads**

Automatic Feeding



Feeding and Orienting 1

The cost of feeding each part is given by:

$$C_f = \left(\frac{60}{F_r}\right) R_f \text{ cents}$$

Where:

F_r = required delivery rate (parts/min)

R_f = cost (cents/s) of using the feeding equipment

Feeding and Orienting 2

Using a simple payback method we have:

$$R_f = \frac{C_F\, E_0}{5760\, P_b S_n} \text{ cents/s}$$

Where:

C_F = Feeder cost ($)

E_0 = Equipment factory overheads

P_b = payback period (months)

S_n = number of shift per day

5760 = number of available seconds in one shift working for a month divided by 10
convert dollars in cents

Feeding and Orienting 3

Assuming:

$C_F = 5.000$ \$

$E_0 = 2$ (factory overheads = 100%)

$P_b = 30$ months

$S_n = 2$ shifts per day

$$R_f = \frac{5000*2}{5760*30*2} = 0{,}03 \text{ cents/s}$$

Feeding and Orienting 4

The cost of feeding each part is therfore:

$$C_f = 0.03\left(\frac{60}{F_r}\right)C_r \text{ cents}$$

Where:

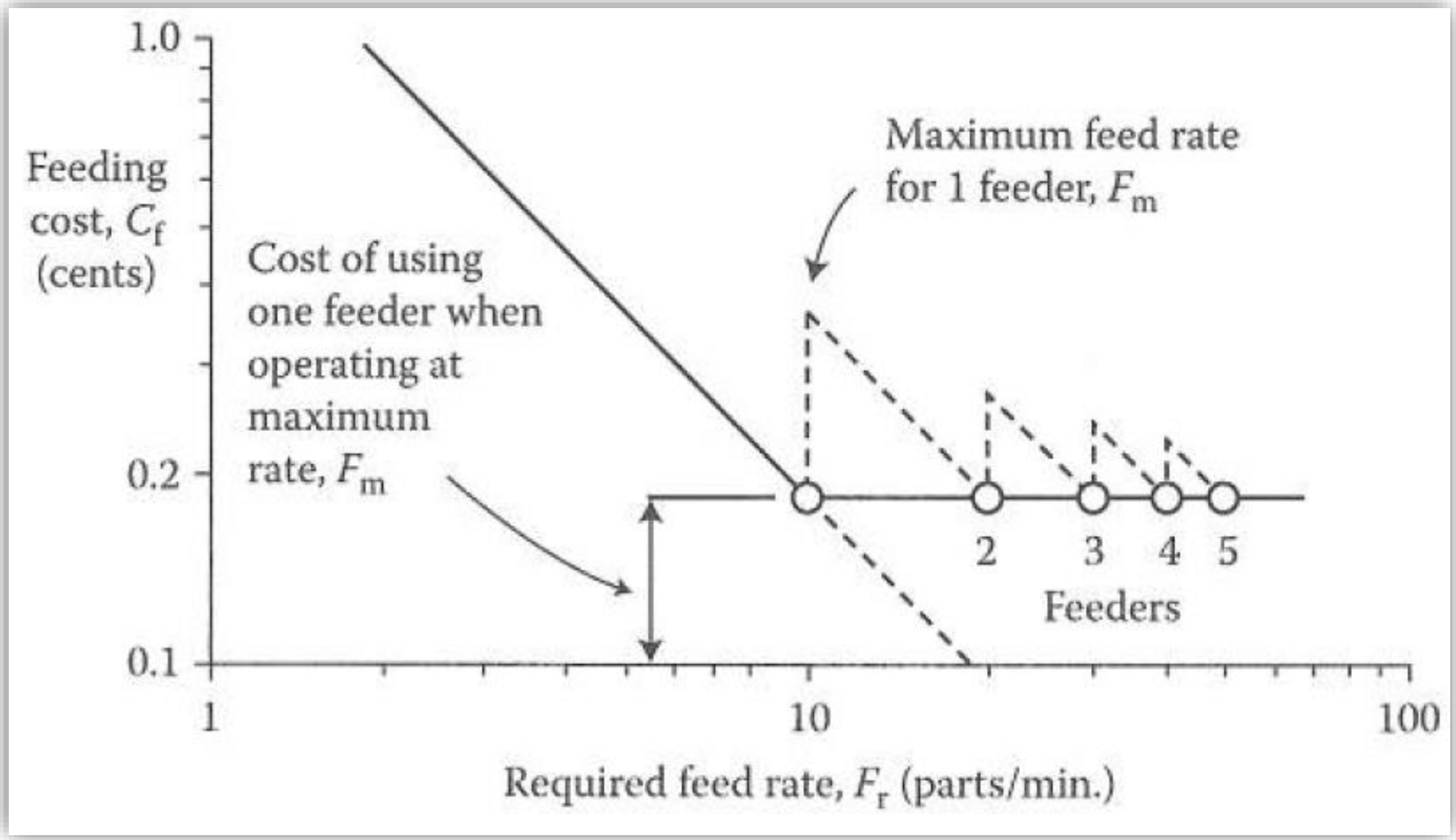
$C_r =$ relative cost factor to any feeder in consideration (function of the complexity of the part: see related table)

Feeding and Orienting 5

Conclusion:

- The higher the required feeding rate the lower the cost of automatic feeding: i.e. a machine that cycle in 6s has an associated cost that is double compared to a machine that cycle in 3s
- The more expensive the equipment the higher the cost of automatic feeding

Feeding and Orienting 6



Feeding and Orienting 7

The maximum feed rate is given by:

$$F_m = 1500\,\frac{E}{l}\ \text{parts/min}$$

Where:

E = orienting efficiency (from empirically defined tables)

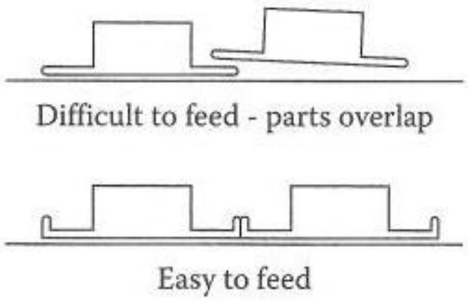
l = part dimension in the direction of feeding

And assuming a feeding speed of 25 mm/s

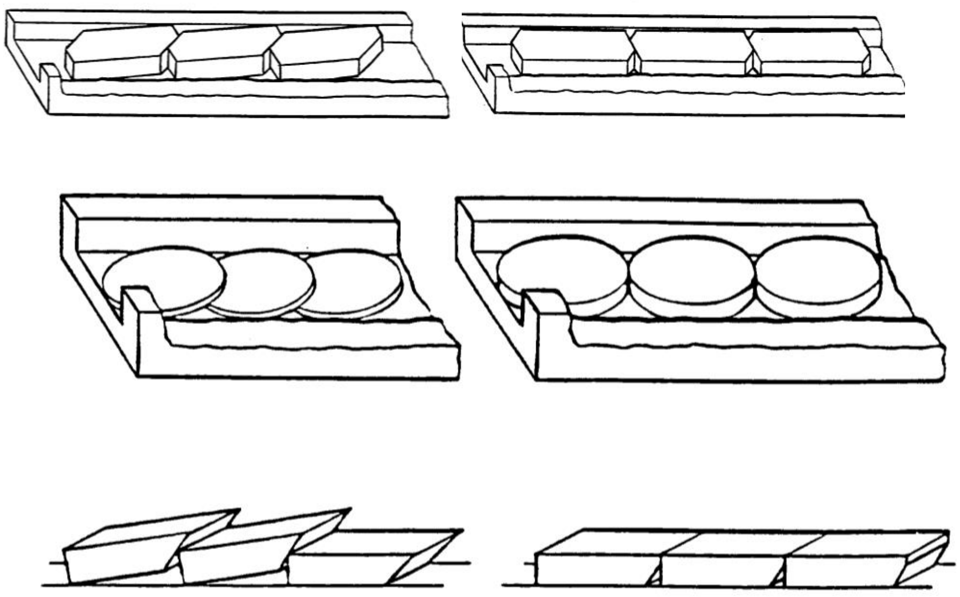
Feeding Difficulties

Problems in feeding might arise because of:

- Shape of the part
  - Thin edges (ovelapping)
  - Tangle
  - Nest
- Size of the part
- Light weight parts
- Sticky parts
- Delicate parts
- Flexible parts
- Abrasive parts



Avoid   Better



Insertion 1

In high speed automatic assembly system insertions are performed through specifically designed workheads. The cost of using such workheads on each part is given by:

$$C_i = \left(\frac{60}{F_r}\right) R_i \text{ cents}$$

Where:

F_r = required delivery rate (parts/min)

R_i = cost (cents/s) of using the workhead

Insertion 2

Using again a simple payback method we have:

$$R_i = \frac{W_c\, E_0}{5760\ P_b S_n}\ \text{cents/s}$$

Where:

W_c = Workhead cost ($)

E_0 = Equipment factory overheads

P_b = payback period (months)

S_n = number of shift per day

5760 = number of available seconds in one shift working for a month divided by 100
convert dollars in cents

Insertion 3

Assuming:

$W_c = 10.000\ \$$

$E_0 = 2$ (factory overheads = 100%)

$P_b = 30$ months

$S_n = 2$ shifts per day

$$R_i = \frac{10000*2}{5760*30*2} = 0{,}06 \text{ cents/s}$$

Insertion 4

The cost of feeding each part is therfore:

$$C_i = 0.06\left(\frac{60}{F_r}\right)W_r$$

Where:

W_r = relative cost factor to any workhead in consideration (function of the complexity of the process: see related table)

Nominal Assembly Rate

The required rate of output of the system. It is determined by:

- Required volumes
- Number of working days in a year
- Number of shifts
- Minutes in a working shift

Nominal Assembly Rate

A simplified expression for it is given by:

$$F_r = \frac{V_r}{T_a}$$

Where:

$V_r =$ required Volumes per year

$T_a =$ available minutes per year

$$T_a = 480 D_w S_n$$

$D_w =$ working days per year

$S_n =$ working shifts per day

480 = minutes in a shift

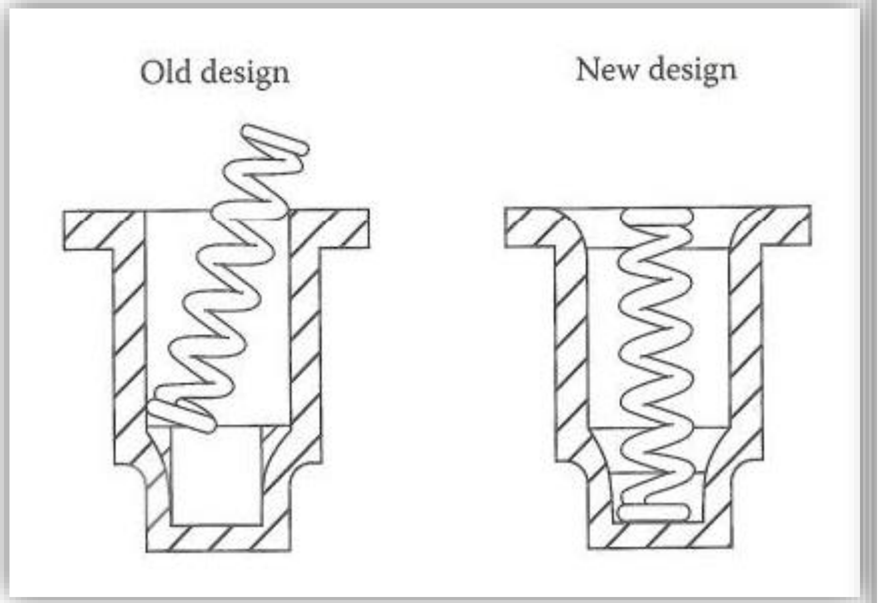
Design Guidelines for Automatic Assembly

