Session 6
DFMA Methodologies

Lecture delivered by
Prof. M. N. Sudhindra Kumar
Professor MSRSAS-Bangalore
Session Objectives

At the end of the session the delegate would have understood

• The need for DFMA methodologies
• DFMA methodologies available
Session Topics

- The need for DFMA methodologies
- DFMA methodologies available
- Hitachi assemblability
- Boothroyd-Dewhurst DFMA
- Lucas/Hull DFA
- Design Rules
- DFMA examples
An overview of formal methodologies

1. The previous sessions described in general terms the kind of issues to be considered when designing products, which involve assembly.

2. Research work in the 70’s and 80’s concluded that although such general advice was useful and desirable, its impact could be much greater if a structured approach was taken. This work led to several "methodologies" being developed. Initial results were so good that the methodologies have flourished and development continues today.
Methodology

What is a methodology and why use one in Design for Assembly?

– One dictionary definition of a methodology is: "A particular method or procedure"
A methodology is useful in Design for Assembly for several reasons:

- FORMALISES the procedure - it makes it repeatable and steers the designer towards a good solution using proven techniques.
- OPENS UP the procedure - documenting it makes DFA skills accessible to "non-experts".
- QUANTIFIES the design’s performance - it provides measurable standards, allowing comparison of competing concepts; and
- HIGHLIGHTS a design’s deficiencies - it allows targeting of improvement efforts.
There are possible drawbacks in using a DFA methodology

- SLOWING DOWN the concept-generation phase in design;
- giving the designer a BLINKERED VIEW, looking only at assembly issues;
- requiring SIGNIFICANT TRAINING or MANAGEMENT EFFORT to establish the discipline of use; and
- Requiring additional DESIGN EFFORT before the benefits of long term savings are seen.
On balance,

However, the literature reports significant benefits as a result of applying almost any formal DFA methodology. Boothroyd (1994), for example surveyed 43 cases of application of his own "DFMA" methodology and cites such improvements as:

- 12 cases involved reduction of separate fasteners - average reduction 72%
- 31 cases achieved reductions in assembly time - average reduction 61%
- 12 cases achieved reductions in product cost - average reduction 37%
• From all the DFA methodologies available, common goals and results emerge, justifying the use of a good methodology.
1:

- Parts count reduction:
- Besides reducing direct assembly costs, the leverage benefits of parts count reduction are very large, through overhead and direct savings in the upstream supply chain. Major cost savings can be achieved in the areas of detail design, tooling development, purchasing, vendor appraisal, order processing, shipping, stockholding, design records, etc.
2:

• **Faster new product introduction:**

• This again follows from the reduction in parts. Generally, fewer parts need fewer development tasks and less overall development effort. Less development effort means that finite resources can achieve more in a given timescale, or achieve the same project outcomes in a shorter time.
3:

- **Assembly process simplification:**
- As well as reducing the parts count, what parts remain are joined by simpler assembly processes, further reducing assembly costs
4:

- **Easier automation:**
- In cases where automation is desired, a good DFA methodology will optimise the feeding and handling of parts, allowing simpler, cheaper feeding and handling equipment.
5:

- **Improved quality:**
- By reducing the complexity of the product, the potential for operator error is reduced, improving process capability and raising quality.
What formal DFA methodologies are available?

• Reported methodologies include:
  Those using design principles and rules, such as those by:
  – General Electric (USA) - which actually focused on part manufacture rather than assembly;
  – Andreasen;
  – Weissmantel;
  – Suh.
• Those using quantitative evaluation methods, such as those by:
  – IPA Stuttgart;
  – Sony;
  – NEC Corporation - Design for PCB assembly;
  – Hitachi - Assemblability Evaluation Method (AEM);
  – Boothroyd & Dewhurst (BDI’s DFMA).
• Those using a knowledge-based approach, such as that by:
  – Swift - the so-called "Lucas/Hull DFA" method (incorporated in CSC’s TeamSET)
DFA methods

There are several design methods available to support product development. Sackett and Holbrook (1988) report in 1988 of nine different research systems for DFA. More recently Egan (1997) reports of twelve commercially available DFA methods:

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

Table 1: Commercially available DFA methods (Egan, 1997).
Hitachi Assemblablility

1. This method was developed in the late 1970’s as part of Hitachi’s desire for products, which could be efficiently assembled by automation.

