

Design For Manufacturing/Assembly (DFM, DFA, DFMA)

Much of the early and significant work on DFM and DFA was done in the early 1970s by Boothroyd and Dewhurst. Traditionally, product development was essentially done in several stages. The designer(s) (who usually had very good knowledge of materials, mechanisms, etc.) would design the product, and sometimes would construct working prototypes. Once the prototype was tested and approved, the manufacturing team would then construct manufacturing plans for the product, including the tooling etc. Often, different materials (e.g. different thickness or type of sheet metal), and different components (e.g. different sized screws etc), would be substituted by the manufacturing team. Their goal was to achieve the same functionality, but make mass production more efficient. However, the majority of the design remained unchanged, since the manufacturing engineers could never be sure whether a change would affect some functional requirement.

Two things changed in the 1970's:

- (i) Many new types of plastics were developed, and injection moulding technology became widely available, resulting in the possibility of low cost plastic components. An advantage of these new plastic materials was that they provided different material behaviour (e.g. many cycles of large elastic deformations without failure – a property useful in making snap-fit mating components). Thus parts that had to be made from metal and screwed together could just be made out of plastic and snap fitted. This reduced assembly time, assembly components, and production costs.
- (ii) Several companies were trying to bring their products to the market faster. One problem with the earlier method of doing things was that each time there was a design change made by the manufacturing engineer, product development was held up, waiting for the engineering change notice (ECN) to be approved by the designer. Often, this process introduced delays because the design engineer would be busy with other tasks, or unavailable. To avoid this, the concept of **concurrent engineering (CE)** became popular. The idea here was that a combined team of engineers and management would be assigned to each new product. This team may consist of mechanical designers, electrical engineers, software engineers, production engineers, marketing and sales, and management. Thus, as the design was being generated by the designers, the production people would give feedback about feasibility to manufacture, more economical alternatives etc. At the same time, sales people would negotiate of product outlook and features, and so on. The biggest advantage of CE was that the

product was designed in a way that manufacturing cost and time would be low during production.

At this time, working with many different companies, Boothroyd's team analysed existing designs of hundreds of products, and suggested design improvements based on manufacturing and assembly ease. Using the experience of these projects, they then developed a very large set of guidelines on how to estimate whether a design was designed well (from a manufacturing point of view), and potential methods to improve the designs.

In subsequent years, the idea of DFM and DFA were extended to include other aspects of better designs – including design for maintenance, design for environment, design for cost, etc. Often, this application of CE is referred to as DFX, where X is a variable selected from the set {manufacture, assembly, ...}. We shall restrict our study of manufacturing decisions to those related to fabrication and assembly.

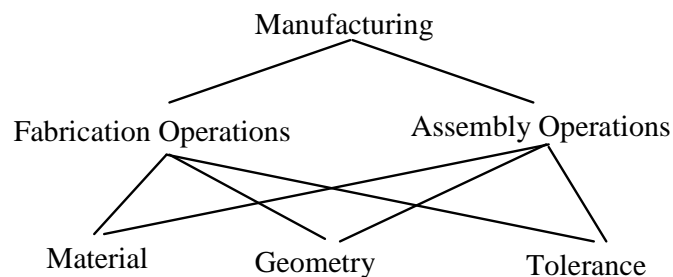


Figure 1. Effects of design (materials, geometry, tolerances) on manufacturing

Effects of Tolerance on Fabrication

Tight tolerances will require

- More care to be taken during machining → larger processing time
- Higher reject rates
- More expensive measurement/inspection systems
- Restricted set of machine tools (so ... ?)

Effects of Geometry on Fabrication

Different geometry (due to different design of product/part) will mean:

- Different process plans
- Different raw material costs (why ?)
- Different processing costs

Example:

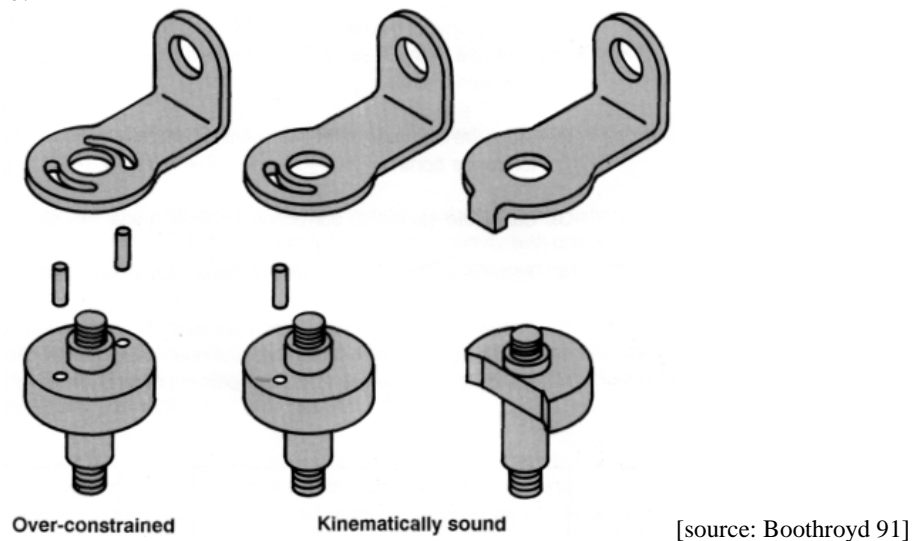


Figure 2. Different components have different production costs

Effect of Material on Fabrication

Different materials of designed part implies:

- Different process plans
- Different fabrication processes

Examples ?

Effects of Geometry, Material, Tolerance effects on Assembly

Boothroyd *et. al* studied many of these to compose a systematic methodology. The emphasis was to **relate** *Product design*, *Assembly operations*, and *Assembly Method* to the **single decision factor: the cost**. We shall study the Boothroyd method in detail. Note that there are other systems based on very similar principals: The Hitachi Assembly Evaluation Method, developed at Hitachi in Japan, used very similar ideas.

Basic idea: reduction of cost of a product through simplification of its design.

How ?

- Reduction of number of components
- Ensuring that parts are easy to assemble
- Increasing the use of standardized parts across entire product range
- Designing with widest possible tolerances
- Material selection must consider manufacturing also, not just function.

Why do these ideas work ?

Fewer components in a design imply:

Manual assembly:

Fewer assembly operations → fewer assembly workers

Automated assembly:

Reduction of one entire section of Assembly station

Fewer fixtures/jigs, feeders, etc.

Also, fewer parts usually mean smaller stacked tolerances, and therefore lead to better functioning of the assemblies, and fewer rejects (why ?)

The **Boothroyd-Dewhurst method** includes:

Preliminary (rough) design

Selection of Assembly Method (manual, robotic, or high-speed automated)

Design/Redesign of product for selected method

The selection of assembly method must be done at an early stage in the product design process (why?). One factor that affects this decision is the production volume (that is, forecast demand).

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 (labour costs, technical requirements, e.g. in spray painting) **robotic assembly** may be optimal.

Typical hardware involved in each method, and its characteristics are listed below.

Manual Assembly:

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 ?)

High-speed (Special Purpose) Transfer Assembly:

Machines are built to produce specific product.

Components:

- Part feeders [indexed/asynchronous]

- Single purpose workheads

- Transfer devices (usually equipped with workheads)

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.

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.