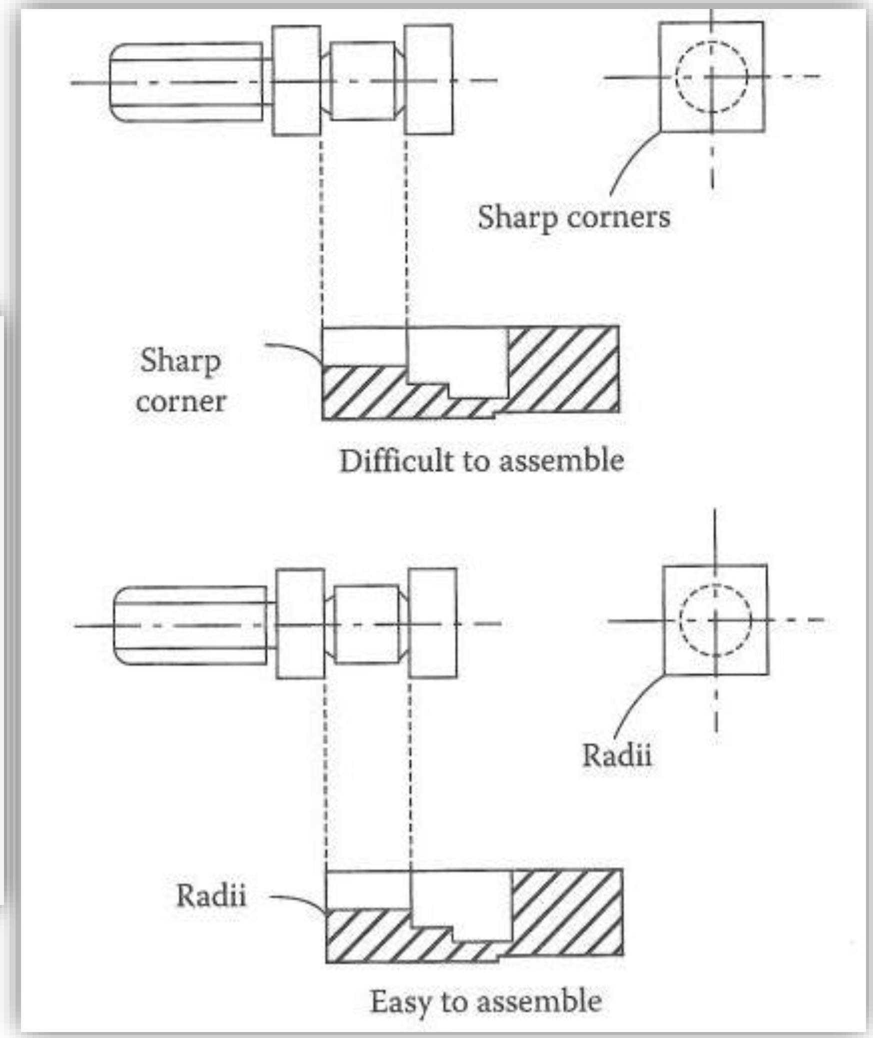
Part reduction is even more important in automatic assembly as each part requires:

- Feeder
- Workhead
- Portion of the transfer device

Design Guidelines for Automatic Assembly

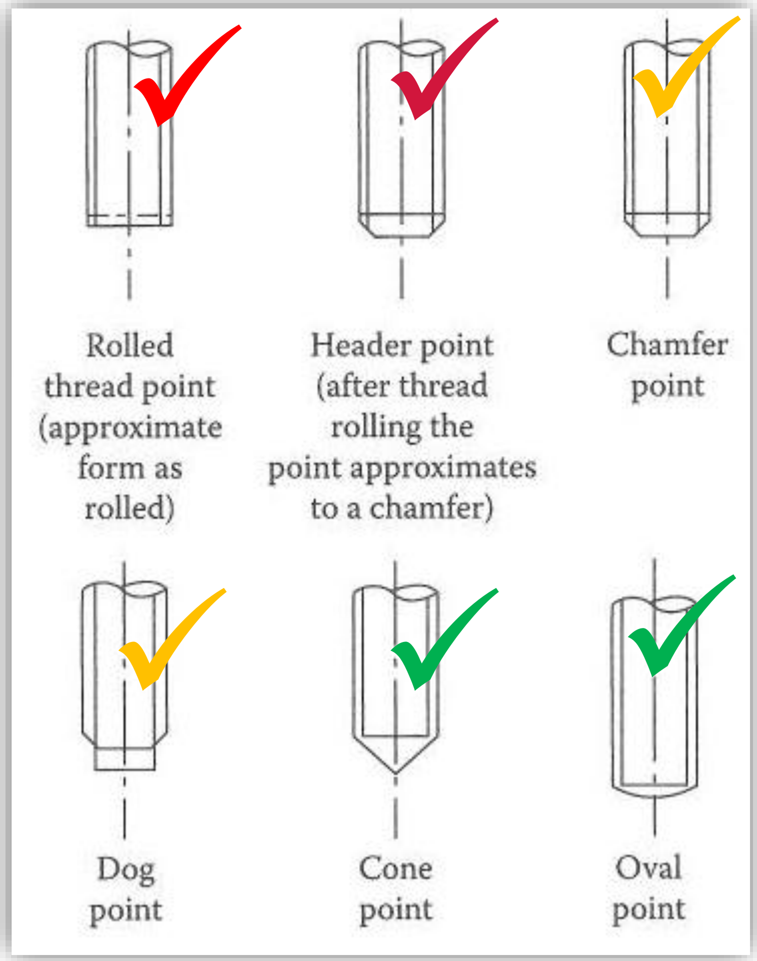
Chamfer and guides





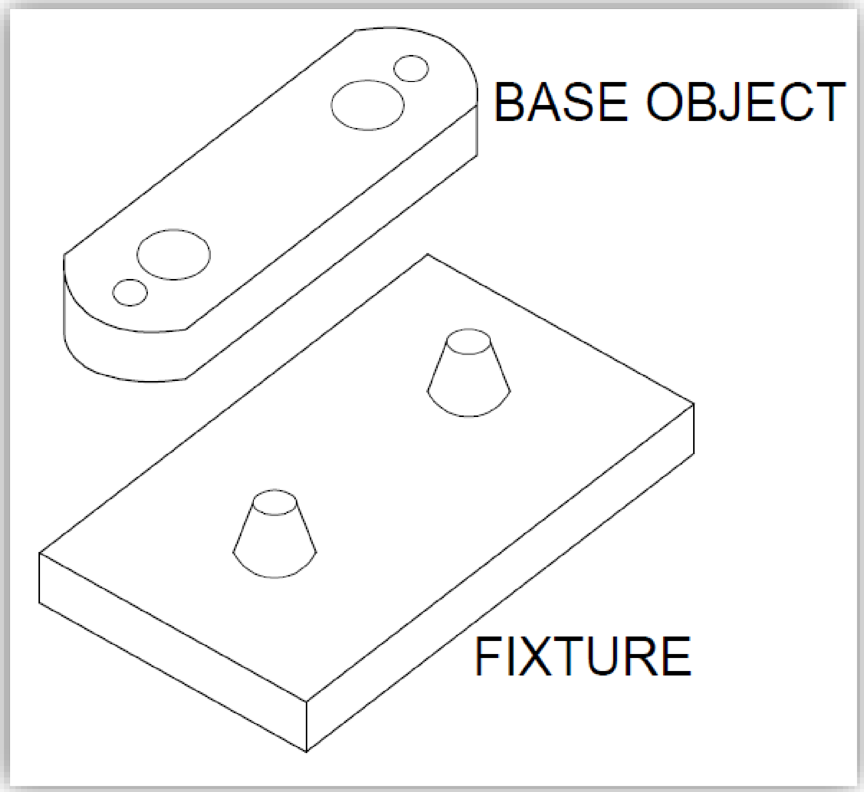
Design Guidelines for Automatic Assembly

Self centralizing screws

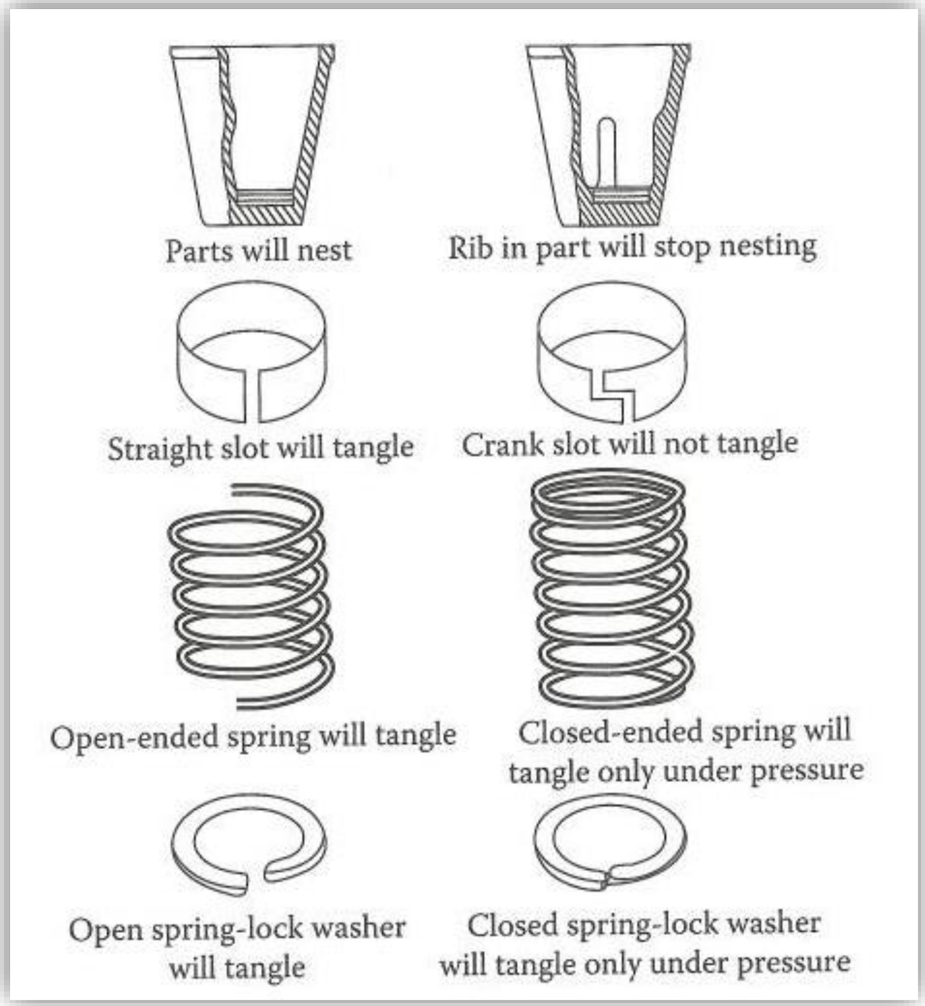


Design Guidelines for Automatic Assembly

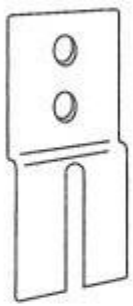
Automatic assembly requires always a base object on which the assembly can be built. Suche base object should be designed for a for a quick and accurate location on the work carrier