2. It was developed coincidentally with the work of Boothroyd and is described fully by Miyakawa and Ohashi (1986).
3. The essential principle of the method is that of "one part - one motion": for each part of the assembly there should be only one straightforward, simple motion required to fit and secure it. An assembly scoring system is used, where simple straight motions score no losses, and more complex motions score progressively greater losses. Two performance indicators are used, the "Design Quality" E and the "Assembly Cost Ratio" K. The objective is to minimise E and K.

4. This method was a very primitive one hence not practiced in general.
Boothroyd and Dewhurst DFMA

One part of the Boothroyd and Dewhurst DFMA is the DFA method. There are DFA methods for manual, robotic, automatic and printed circuit board assembly available from Boothroyd and Dewhurst Incorporated, BDI. The most well known and most used DFA method is for manual assembly.

The manual DFA method is based on a database of estimated assembly times from a motion-time-measurement (MTM) study. The database contains estimated assembly times for different assembly operations. Every assembly operation depends on the design of a part and how it is assembled. By analysing how a part is handled and inserted, an estimated assembly time may be calculated.

A product or a drawing of the product is required to perform an analysis. Analysis is performed while assembling all parts of the product. Each part is analysed in two ways:

1. Possibility to eliminate the part.
2. Possibility to redesign the part to be easier to assemble.
Elimination/integration of parts

Reducing part count is an important step in this method. To decide whether or not a part is a candidate for integration or reduction, three questions are used (Boothroyd and Dewhurst, 1987):

1. Does the part move relative to other already assembled parts when the product is working in a normal way?
2. Does the part have to be of other material or isolated from other already assembled parts? Only fundamental material aspects are acceptable.
3. Does the part have to be separate from other already assembled parts because assembly or disassembly of other parts otherwise would be impossible?

If the answer to all these three questions is "no", the part is a candidate for elimination or integration.
Geometrical analysis of parts

The geometrical properties of each part are analysed. This analysis contains two steps. First, analyse how difficult the part is to handle. Second, analyse how the part is inserted while assembling. In each of these steps, the assembly process is used for comparing assembly movements with the estimated assembly times in the database. In this way, every assembly operation is quantified with an assembly time. In the method, the ideal handling time for a part, that is 1*1*1 inches, is 1,5 s and the ideal insertion time is 1,5 s. This sums up to the ideal total assembly time of 3 s for each part.

Any geometric feature that does not follow the ”ideal” design is ”punished” with a longer assembly time since it requires longer time to e.g. orient. Any extra operations, e.g. screwing, are also considered outside the ”ideal” assembly process and results in long assembly time.
Evaluation

All parts are analysed and the total assembly time for the whole product is added up as well as the theoretical decision of whether or not the part could be eliminated or integrated. This information is used to calculate an assembly index. The DFA index gives an overall measure of assembly efficiency. The formula for the DFA index for a whole product is (Boothroyd and Dewhurst, 1987):

\[
\text{DFA - Index} = \frac{3 \times \text{Sum of theoretical minimum of parts}}{\text{Sum of total estimated assembly time}}
\]

The figure ”3” in the formula is the ideal assembly time for handling and inserting a part. The index is a first indication of how well the product is prepared for assembly. Improving the assemblability and DFA index of a product can be done by elimination of ”unnecessary” parts and by redesigning parts to be easier to handle and insert.
Automatic assembly

It is also possible to analyse products for automatic assembly. This part of the DFA method is focused on high-speed assembly or robotic assembly. The main difference between these different foci is the flexibility (lower flexibility required in high speed assembly) and the cost of equipment.

Automatic assembly analysis is carried out almost as manual assembly analysis. When analysing products for automatic assembly, the estimated cost for automatic orientation, handling and assembling is given instead of estimated assembly times (Boothroyd and Dewhurst, 1984). There is also an average assembly cycle time as a result of the evaluation.