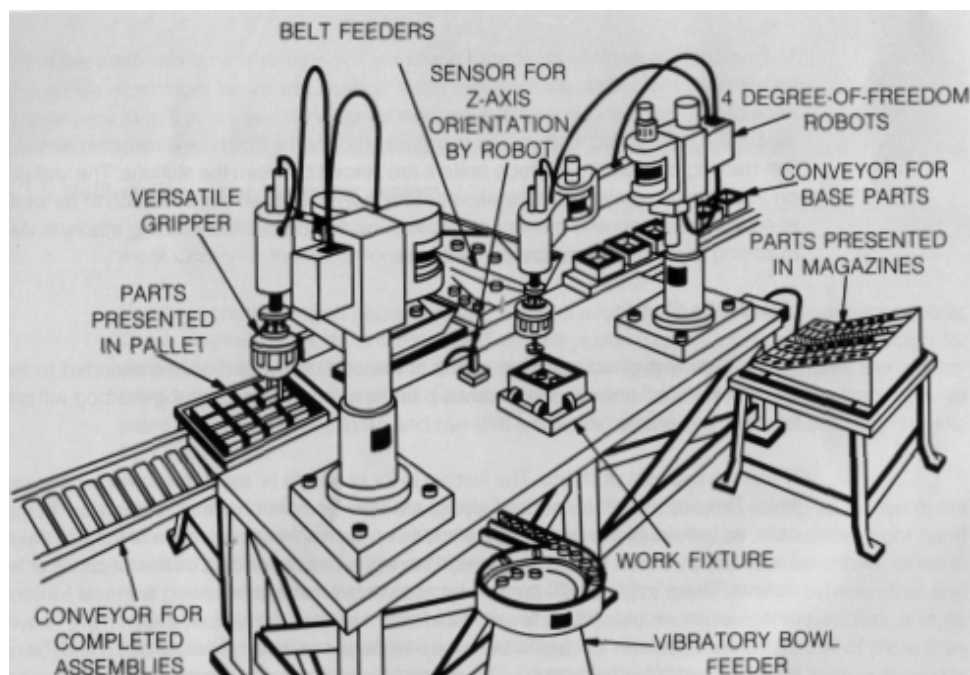


Figure 3. Common assembly automation devices [source Boothroyd 91]

Design for Manual Assembly

The Boothroyd Dewhurst method provides a quantitative measure called the *design efficiency* based on analysis of a product. The efficiency compares the total assembly time for a product with the total assembly time for an *ideal product* (determined by a method suggested by the authors). The efficiency can be used to compare various designs in terms of their relative efficiencies (for manual assembly).

The design improvement is brought about by two considerations:

1. A decision is made as to whether the part can be considered a candidate for elimination, or combination with other parts of the assembly
2. An estimation of the time taken to grasp, manipulate, and insert the part.

The procedure:

STEP 1. Obtain design details

Engineering drawings, or Exploded 3-D views, or Existing product, or Prototype

STEP 2.. Take assembly apart (or imagine doing so) -- assigning identification to each part as it is removed.

Consider sub-assemblies as parts, and analyse them separately (recursively).

STEP 3. Begin re-assembly of the product. Start with the part with the highest identification number, going all the way up to the part 1.

Fill up the assembly worksheet as you go along.

[note: the method requires that the product is assembled one part at a time. In reality, assembly workers use both hands and often assemble two parts in a step. However, a change in the assembly procedure will correspondingly change the assembly time for the ideal product -- thereby keeping the efficiency constant.]

STEP 4. Compute the design efficiency, given as:

$$EM = 3 \times NM / TM$$

We go through an example to see how the method works.

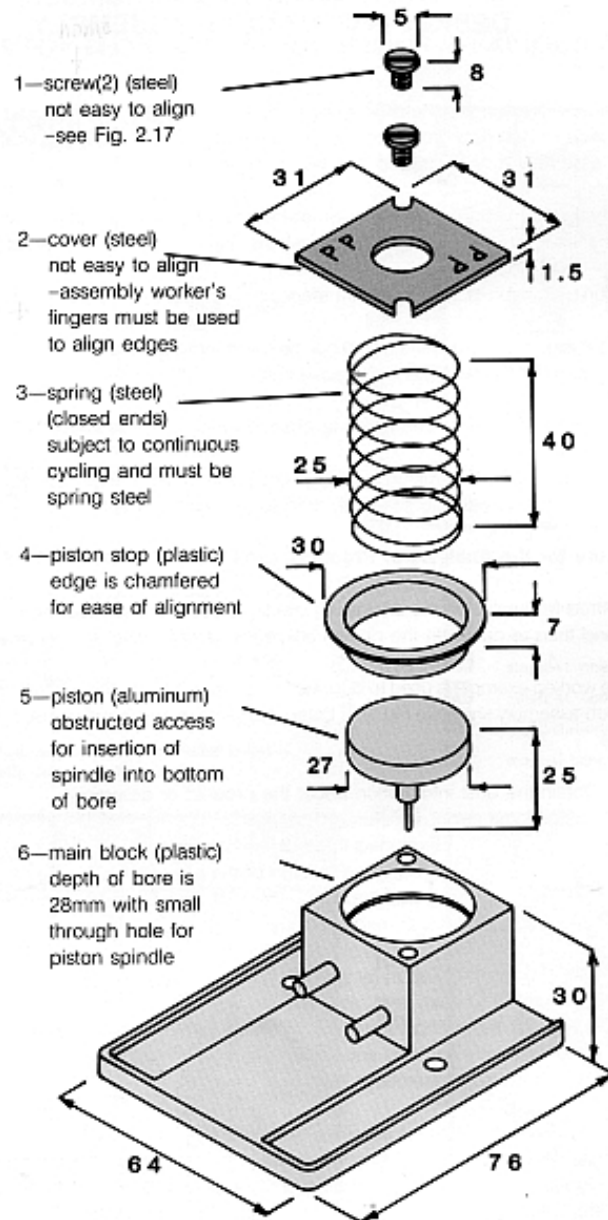


Figure 4. A piston-assembly design [source Boothroyd 91]