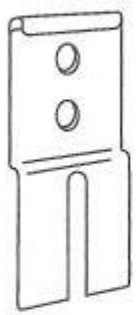
Design Guidelines for Feeding and Orienting



Design Guidelines for Feeding and Orienting

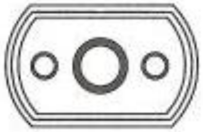


No feature sufficiently significant for orientation

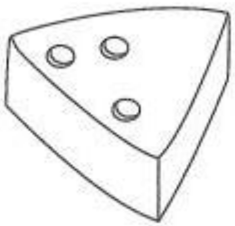


When correctly oriented will hang from rail

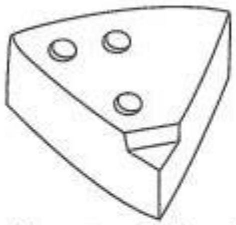
Difficult to orient with respect to small holes



Flats on the sides make it much easier to orient with respect to small holes

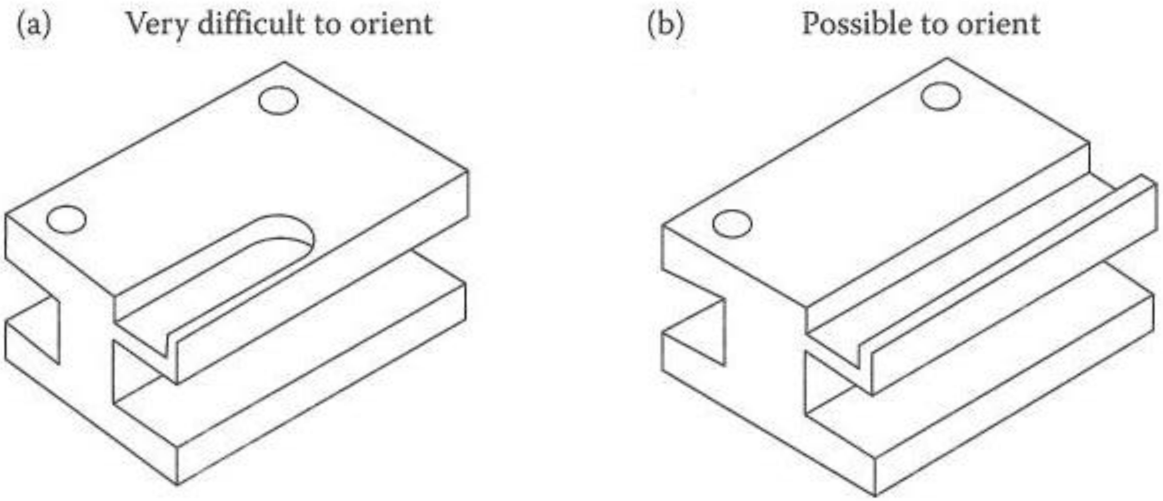


Triangular shape of part makes automatic hole orientation difficult



Nonfunctional shoulder permits proper orientation to be established in a vibrant feeder and maintained in transport rails

Design Guidelines for Feeding and Orienting



Because it has a Through Groove!!!

Design Guidelines for Product Design

- If possible design the product so that it can be built in layers, each part being assembled from above.
- Avoid expensive and time-consuming fastening operations such as screws and soldering
- Avoid shapes that allow the part to tangle with similar part when placed in bulk in the feeder.
- Makes the part symmetrical, or if not possible exagerate asymmetrical features to facilitate orienting

DFAA

This section is based on a method developed at KTH in 2001 by Dr. **Stephan Eskilander**.

Design for Automatic Assembly

A Method for Product Design: DFA2

DFAA

This method is based on scores and it is articulated in two levels of evaluation:

-Product

-Single Part

and on the following calculation of these indexes:

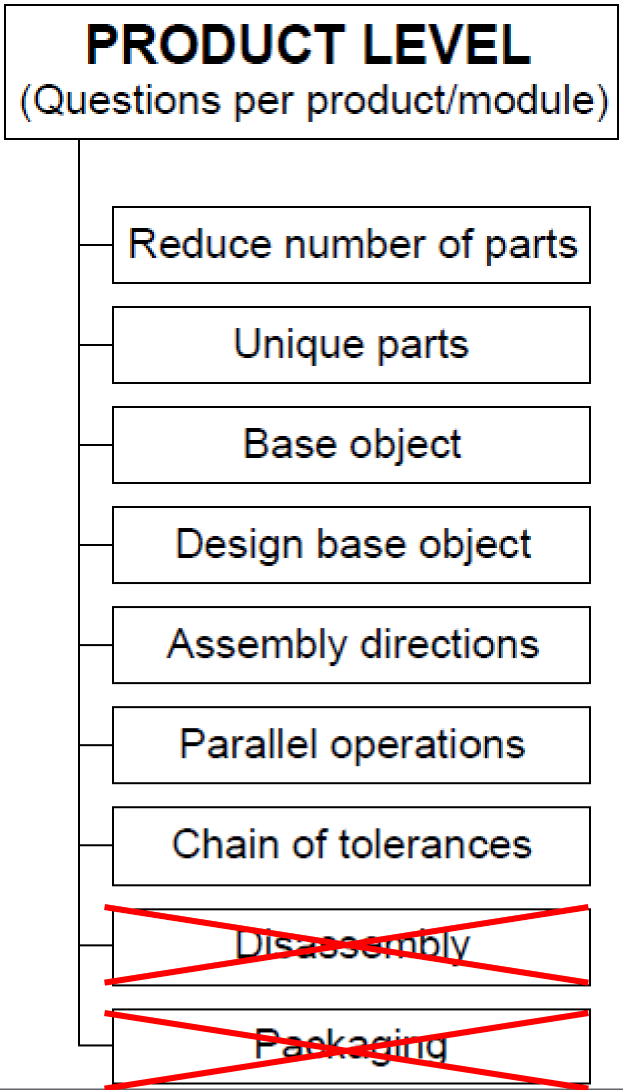
Product level

$$Assembly\ Index = \frac{Total\ sum}{Maximum\ point} = \frac{Score}{63} = \_\_\%$$

Part level

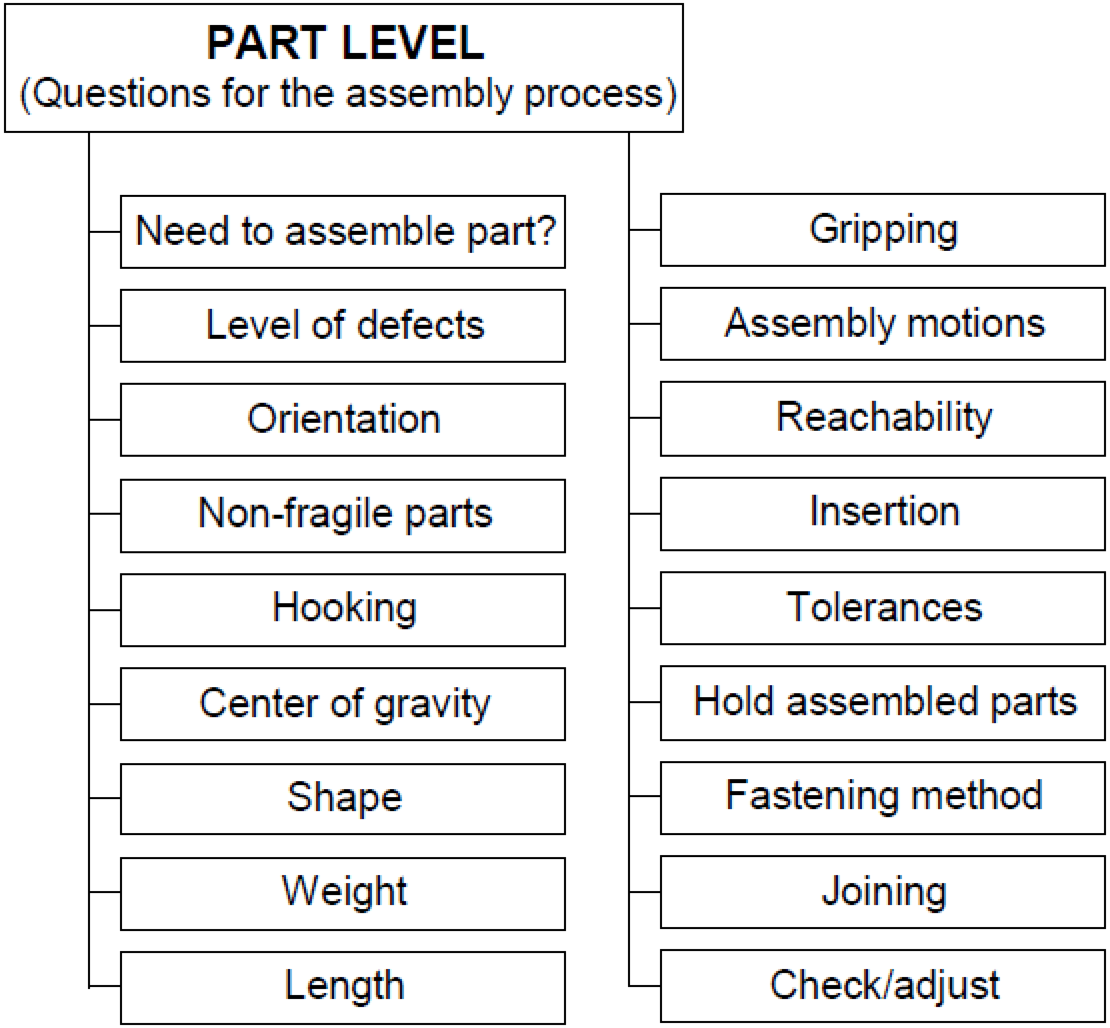
$$Assembly\ Index = \frac{Total\ sum}{Maximum\ point * number\ of\ parts} = \frac{Score}{162 * \_\_} = \_\_\%$$