Improvement of the product

A low DFA index is an indication for redesigning a product. Parts that are not theoretically necessary should be eliminated. Parts that require high assembly times should be redesigned to better resemble the assembly process that requires the shortest assembly time.
Drawbacks

The BDI DFMA method is not primarily focused on automatic assembly difficulties. For example, there is no evaluation of a whole assembly sequence. An overall view of a product or module is missing. Furthermore, there is no support in how to re-design the product if the evaluation shows poor results.
Boothroyd-Dewhurst DFMA

This method is a very comprehensive guide, which includes in its scope:

- Support for key decision-making (e.g. manual-v/s-automated, flexible-v/s-dedicated);
- Analysis of design for manual assembly;
- Coding systems and design data for manual handling and assembly;
- Analysis of design for automated assembly;
- Coding systems and design data for automated handling and assembly;
- Analysis of the manufacturing requirements of components
Decision support

• Questions are asked regarding:
  – market life and predicted fluctuations in demand;
  – product complexity;
  – number of design changes predicted;
  – number and scope of product variants
  – annual volumes;
• These questions, combined with several tables, are used to generate recommendations for the general type of process to be used for assembly, from the following categories:
  – purely manual;
  – manual with mechanical assistance;
  – dedicated automation on indexing machines;
  – dedicated automation on stations linked by free-transfer device;
  – flexible automation using programmable or selectable work heads (pick & place units);
  – Flexible automation using programmable manipulators (robots).

• The outcome of this stage also includes an indication of the relative cost of assembly, which can be used for comparisons between designs or benchmarking across competitors.
Design analysis for manual assembly

- The key element here is the identification of ESSENTIAL parts. Essential parts are those which:
  - must have gross relative movement to all previously-assembled parts during product operation, OR:
  - must be made of a different material from all previously-assembled parts, OR:
  - Must be separate for reasons of assembly or necessary disassembly.

**Agenda for redesign - the number of non-essential parts must be minimized.**
Coding systems and design data for handling and assembly

- Parts, which survive the initial review, are now assessed for difficulty of handling and presentation. Assessment areas include:
  - part symmetry (about two orthogonal axes);
  - Parts feeding/presentation difficulty (weight, size, tangling, nesting, shingling...);
  - access to the site of assembly;
  - direction of assembly;
  - fitting and manipulation difficulty (skill levels, need for tools...etc.; time estimates are generated for standard operations);
  - Security of assembly (need for/presence of fasteners and inter-stage transfer).

This process produces cost estimates for the assembly process alone
Part cost estimation and manufacturing process optimization

• As well as estimating the cost of assembly, the "M" of DFMA estimates the basic cost of manufacturing the components, identifies suitable basic manufacturing processes and then optimizes parts for their relevant process.

• The DFMA method is available on paper or in software. The software is now available as part of a package of "Design for..." products marketed by Boothroyd-Dewhurst Inc.
Lucas/Hull DFA

- This methodology is similar in some ways to Boothroyd-Dewhurst (the originator worked on the B-D method in its early days), and also uses a structured, cyclic approach in which analysis, evaluation, and synthesis are carried out iteratively.
Lucas Method

• There are three essential stages to the process, each with its own "pass" criterion:
  – Functional Analysis;
  – Handling Analysis (manual assembly) or Feeding Analysis (automated assembly);
  – Fitting Analysis.
1. Collaborative work during the late 1980’s between Professor K. G. Swift of the University of Hull and the Engineering and Systems division of Lucas plc produced a commercially available Design for Assembly (DFA) method.

2. Professor Swift, an international leading academic on DFA methodology based the Lucas method in part on collaborative work undertaken with Professor G. Boothroyd in 1980.

3. The initial Lucas/Hull DFA method documented the DFA knowledge into a paper manual. This has since been developed to a commercial computer based system incorporating a knowledge-based evaluation technique. This interactive system has a major advantage compared to other systems in that it is designed to integrate with a CAD system. Information analysis is greatly improved by a more structured and consistent information evaluation, hence saving time, money and effort.
Functional Analysis

• All parts of the assembly are critically investigated and categorized into "A" Parts (demanded by the function), and "B" Parts (required by that design solution only). The details of the classification process are proprietary to the methodology’s owners, but an idea of the general principle is given by Boothroyd, who defined these categories by posing three critical questions:
Three Critical Questions:

- During the operation of the product does the part move relative to all the other parts already assembled? Only gross movement should be considered; small motions that can be accommodated by integral elastic elements, for example are not sufficient for a positive answer.
- Must the part be of a material that is different from those of all the other parts already assembled or must it be isolated from these? Only fundamental reasons relating to material properties are acceptable.
- Must the part be separate from all the other parts already assembled because necessary assembly or disassembly of other separate parts would otherwise be impossible?
Design Efficiency:

• Design Efficiency is calculated from the expression:

\[
\frac{\sum A \text{ parts}}{\sum A \text{ parts} + \sum B \text{ parts}}
\]

The assembly is to exceed an arbitrary 60% target value.
Handling-Feeding Analysis

- "Handling" is the term used for presentation of parts in manual assembly, while "Feeding" is the corresponding term in automated assembly.