The computation is done by systematically completing the data in the following table. The data requires several estimates for assembly efficiency of different components based on their characteristics. This data is compiled empirically – by a large number of time-motion studies conducted over many years. We will use the charts from Boothroyd (handouts given in class).

c1	c2	c3	c4	c5	c6	c7	c8	c9	Name of Assembly
Part ID	No of times the operation is carried out consecutively	Manual handling code	Manual handling time per part	Manual insertion code	manual insertion time per part	Operation time $c2(c4 + c6)$	Operation cost $0.4 c7$	Estimation for theoretical minimum parts	
Total:									Design efficiency = $3 NM/TM =$
						TM	CM	NM	

Table 1. Table for computation of Design efficiency (Source: Boothroyd 91).

One of the key features of the Boothroyd-Dewhurst method is estimation of the ideal product -- which translates to the method of filling up column 9 in the chart. They give the following guidelines:

Rule 1. During operation of the product, does the part move relative to all other parts already assembled?

Rule 2. Must the part be of a different material than the parts already assembled? [Only fundamental reasons associated with material properties are acceptable.]

Rule 3. Must the part be separate from all parts already assembled (because otherwise necessary assembly/disassembly of other parts would be impossible)?

If the answer to any of these questions is YES, a 1 is entered in column 9 (except if there are multiple parts in column 2, in which case the minimum number of separate parts required is entered in column 9.)

c1	c2	c3	c4	c5	c6	c7	c8	c9	Name of Assembly
Part ID	No of times the operation is carried out consecutively	Manual handling code	Manual handling time per part	Manual insertion code	manual insertion time per part	Operation time $c2(c4 + c6)$	Operation cost $0.4 c7$	Estimation for theoretical minimum parts	PNEUMATIC PISTON
6	1	30	1.95	00	1.5	3.45	1.38	1	MAIN BLOCK
5	1	10	1.5	10	4.0	5.50	2.2	1	PISTON
4	1	10	1.5	00	1.5	3.00	1.2	1	PISTON STOP
3	1	05	1.84	00	1.5	3.34	1.34	1	SPRING
2	1	23	2.36	08	6.5	8.86	3.54	0	COVER
1	2	11	1.8	39	8.0	16.6	6.64	0	SCREW
Total:						40.75	16.3	4	Design efficiency = $3 NM/TM = 0.29$
						TM	CM	NM	

Table 2. Evaluating the design efficiency of Piston

Improving the design:

The following considerations are important:

STEP 1. Is the number in column 9 < the number in column 2 ?

If yes, there is an opportunity for reduction in number of parts.

STEP 2. Examine columns 4 and 6. These figures indicate potential for assembly time reduction.

Based on these ideas, a redesign of the piston assembly is presented below. Notice how the new design presents a design efficiency of 90%.