Product level



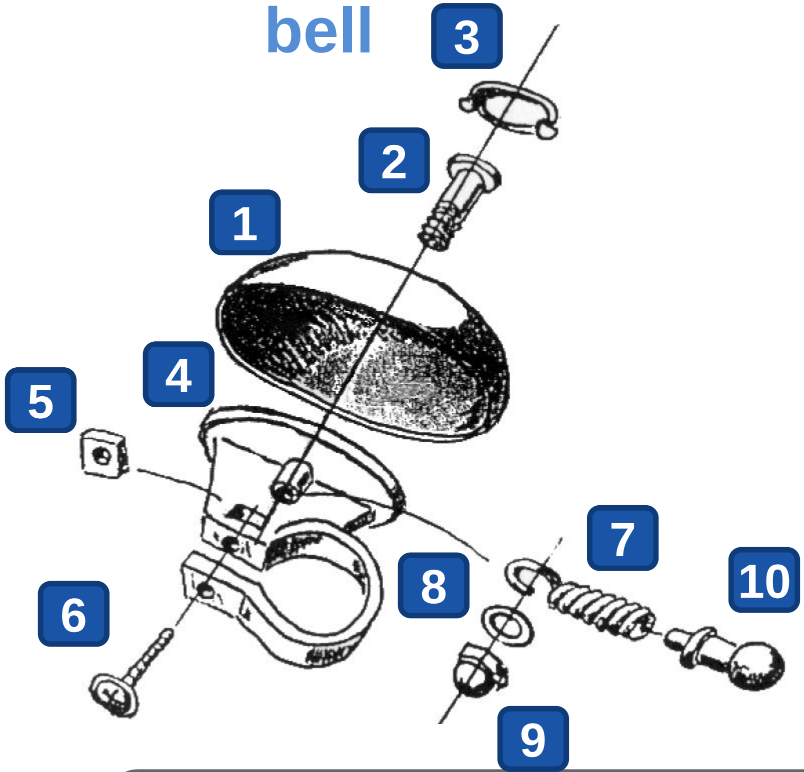
Design for Disassembly including Repair and Recyclying has traditionally been part of DFA. The rise in importance in the last years, due to environmental legislation, has pushed to develop more customized methodologies

Part level


PART LEVEL
(Questions for the assembly process)
Need to assemble part?
Level of defects
Orientation
Non-fragile parts
Hooking
Center of gravity
Shape
Weight
Length
Gripping
Assembly motions
Reachability
Insertion
Tolerances
Hold assembled parts
Fastening method
Joining
Check/adjust

Example of Application

Bicycle bell



ID	Component
1	Metal cupola
2	Long screw
3	Plastic top
4	Base unit
5	Square nut
6	Screw
7	Spring
8	Washer
9	Nut
10	Plastic knob

Product level

PRODUCT LEVEL
(Questions per product/module)

- Reduce number of parts
- Unique parts
- Base object
- Design base object
- Assembly directions
- Parallel operations
- Chain of tolerances
- Disassembly
- Packaging

Product level

Reduce number of parts within each module. Too many parts contribute to large work content within the module.	
Number of parts ≤ 20	9 points
20 < Number of parts ≤30	3 points
Number of parts > 30	1 point

The parts in the bicycle bell are 10 therefore the score we assign is 9

Product level

Proportion of unique parts is the ratio $\frac{\text{Number of unique parts in the object}}{\text{Total number of parts in the object}}$ Use only one type of part where it is possible.	
Proportion of unique parts < 40 %	9 points
40 % ≤ Proportion of unique parts ≤ 70 %	3 points
Proportion of unique parts >70 %	1 point

None of the 10 parts in the bicycle bell is repeated therefore the score we assign is 1

Product level

Base object is a first part that the rest of the assembly can proceed from. All assembly operations are performed on the base object, which leads to simple fixtures and few assembly directions.	
With base object.	9 points
Without base object.	1 point

The part called *base unit* can be used as base object therefore the score we assign is 9

Product level

Design base object for easy fixturing.	
The base object is designed in a way that no further fixture, besides for the base object itself, is needed for the rest of the assembly. The base object does not need repositioning during assembly. One assembly direction.	9 points
Assembling the module requires multiple fixtures that each has only one fixed position. The base object has to be reoriented or transferred between fixtures during assembly.	3 points
Assembling the module requires one or multiple fixtures that have several movable positions. The base object must be transferred between and/or repositioned in the fixtures during assembly.	1 point

The base object needs to be reoriented during the assembly therefore the score we assign is 3

Product level

Assembly directions, totally in the whole product/module	
One assembly direction into a fixed base object.	9 points
Two assembly directions into a fixed base object (alternatively one assembly direction in a movable base object with two different fixed positions).	3 points
Three or more assembly directions into a fixed base object (alternatively assembly in a movable base object with several different fixed positions).	1 point

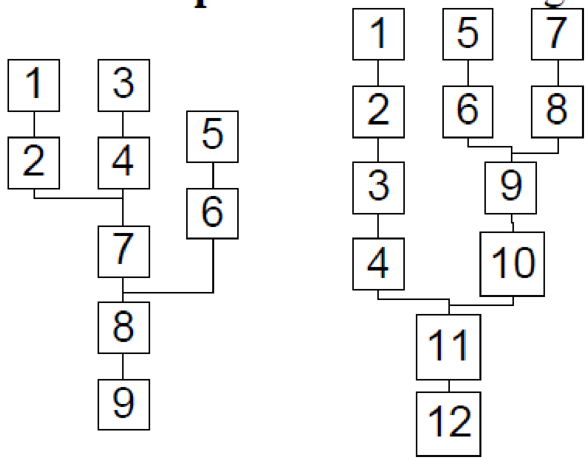
The Assembly requires more than three assembly directions in a multi positioned base object therefore the score we assign is 1

Assembly Directions

The product should be structured to ensure that all assembly operations occur from one direction, preferably from above (also called hamburger assembly, pyramid assembly or sanwitch assembly).

Product level

Parallel operations according to the following example:



The assembly sequence to the left has $\frac{7}{9}$ parallel operations;

the sequence to the right has $\frac{10}{12}$ parallel operations.

> 50 % parallel operations	9 points
0 % < parallel operations ≤ 50 %	3 points
No parallel operations.	1 point

Product level

The assembly process can be largely been carried on in parallel therefore the score we assign is 9

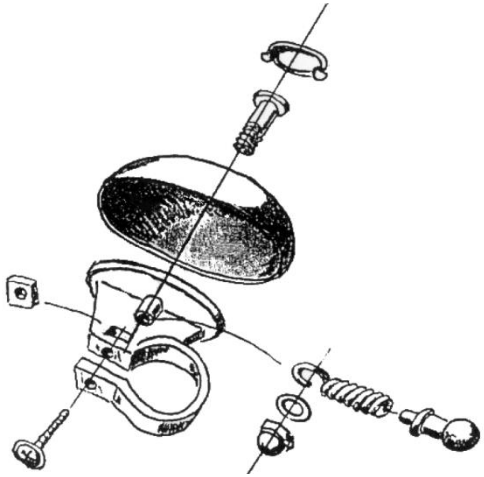
Product level

Chains of tolerances should be minimised to have a more reliable assembly process.	
No chains of tolerances significant for the assembly process. Only the tolerance of each individual part is significant.	9 points
There are chains of two tolerances significant for the assembly process in the module.	3 points
There are chains of three or more tolerances significant for the assembly process in the module.	1 point

The assembly requires correct relative positioning of subsets screw-nut, therefore the score we assign is 3

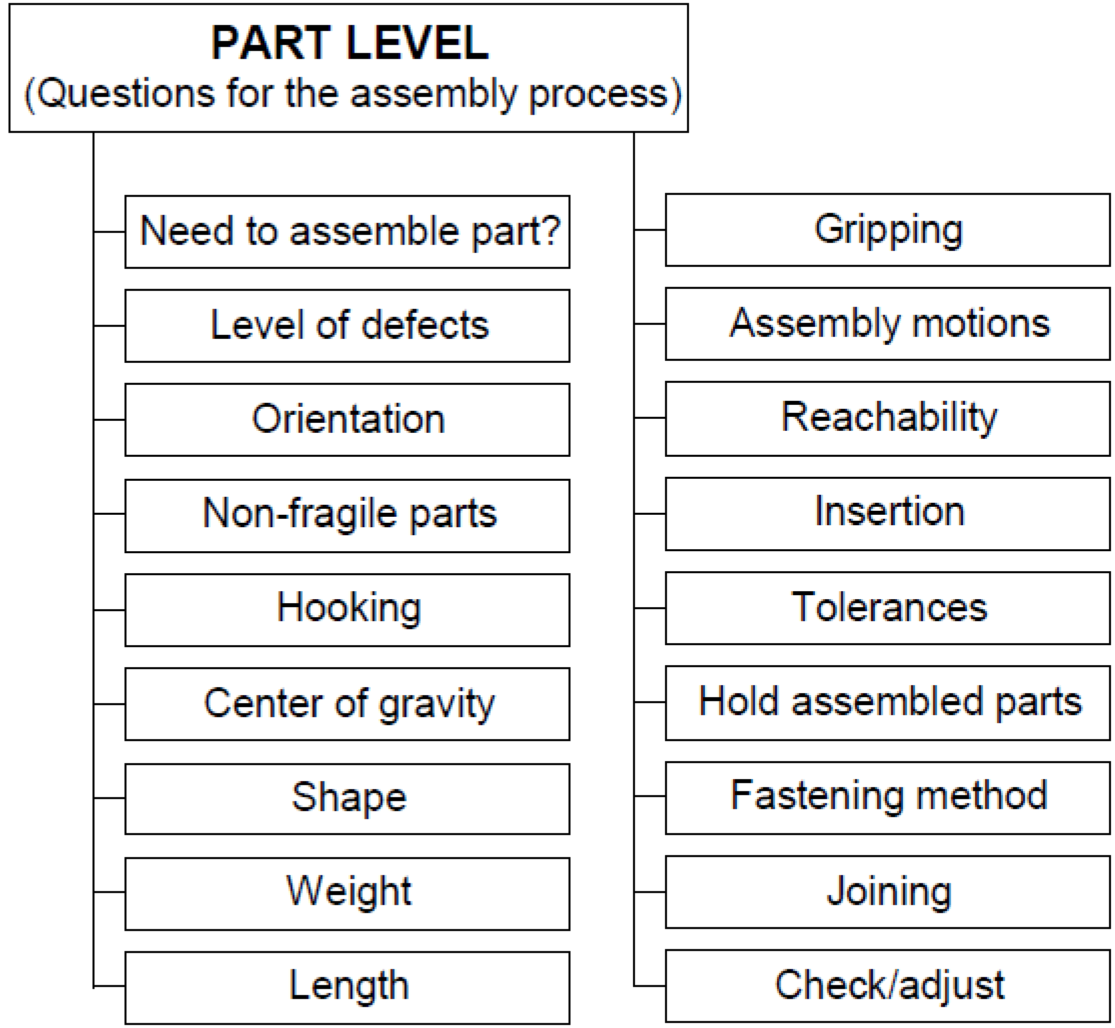
Summary: product level

PRODUCT LEVEL							
Reduce number of parts	Unique parts	Base object	Design base object	Assembly directions	Parallel operations	Chain of tolerances	**SUM**
9	1	9	3	1	9	3	35



$$Assembly\ Index = \frac{Total\ sum}{Maximum\ point} = \frac{35}{63} \approx 56\%$$

Part level


PART LEVEL
(Questions for the assembly process)
Need to assemble part?
Level of defects
Orientation
Non-fragile parts
Hooking
Center of gravity
Shape
Weight
Length
Gripping
Assembly motions
Reachability
Insertion
Tolerances
Hold assembled parts
Fastening method
Joining
Check/adjust

Part level

Questions:

1. Does the part move, relative to other already assembled parts during normal use of the finished product?
2. Does the part has to be of other material than already assembled parts, or isolated from them?
3. Does the part has to be separate from already assembled parts because assembly or disassembly otherwise is impossible?