- A handling/feeding analysis scores the components on the basis of performance in three areas:
  - the size of the component
  - the weight of the component
  - handling difficulties and part orientation
Handling / Feeding Ratio

The sum of all the scores is calculated, and the Handling / Feeding Ratio is given by:

Handling feeding ratio

\[
\frac{\text{Total score of indices}}{\text{number of category } "A" \text{ parts}}
\]
Fitting-Insertion analysis.

• The fitting analysis requires the designer to construct an assembly sequence flow chart and to assign a fitting index to each of the assembly processes.
Fitting-Insertion analysis.

- Each component is scored on the basis of the following requirements:
- Does it require holding in a fixture?
- The assembly direction?
- Alignment problems?
- Restricted vision or access?
- The required insertion force?
Fitting Ratio

\[
\text{Fitting Ratio} := \frac{\text{Sum of indices}}{\text{Number of "A" parts}}
\]

Swift again recommends a target of <2.5, with improvements being focused on parts with a ratio of over 1.5
Automatic assembly: product requirements

To visualise the requirements for designing products for flexible automated assembly Gairola (1986) shows the relations between design features and assembly process features, Fig 19.

Fig 19: Requirements for design for flexible automatic assembly (Gairola, 1986).
Design Rules:

The approach of using design rules provides the designer with qualitative descriptions of good design practice, Fig 20. The design rules represent guidelines for how to carry out product design, including steps for the avoidance of problems (Tichem, 1997).

Fig 20: Schematic overview of the design rules approach, (Tichem, 1997).
DESIGN RULES

The main advantage with the use of design rules is that they are usually relatively easy to understand. This can also be the drawback, since the design rules may be over-simplified for solving a specific design problem. Tichem (1997) further points out the following drawbacks in the use of design rules:

- The application of a specific design rule is left to the judgement of the designer: there are no mechanisms, which trigger the designer to select a certain design rule.
- There is no support in deciding when to implement a design rule or when to reject it.
- The translation of the design rule into information regarding the actual design is also left to the designer.
- Design rules seldom contain a quantification of the effects reached in applying a design rule.
The key differences between the methodologies

1. **Scope:** The broadest in scope is Boothroyd-Dewhurst’s DFMA. It is the only method, which supports high-level decision making as to which assembly method to use - manual, dedicated automation or flexible automation.
2. That said, the commercial software implementation of the Lucas/Hull method goes far beyond DFA and supports many other aspects of the New Product Introduction Process.

3. The narrowest in scope is the Hitachi method. The focus is entirely on automated assembly, and it is not clear at the time of writing the degree to which the method takes account of piece-part manufacturing costs.
Track record

1. The DFMA and DFA methods both have excellent credentials with a wide range of UK and US clients.

2. DFMA includes in its client list US giants such as Ford, IBM, Polaroid, Brown & Sharpe, Digital, NCR and Texas Instruments. The Lucas DFA method has built on its UK auto industry roots, and is used by organizations of all sizes, including Rover Group, manufacturers of domestic appliances and international aerospace companies.

3. The track record of the Hitachi method is harder to bring into focus. Although successful within Hitachi, and commercially available outside, it is difficult to track down hard indications of widespread use beyond the originators.
Implementation and Ease of Use

1. Both DFMA and DFA are available as paper and software implementations.
Emerging Methodologies

- Design for Environment (Green Design)
- Design for test and Maintenance
- Design for Reliability.
Part- count reduction
Part- Count Reduction
Part- Count Reduction
Part- Count Reduction

2 2 2 3 4 5 5 4

Rs. 40  Rs. 375
DFMA – GUIDE LINES
Part - Count Reduction

23 to 1

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This totalizer wheel, injection-molded of Du Pont DELRIN acetal resin, takes over the five functions of what would normally be a 23-part metal assembly in an adding machine. It acts as an indexing gear, integral bearing, integral spring, position stop and print wheel. As an engineer, you can tally up the remarkable combination of properties that DELRIN contributed to this design: strength, stiffness in thin sections, resilience, fatigue endurance, hard surface, low friction, resistance to wear, to creep, to impact, to inks.