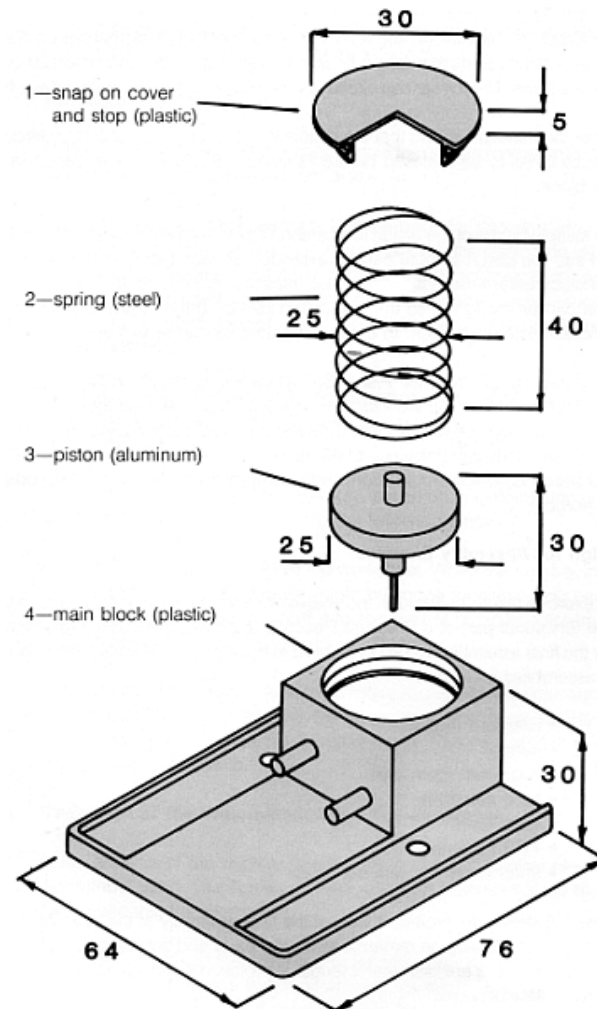


Figure 5. An improved piston design [Source: Boothroyd 91]

c1	c2	c3	c4	c5	c6	c7	c8	c9	Name of Assembly
Part ID	No of times the operation is carried out consecutively	Manual handling code	Manual handling time per part	Manual insertion code	manual insertion time per part	Operation time c2(c4 + c6)	Operation cost 0.4 c7	Estimation for theoretical minimum parts	NEW PNEUMATIC PISTON
4	1	30	1.95	00	1.5	3.45	1.38	1	MAIN BLOCK
3	1	10	1.5	00	1.5	3.00	1.2	1	PISTON
2	1	05	1.84	00	1.5	3.34	1.34	1	SPRING
1	1	10	1.5	30	2.0	3.50	1.40	1	COVER and STOP
Total:						13.29	5.32	4	Design efficiency = $3 \text{ NM/TM} = 0.90$
						TM	CM	NM	

Table 3. Evaluating the design efficiency of the re-designed piston

Guidelines for improving design (for assembly) of mechanical products:

1. Reduce Part Count and Part Types

Why ?

- Lower material cost
- Reduced jigs/fixtures cost
- Improved quality
- Less documentation
- Small inventories
- Fewer suppliers
- Simplified production control
- Fewer Inspections
- Less rework

How ?

1. Check the need for the part's existence (apply the three rules above).
2. Eliminate separate fasteners when possible.
3. Design multi-functional parts by maximum use of the capabilities of individual manufacturing processes. For example, use near-net shape moulding and casting when possible to reduce part count.
4. Eliminate product features that are of no value to the customer.
5. Do not over-use piece part producibility guidelines in early stages of design -- they lead to simplified production of individual parts, but much higher part count.

Example: In figure 6, the single component design has potentially higher waste (since an irregular shape must be cut out of the stock sheet; but the assembly cost for the second design is much higher.

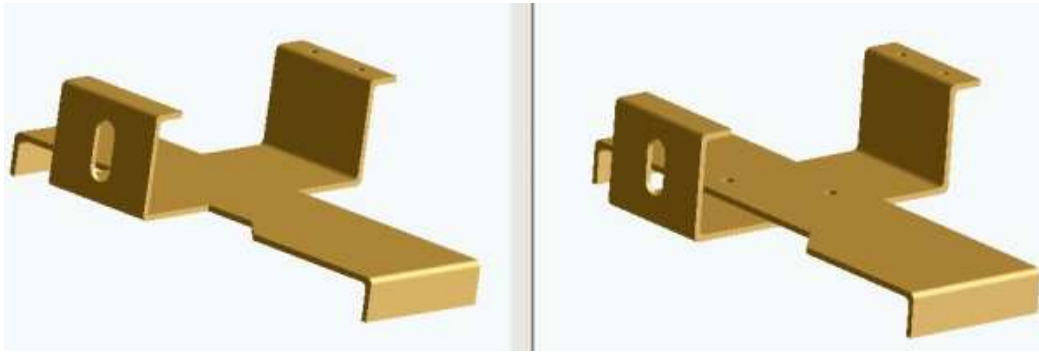


Figure 6a. Single component

Figure 6b. Two-component sub-assembly

2. Try to Eliminate Adjustments

Why ?

Adjustments require decision making during assembly (so...?)

May lead to malfunctions after some usage by customer.

How ?

1. By elimination of parts.

Example:

2. Substitute electronic correction for mechanical adjustment.

3. Use kinematic analysis to guide design rather than gut feeling.

Examples (see figure 1)

3. Design Parts to be Self Locating and Aligning

Why?

Ease of assembly

Better performance of product close to breakdown (since parts tend to stay in position rather than come out/off.)

Why Not?

Higher cost of manufacturing (more operations, in general)

How?