Part level

The first part in an assembly should be a base object and must by definition exist. Thereby, the base object is the teaget of comparison for part number two regarding questions one and two

Part level

Need to assemble parts? The questions described above have to be answered for evaluation. A part that does not perform a relative motion has to be of another material or must be separated in order for assembly/disassembly reasons to be eliminated or integrated.	
The part has reasons for being separate (at least one ”yes” to the three questions)	9 points
The part should be eliminated/integrated (all three questions answered with ”no”) but the part is still a separate part in the product.	1 point

Need to assemble part?

ID	Component	Score
1	Metal cupola	9
2	Long screw	1
3	Plastic top	1
4	Base unit	9
5	Square nut	1
6	Screw	1
7	Spring	9
8	Washer	1
9	Nut	1
10	Plastic knob	1

Begin

Converts the energy from the the spring in sound

Supports the mechanism spring-cupola and provide connection with the bicycle

Transfers and focuses the energy of the user to the cupola

Part level

Level of defects of parts that are to be assembled. Geometric defects that might cause unscheduled stops in an automatic assembly system should be avoided, or parts with functional defects.	
P < 0,1 %	9 points
0,1 % ≤ P ≤ 1,5 %	3 points
P > 1,5 %	1 point

Level of defects

ID	Component	Score
1	Metal cupola	3
2	Long screw	9
3	Plastic top	3
4	Base unit	3
5	Square nut	9
6	Screw	9
7	Spring	1
8	Washer	9
9	Nut	9
10	Plastic knob	3

9 for the consumables
3 for customized parts
1 for the spring
(shape, material issues)

Part level

Orientation. If a part could be delivered oriented, cost and uncertainty in the process would be eliminated.	
No need for re-orientation of the part	9 points
Part is partly orientated, but needs final orientation	3 points
Part orientation needs to be re-created.	1 points

Orientation

- From correct design: shape and center of gravity
- From the supplier: they have the part exactly orientated during the manufacturing process!!

Orientation

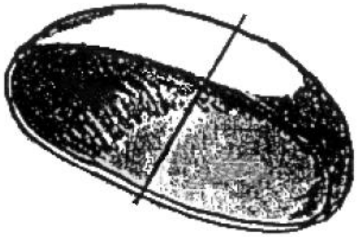
ID	Component	Score
1	Metal cupola	1
2	Long screw	1
3	Plastic top	1
4	Base unit	1
5	Square nut	1
6	Screw	1
7	Spring	1
8	Washer	1
9	Nut	1
10	Plastic knob	1

Part level

Feeding often requires **non-fragile parts**	
Part is not fragile	9 points
Part can be scratched, which is not acceptable.	3 points
Parts can not fall without deforming	1 point

Non-fragile parts

ID	Component	Score
1	Metal cupola	9
2	Long screw	9
3	Plastic top	9
4	Base unit	9
5	Square nut	9
6	Screw	9
7	Spring	9
8	Washer	9
9	Nut	9
10	Plastic knob	9



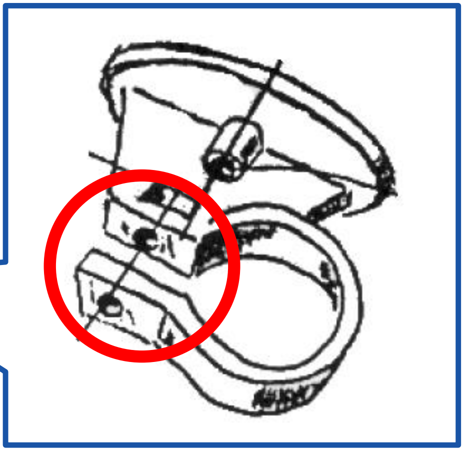
The metal cupola affects the estetic

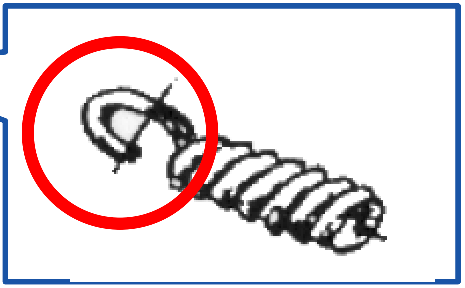
Part level

State during feeding, hooking: There should be no risk of parts hooking into each other for example in a bulk vibration feeder.		**Man. ref. time**
Parts cannot hook to each other and tangle up.	9 points	0 s
Parts can hook to each other and tangle up.	1 point	0,7 s

State during feeding: hooking

ID	Component	Score
1	Metal cupola	9
2	Long screw	9
3	Plastic top	9
4	Base unit	1
5	Square nut	9
6	Screw	9
7	Spring	1
8	Washer	9
9	Nut	9
10	Plastic knob	9





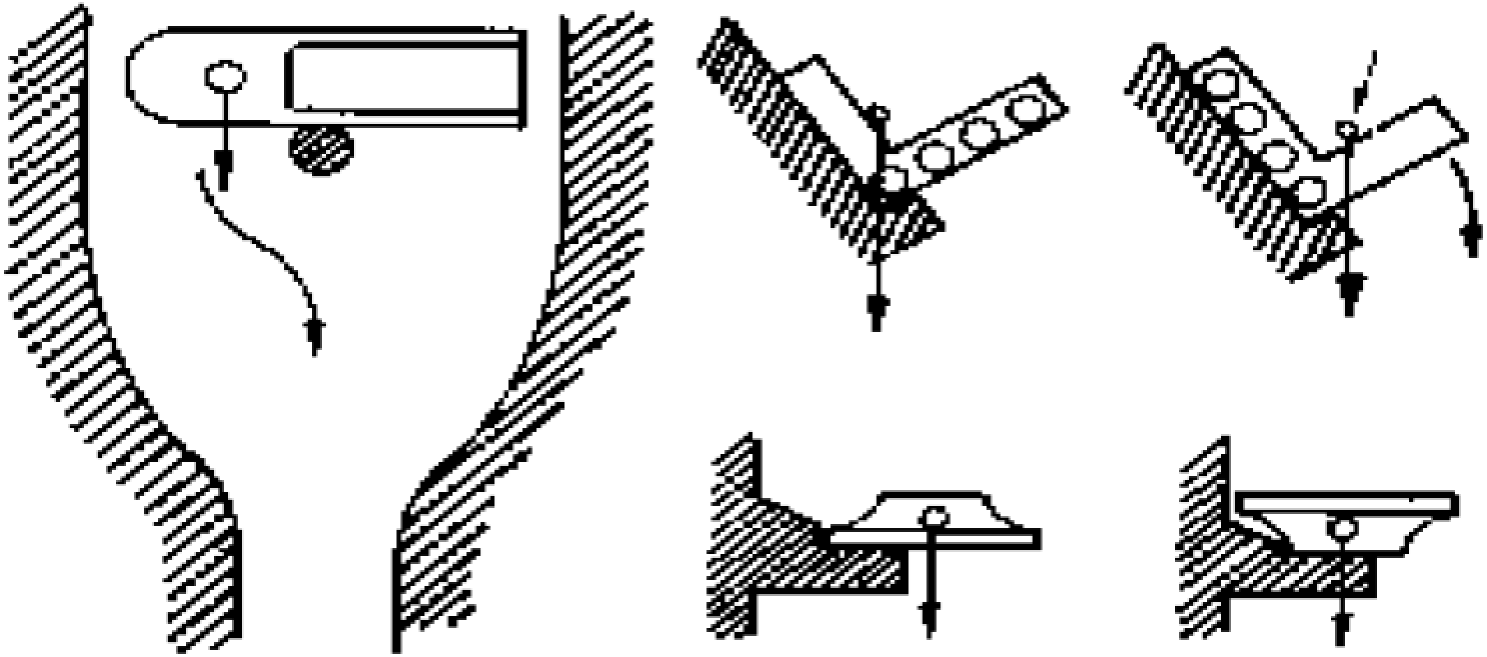
Part level

Centre of gravity for the part should be positioned for use in feeding. Drop the part repeatedly on a table to determine its state of rest. Simple orientation often means reliable and cost effective feeding.	
Part has a stable state of rest and orients itself with correct side upwards.	9 points
Part has a stable state of rest, but orients itself with wrong side upwards.	3 points
Part has an unstable state of rest and orients itself with different sides upwards.	1 point

Center of gravity

ID	Component	Score
1	Metal cupola	3
2	Long screw	9
3	Plastic top	3
4	Base unit	1
5	Square nut	9
6	Screw	9
7	Spring	1
8	Washer	9
9	Nut	1
10	Plastic knob	9

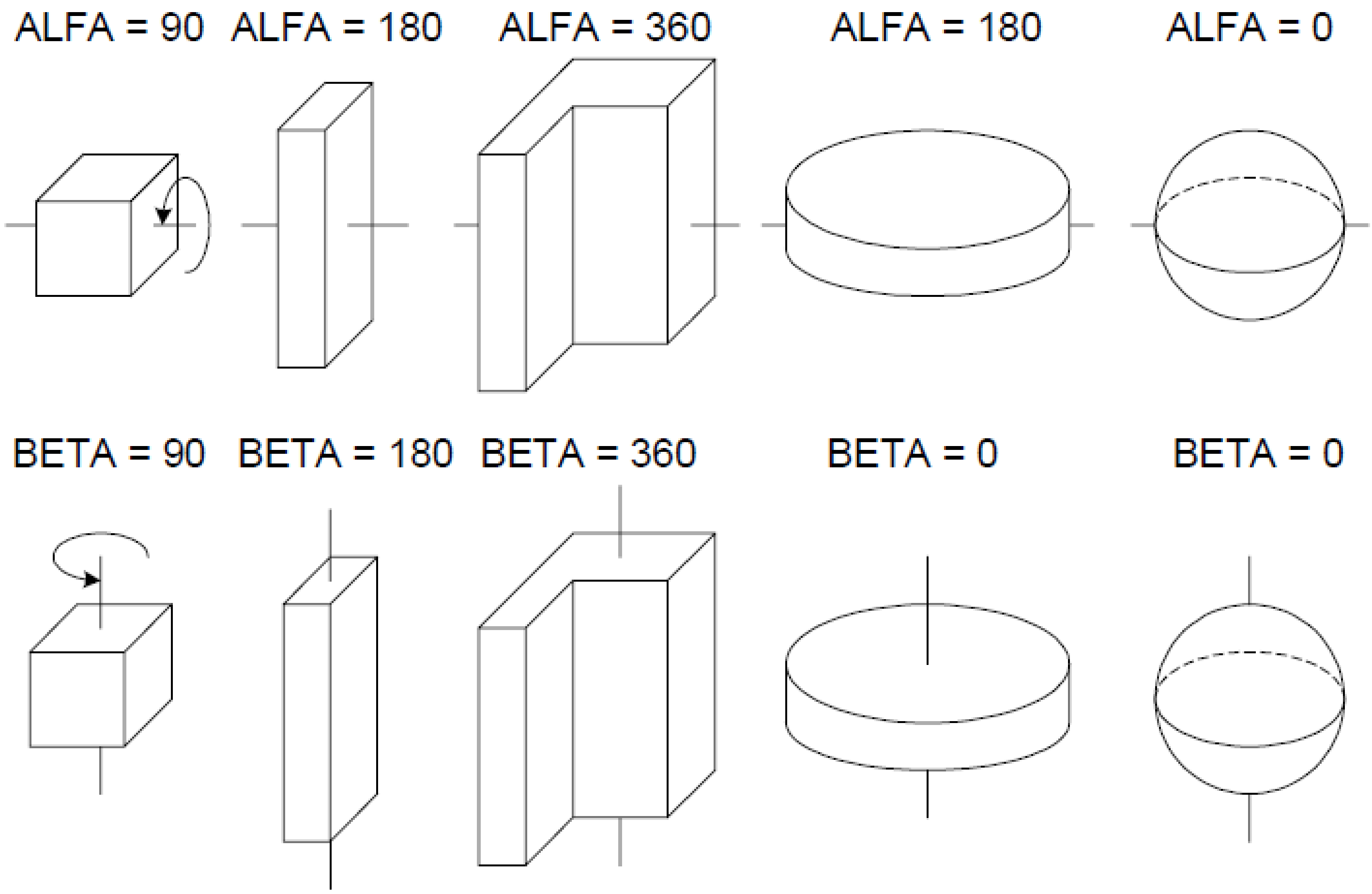
Automatic Feeding: use of center of gravity