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Part- Count Reduction 21 to 9

Today’s ZYTEL nylon helps an engineer reduce cost by eliminating 12 components.

Your new design has to meet more demanding performance requirements. With the right engineering plastics, it can also eliminate a large number of metal parts... simplify assembly... reduce manufacturing costs and stand up to industrial abuse.

After testing 13 materials, including polycarbonates, polyesters and a modified polyphenylene oxide, you find that Du Pont ZYTEL nylon resin has the best combination of toughness and resistance to stress cracking, oils and chemicals. And yet it can be precision molded into a one-piece unit.

Combine multifunction design with “Zyte” nylon and the result is a new industrial dead-front plug having only 9 parts instead of 21 found in some conventional live-front plugs. Costs are down substantially while meeting the more demanding dead-front requirements.

There are more than 100 formulations of “Zyte” nylon resins that can do many things metal can’t. For specs and bulletins, write Du Pont Company, Room 25315, Wilmington, DE 19898.
Part- Count Reduction

12 to 2
Part- Count Reduction
Part- Count Reduction

One-Piece Fishing Pliers

Designers
Steve Visser,
Miro Tasic,
Ashok Midha

This concept for a convenient fish hook remover is based on a compliant mechanism—one part flexes while the rest remains rigid. The single-piece design makes the pliers easy to manufacture and recycle. Injection molded of a durable structural plastic—Delrin—the device will not corrode, and will float if accidentally dropped overboard.
Part- Count Reduction

Three different production methods for zip fasteners. The elements of a metal zip fastener are produced by pressure casting, and are mounted one by one on a band (a). By laying the band in an injection moulding machine, and moulding each element round the band, a process without assembly operations is obtained (b). In another integrating method the zip is formed from plastic cord which is bent and sewn into shape as the teeth of the fastener (c).
Part- Count Reduction

A later process for making zippers
Part- Count Reduction
Part- Count Reduction 4 to 2
STUDENT PROJECT - SACHIDANANDA HEGDE, MSRSAS.

DESIGN FOR ASSEMBLY
DESIGN FOR MANUFACTURE

Design for NO assembly - DFNA
STUDENT PROJECT - RAJIV THOMAS, NTTF
STUDENT PROJECT - RAJIV THOMAS, NTTF

BEFORE DFMA

AFTER DFMA

1 2 3 4

5 6
DFNA – Design for No Assembly

Credit: Prof. Kota, University of Michigan

Four Bar Toggle Switch
DFNA – Design for No Assembly

Credit: Prof. Kota, University of Michigan

Flexure Forceps

One-piece molded polypropylene compliant forceps
(Naige Nunc International, Sweden)
DFNA – Design for No Assembly

Credit: Prof. Kota, University of Michigan

A typical stapler in the market today has about 20 parts.

When we use the concept of compliance, we can carve the whole stapler as a single part.
DFNA – Design for No Assembly

Credit: Prof. Kota, University of Michigan

Single Piece Flexure Stapler
DFNA – Design for No Assembly

Credit: Prof. Kota, University of Michigan
Flexure Grippers

- Flexure Gripper has a unique design with two main configurations

- The first configuration consists of the flexible arm, and the two handles connected with a flexural pivot
Flexure Grippers

The second configuration consists of the extension arm and handles attached as one single piece.

**Application**
Mechanic's or Electrician's Gripper

**Advantages**
Allows small parts such as washers to be held tight without having to squeeze the compliant grippers. It's also electrically insulated.
Summary

• DFMA methodologies
  - formalise the procedure of studying designs
  - provides documentation and makes DFA skills accessible to non experts
  - Quantifies design performance and provides measurable standards for comparison of alternate concepts

• Various methodologies and design rules have been developed for the benefit of designers and to improve product design efficiency of firms