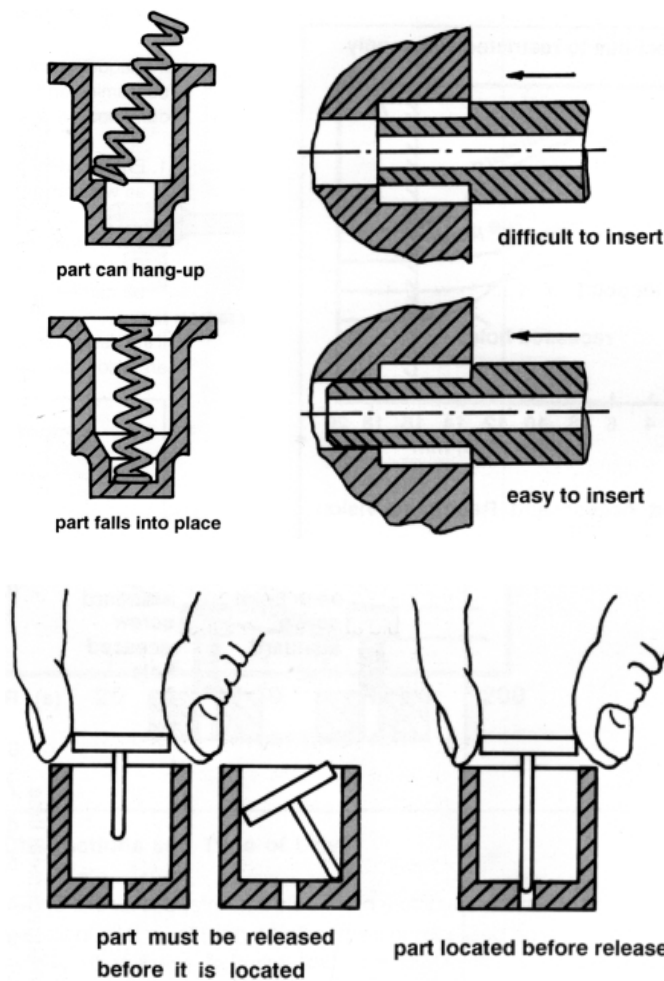


Figure 7. Some guidelines of design for ease of assembly

4. Consider Access and Visibility for Each Operation

Why ?

How?

1. Ensure adequate clearance for hands, tools, testing probes etc.
2. Ensure that the assembly worker has clear visibility of the mating features.

5. Consider Handling Part from Bulk

Why?

Some parts are easily handled when alone, but create a mess when mixed in large numbers.

How?

1. On parts that mate using interlocking tapers, include features that prevent nesting.
2. On parts with combinations of holes, projections, gaps and cut-outs -- there is high probability of tangling.
Close gaps; Enlarge projections; Use closed-end coil springs;
3. Avoid parts which are fragile or sharp, unless functionally necessary. If necessary, include safe-handling features.
4. Avoid use of flexible parts -- if flexible parts are needed, try using those that retain shape when handled.
5. Avoid parts that require special tools for the worker to perform assembly.

6. Design Parts that Cannot be Installed Incorrectly

Why?

Example: Styrofoam packing for TV/Stereo.

How?

- (a) Provide projections that will disallow incorrect assembly.

- (b) Make mating features asymmetrical.
- (c) Make parts symmetrical so that orientation is unimportant.
- (d) If two parts can be assembled incorrectly, ensure that assembly of some subsequent part is impossible.
- (e) If all fails, mark part with assembly markers for identification.
- (f) Eliminate flexible parts that can almost always be assembled incorrectly.

7. Eliminate Need for Reorientation During Assembly

Why?

Reorientation is an operation that adds no value to the assembly.

How?

Design products with single axis of assembly (usually, Exclusive Vertical Insertion is the ideal).

8. Maximize Part Symmetry, or Emphasize Asymmetry

Why?

1. Higher symmetry implies lower orientation time/effort

Example: Keys

2. If the part cannot be made symmetric, then emphasized asymmetry allows us to reach the correct orientation faster.

Example ?

References:

Otto and Wood has a good chapter on DFMA

Product Design for Manufacture and Assembly, Geoffrey Boothroyd, Peter Dewhurst, Winston Knight, 2nd Edition, Marcel Dekker, New York

Several figures in these notes are from the original Boothroyd and Dewhurst workbook:

Product Design for Assembly, Geoffrey Boothroyd and Peter Dewhurst, 1991, Boothroyd Dewhurst Inc.