Part level

Shape of a part is the sum of α- and β-symmetry. Symmetrical parts decrease the need for unique orientation.		**Man. ref. time**
$\alpha + \beta < 360$	9 points	0 s
$360 \leq \alpha + \beta < 540$	3 points	0,6 s
$540 \leq \alpha + \beta \leq 720$	1 point	0,9 s

Shape


ALFA = 90
ALFA = 180
ALFA = 360
ALFA = 180
ALFA = 0
BETA = 90
BETA = 180
BETA = 360
BETA = 0
BETA = 0

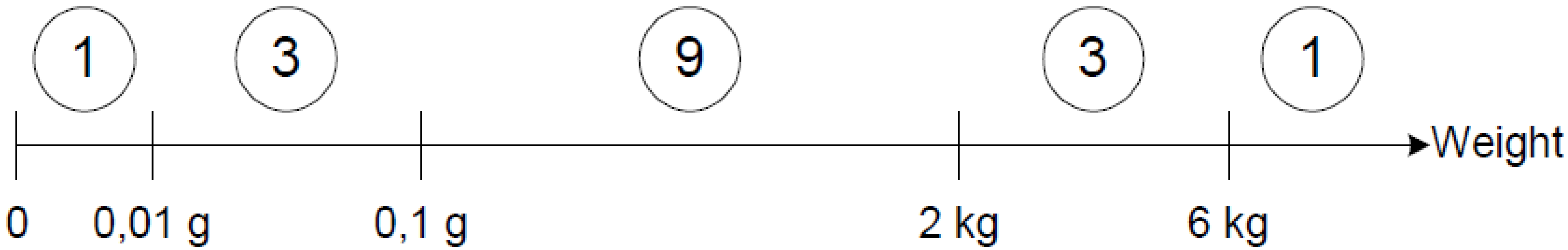
Shape

ID	Component	Score
1	Metal cupola	3
2	Long screw	3
3	Plastic top	3
4	Base unit	1
5	Square nut	9
6	Screw	3
7	Spring	1
8	Washer	9
9	Nut	3
10	Plastic knob	3

Part level

Weight, of the part. This affects the choice of equipment.		**Man. ref. time**
0,1 g ≤ G ≤ 2 kg	9 points	0 s
0,01 g ≤ G < 0,1 g or 2 kg < G ≤ 6 kg	3 points	1,5 s
G < 0,01 g or G > 6 kg	1 point	3 s

See Fig 64 for a graphical representation of the evaluation criterion.



Weight

Heavy parts:

- Needs for larger and stiffer equipment
- Risk connected with impact stress

Light parts:

- Lower handling and fitting time
- Cheaper equipment

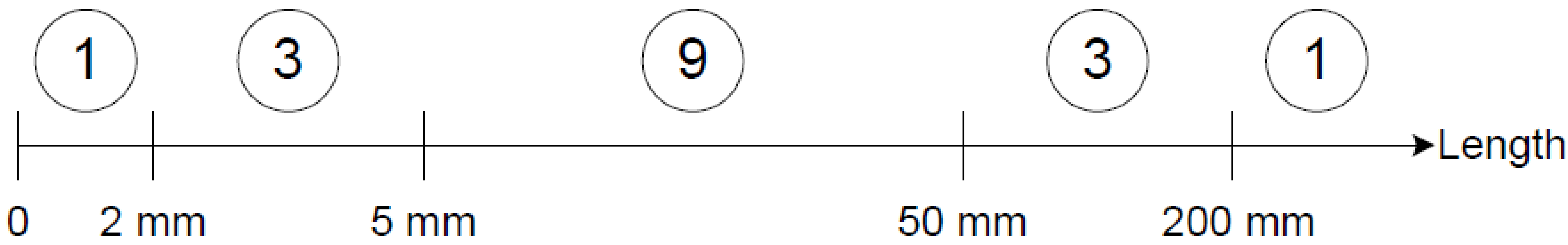
However, with too low a weigh there might be problems with adhesion forces!!!

Weight

ID	Component	Score
1	Metal cupola	9
2	Long screw	9
3	Plastic top	9
4	Base unit	9
5	Square nut	9
6	Screw	9
7	Spring	9
8	Washer	9
9	Nut	9
10	Plastic knob	9

Part level

Length. The length of a part is the longest side of an enclosing prism. This affects the choice of equipment.		**Man. ref. time**
5 mm ≤ L ≤ 50 mm	9 points	0 s
2 mm ≤ L < 5 mm or 50 mm < L ≤ 200 mm	3 points	0,7 s
L < 2 mm or L > 200 mm	1 point	1,2 s



Length

Long parts:

- Needs for larger or special equipment

Short parts:

- Difficulties in handling them

Length

ID	Component	Score
1	Metal cupola	9
2	Long screw	9
3	Plastic top	9
4	Base unit	9
5	Square nut	9
6	Screw	9
7	Spring	9
8	Washer	9
9	Nut	9
10	Plastic knob	9

Part level

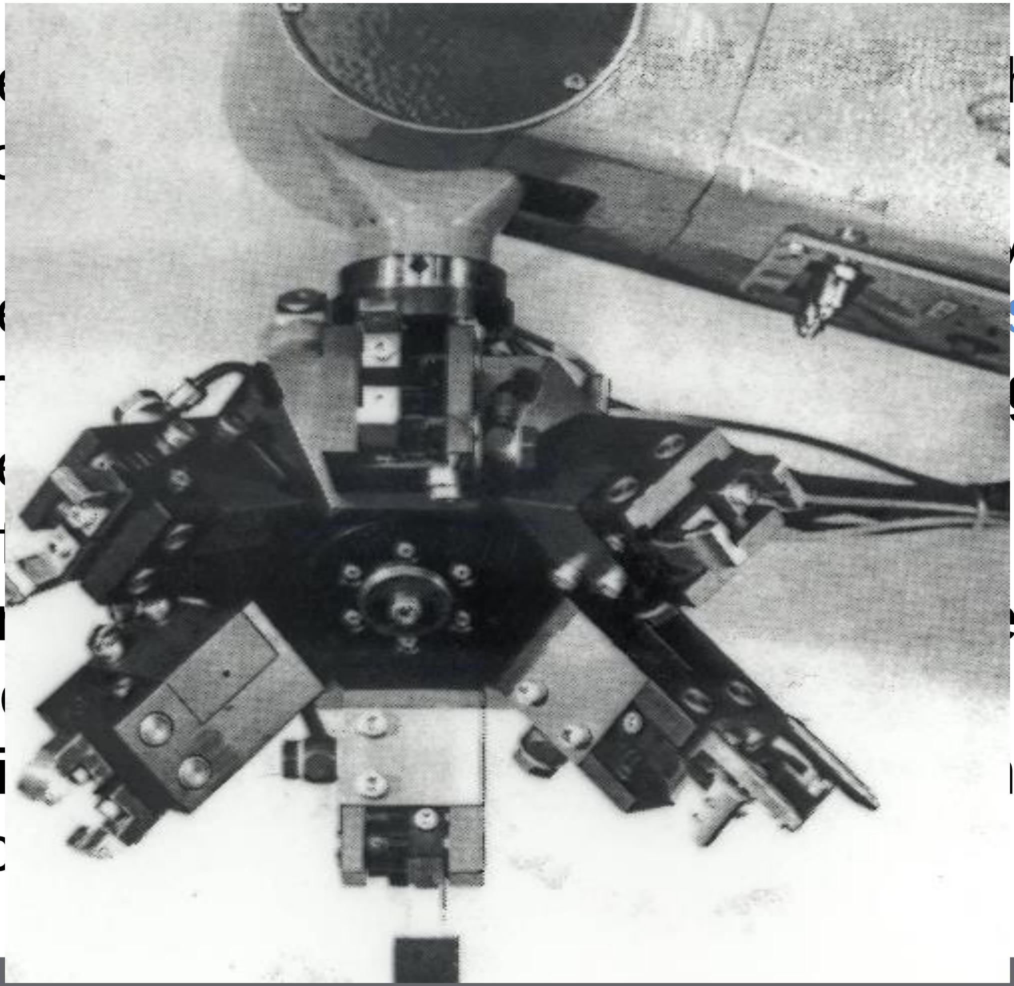
Gripping is simplified if there are defined surfaces with determined geometry for use. Soft parts, e.g. plastics and rubber, are difficult to grip with a mechanical gripper since the parts can deform from the forces in the gripper.		**Man. ref. time**
Part has surfaces for gripping and can be gripped with the same gripper as the previous part.	9 points	0 s
Part has surfaces for gripping, but requires a new, unique gripper that could not be used for the previous part. Part has surfaces for gripping and can use the same gripper as used earlier, but not for the previous part.	3 points	0 s
Part has no surfaces for gripping or is flexible.	1 point	1 s

Gripping

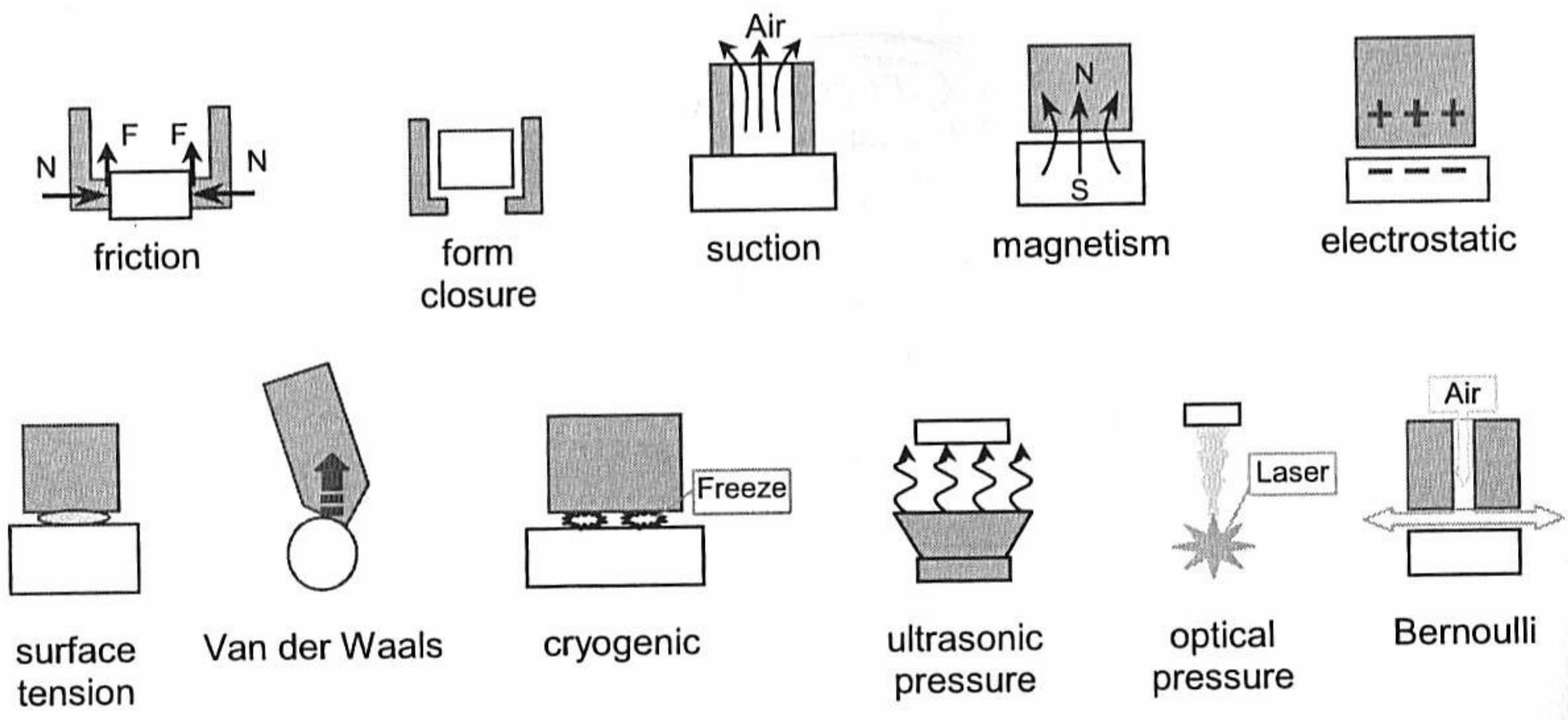
- Grippers are less flexible than human hands: if a part can be assembled with a thumb and index finger it is suitable for automatic assembly
- Grippers that can be used for more parts are to be prefered: the single parts can be redesigned to be handled with as few grippers as possible
- Specific gripping surfaces are not always necessary, but once again can be beneficial for reducing the number of necessary grippers
- Gripping and feeding should use different reference surfaces

Gripping

- Gripp… hands: if a part c… and index finger… y
- Gripp… s are to be prefer… gned to be handl…
- Speci… necessary, but o… educing the numb…
- Grippi… t reference surfac…



Gripping principles



Gripping

ID	Component	Score
1	Metal cupola	9
2	Long screw	3
3	Plastic top	9
4	Base unit	3
5	Square nut	3
6	Screw	3
7	Spring	3
8	Washer	3
9	Nut	3
10	Plastic knob	3

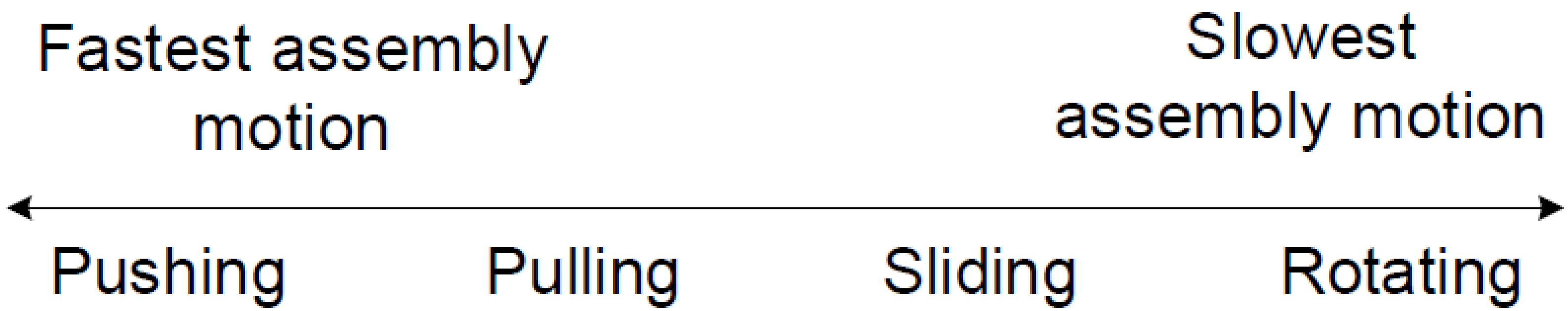
3 = gripper exchange needed!

Batch Principle!

Part level

Assembly motions (during insertion) will be faster, the simpler they are.		**Man. ref. time**
Assembly motion consists of a pressing motion with one part being assembled to already assembled parts.	9 points	0 s
Assembly motion consists of further motions than pressing motion with one part.	3 points	0,5 s
Assembly motion is an operation with multiple movable parts that simultaneously are assembled to already assembled parts with other motions than pressing motion.	1 point	0,8 s

Assembly Motion



Assembly Motion

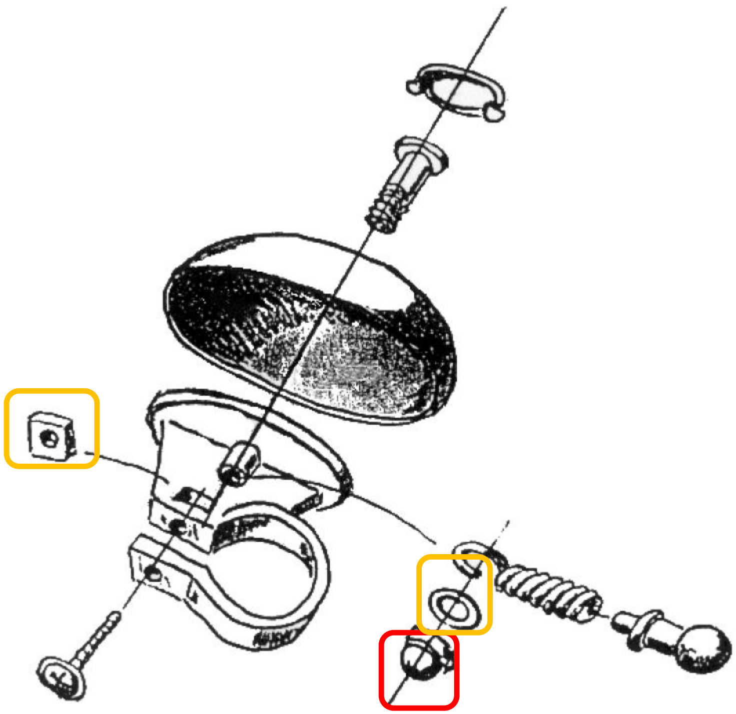
ID	Component	Score
1	Metal cupola	9
2	Long screw	9
3	Plastic top	9
4	Base unit	9
5	Square nut	9
6	Screw	9
7	Spring	9
8	Washer	9
9	Nut	9
10	Plastic knob	9

Part level

Reachability for assembly operation should not be limited. All parts should be inserted in the same direction.		**Man. ref. time**
No restrictions or problems for reaching when fitting the part.	9 points	0 s
Reachability is limited. Other assembly direction than previous part.	3 points	4,5 s
Reachability is limited and requires special tools or grippers to perform the assembly operation. Other assembly direction than previous part.	1 point	7 s

Reachability

ID	Component	Score
1	Metal cupola	9
2	Long screw	9
3	Plastic top	9
4	Base unit	9
5	Square nut	3
6	Screw	9
7	Spring	9
8	Washer	3
9	Nut	1
10	Plastic knob	9



- Need to change position of the assembly to introduce them properly: the screw is on the opposite side!
- For the nut it is also necessary to use particular tools.

Part level

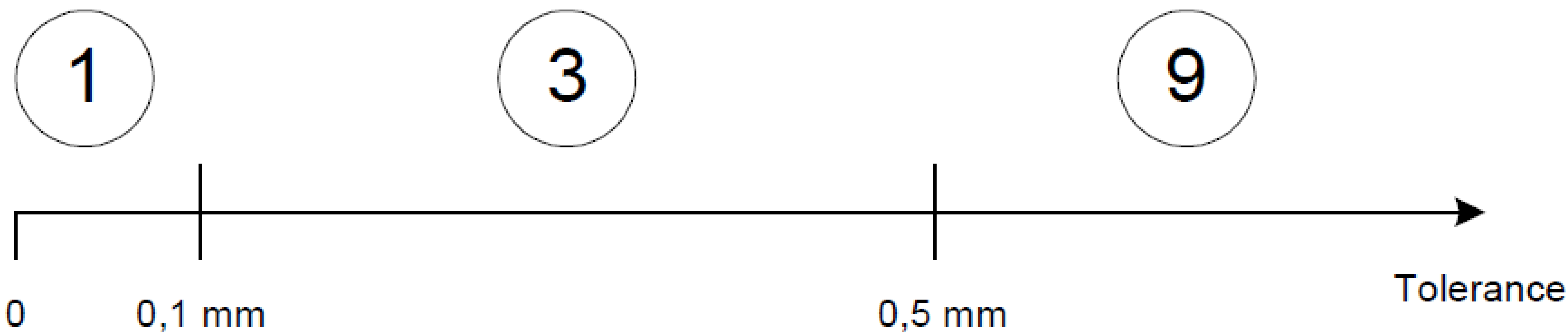
Insertion is simplified if there are chamfers or other guiding surfaces, e.g. an edge that can be used as a mechanical guide for the fitting operation, in the part.		**Man. ref. time**
Chamfers exist to simplify the insertion operation.	9 points	0 s
No chamfers, but other guiding surfaces simplifies the insertion operation.	3 points	0,2 s
No chamfers or other guiding surfaces.	1 point	0,5 s

Insertion

ID	Component	Score
1	Metal cupola	9
2	Long screw	3
3	Plastic top	9
4	Base unit	3
5	Square nut	3
6	Screw	1
7	Spring	3
8	Washer	1
9	Nut	1
10	Plastic knob	1

Part level

Tolerances for insertion operations, for example the distance between a peg and a hole during insertion or whenever there is manipulation of parts relative to each other. Too small tolerances increases the risk of failure during insertion and the system could stop.		**Man. ref. time**
Tolerance > 0,5 mm	9 points	0 s
0,1 mm ≤ Tolerance ≤ 0,5 mm	3 points	0,2 s
Tolerance < 0,1 mm	1 point	0,4 s



Tolerances

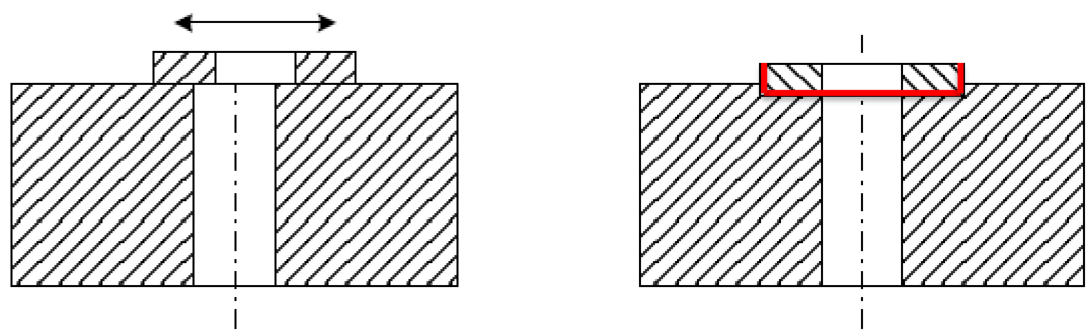
ID	Component	Score
1	Metal cupola	9
2	Long screw	9
3	Plastic top	1
4	Base unit	9
5	Square nut	3
6	Screw	3
7	Spring	9
8	Washer	3
9	Nut	3
10	Plastic knob	3

Tolerances decides what equipment is needed!!!

Ø close to the Long screw one

Part level

Holding assembled parts is necessary if parts cannot keep orientation and position after assembly. Parts that are secured immediately, i.e. does not lose orientation or position if the assembly is turned up side down, ensures a more reliable assembly process.		**Man. ref. time**
Part is secured immediately at insertion.	9 points	0,s
Part keeps orientation and position, but is not secured.	3 points	0 s
Part must be held after insertion to keep orientation and position.	1 point	4 s



Holding assembled part

ID	Component	Score
1	Metal cupola	3
2	Long screw	3
3	Plastic top	9
4	Base unit	1
5	Square nut	1
6	Screw	3
7	Spring	1
8	Washer	3
9	Nut	1
10	Plastic knob	3

Part level

Fastening method. How is the analysed part itself fastened?		**Man. ref. time**
No fastening method at all (the part is placed on or in an already assembled part), or only snap fits.	9 points	0 s
Screwing- or pressing operations.	3 points	3 s
Adhesive fastening methods, welding, soldering, riveting	1 point	8 s

Fastening method

ID	Component	Score
1	Metal cupola	9
2	Long screw	9
3	Plastic top	9
4	Base unit	9
5	Square nut	9
6	Screw	3
7	Spring	9
8	Washer	9
9	Nut	3
10	Plastic knob	3

Screwing

Screwing

Pressing

Part level

Joining: Extra equipment or tools (e.g. press tools or screwdrivers) should not be needed to fit the part into place.		**Man. ref. time**
No extra equipment is needed.	9 points	0 s
Extra equipment or tools are needed to fit the part in place and the extra operation is performed in assembly direction.	3 points	2 s
Extra equipment or tools are needed to fit the part in place and the extra operation is not performed in assembly direction.	1 point	3 s

Joining

ID	Component	Score
1	Metal cupola	9
2	Long screw	9
3	Plastic top	9
4	Base unit	9
5	Square nut	9
6	Screw	3
7	Spring	9
8	Washer	9
9	Nut	3
10	Plastic knob	3

Screwdriver

Spanner

Spring Holder

Part level

Check/adjust is not needed if the product is designed according to ”poka yoke”, i.e. it is impossible to assemble the part in more than one way. Every extra operation for checking or adjusting is extra work and a symptom of a design that is not quite satisfactory.		**Man. ref. time**
Unnecessary to check if part is in place.	9 points	0 s
Necessary to check if part is in place or assembled correctly.	3 points	1 s
Necessary to adjust or re-orient part.	1 point	2 s

Check/adjust

ID	Component	Score
1	Metal cupola	9
2	Long screw	9
3	Plastic top	9
4	Base unit	9
5	Square nut	3
6	Screw	9
7	Spring	9
8	Washer	9
9	Nut	9
10	Plastic knob	9

Alignment

Summary: part level

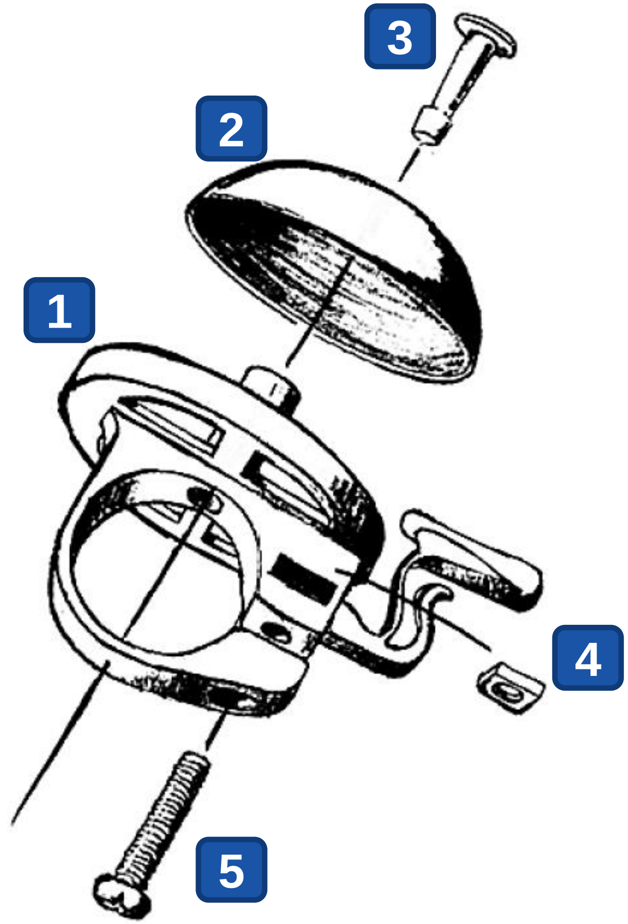
List of all parts	Number of identical parts	Need to assemble part?	Level of defects	Orientation	Fragile parts	Hooking	Centre of gravity	Shape	Weight	Length	Gripping	Assembly motions	Reachability	Insertion	Tolerances	Holding assembled parts	Fastening method	Joining	Check/adjust	SUM
Metal cupola	1	9	3	1	9	9	3	3	9	9	9	9	9	9	9	3	9	9	9	130
Long screw	1	1	9	1	9	9	9	3	9	9	3	9	9	3	9	3	9	9	9	122
Plastic top	1	1	3	1	9	9	3	3	9	9	9	9	9	9	1	9	9	9	9	120
Base unit	1	9	3	1	9	1	1	1	9	9	3	9	9	3	9	1	9	9	9	104
Square nut	1	1	9	1	9	9	9	9	9	9	3	9	3	3	3	1	9	9	3	108
Screw	1	1	9	1	9	9	9	3	9	9	3	9	9	1	3	3	3	3	9	102
Spring	1	9	1	1	9	1	1	1	9	9	3	9	9	3	9	1	9	9	9	102
Washer	1	1	9	1	9	9	9	9	9	9	3	9	3	1	3	3	9	9	9	114
Nut	1	1	9	1	9	9	1	3	9	9	3	9	1	1	3	1	3	3	9	84
Plastic knob	1	1	3	1	9	9	9	3	9	9	3	9	9	1	3	3	3	3	9	93

Part level

TOTAL SUM: 1079

$$Assembly\ Index = \frac{Total\ sum}{Maximum\ point * number\ of\ parts} = \frac{1079}{162*10} \approx 67\%$$

Redesign: first iteration



ID	Component
1	Base unit
2	Metal cupola
3	Rivet
4	Square nut
5	Screw

Summary of the redesign evaluation

	PRODUCT LEVEL							
	Reduce number of parts	Unique parts	Base object	Design base object	Assembly directions	Parallel operations	Chain of tolerances	**SUM**
Object/Product/Module	9	1	9	3	1	3	3	29

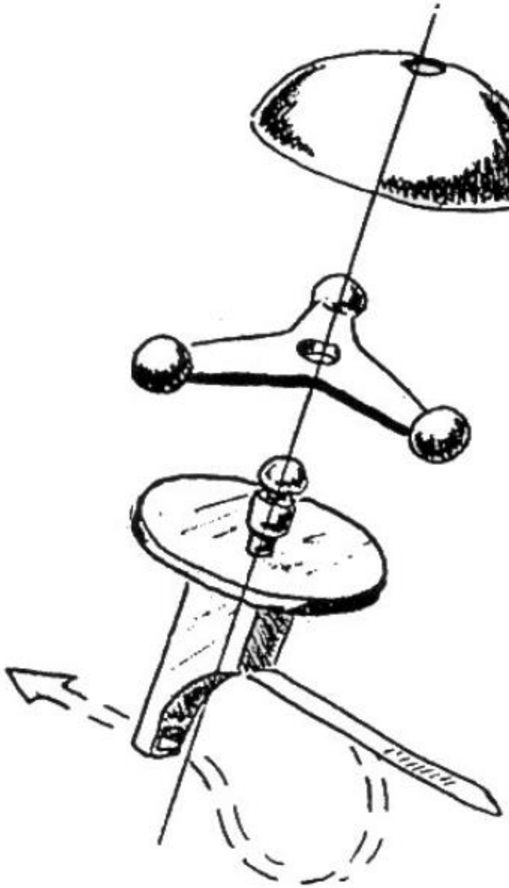
Part level

List of all parts	Number of identical parts	Need to assemble part?	Level of defects	Orientation	Fragile parts	Hooking	Centre of gravity	Shape	Weight	Length	Gripping	Assembly motions	Reachability	Insertion	Tolerances	Holding assembled parts	Fastening method	Joining	Check/adjust	**SUM**
Base unit	1	9	9	9	9	1	3	1	9	9	9	9	9	9	9	3	9	9	9	134
Metal cupola	1	9	9	3	3	9	3	3	9	9	9	9	9	9	9	3	9	9	9	132
Rivet	1	1	9	1	9	9	9	3	9	9	3	9	9	9	3	9	9	9	9	128
Square nut	1	1	9	1	9	9	9	9	9	9	3	9	3	9	3	3	9	9	9	122
Screw	1	1	9	1	9	9	9	3	9	9	3	9	3	9	9	9	3	3	9	116

TOTAL SUM: 732

$$Assembly\ Index = \frac{Total\ sum}{Maximum\ point * number\ of\ parts} = \frac{732}{162*5} \approx 90\%$$

Further improvements…



- Only the three theoretically necessary parts have been included
- The connection with the bicycle is simplified

References

- Boothroyd, G., P. Dewhurst, et al. (2010). Product Design for Manufacture and Assembly, CRC.
- Eskilander, S. (2001). Design For Automatic Assembly--A Method for Product Design: DFA2.