DEVELOPMENT OF A METHODOLOGY TO ENHANCE DESIGN FOR ASSEMBLY

by

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NOMENCLATURE

2D	Two Dimensional
3D	Three Dimensional
3D rendering	The process of translating three-dimensional geometrically defined objects into images that appear to have depth. 3D rendering techniques include ray tracing and radiosity, but neither is suitable for producing real-time 3D graphics
AEM	Assemblability Evaluation Method
API	Application Programming Interface
Browser	Software that provides the user with a means of viewing and navigating through a virtual world
C++	An object-oriented programming language
CAD	Computer Aided Design
CAD/CAM	Computer Aided Design / Computer Aided Manufacturing
CAE	Computer Aided Engineering
CD	Conceptual Design
CE	Concurrent Engineering
CGI	Common Gateway Interface
Con-Con	Evaluation and Convergence
CSC	Computer Sciences Corporation
DAC	Design for Assembly Cost - Effectiveness
DFA	Design for Assembly
DFM	Design for Manufacture
DFMA	Design for Manufacture and Assembly
DIANA	Disassembly Analysis
DLLs	Dynamic Link Libraries
E	Assemblability evaluation score ratio
EAI	External Authoring Interface
ECO's	Engineering Change Orders
EDFA	Enhanced Design For Assembly
GUI	Graphical User Interface
HTML	Hyper Text Markup Language
IEC	The International Electro technical Commission
IGES	Initial Graphics Exchange Specifications

IPPD	Integrated Product Process Development
ISO	International Organization for Standardization
Jar	Java archive file
Java	An object-oriented programming language
K	Assembly cost ratio
MN	Market Needs
Node	A basic syntactic element in VRML
OCX	OLE Custom Control
OLE	Object Linking and Embedding
PC	Personal Computer
PDES	Product Data Exchange using STEP (originally: Product Data Exchange specification) a US programmed of work
PROTO	Prototype
QFD	Quality Function Deployment
RGB	The color space that is defined by red, green, and blue intensity values
SGI	Silicon Graphics, Inc.
Shells	An object-oriented programming language
SP	Specifications
SQL	Structured Query Language
STEP	Standard for the Exchange of Product Model Data
TCL	An object-oriented programming language
URL	Uniform Resource Locator
UTF-8	The character set used to encode VRML files
VA	Virtual Assembly
Visual Basic	An object-oriented programming language
VM	Virtual Manufacturing
VP	Virtual Prototyping
VR	Virtual Reality
VRML	Virtual Reality Modeling Language
VRP	Virtual Reality Prototyping
WWW	World Wide Web

PEMBANGUNAN KAEDAH UNTUK MEMPERKASA REKA BENTUK UNTUK PEMASANGAN

ABSTRAK

Pemasangan adalah aktiviti yang mana reka bentuk kejuruteraan, pembuatan, dan logistic di bawa bersama untuk mencipta objek yang menjalankan sesuatu fungsi. Reka bentuk untuk Pemasangan (DFA) adalah pendekatan yang menekankan simplifikasi struktur produk, di mana jumlah komponen yang rendah bagi sesuatu produk adalah penunjuk utama dalam kualiti pemasangan produk. Objektif kajian ini adalah untuk membangunkan kaedah untuk membantu pereka bentuk memperbaiki pembangunan dan reka bentuk produk. Dua konsep utama yang merupakan pusat kepada pembangunan DFA ini iaitu pertama bagaimana untuk memperkasa DFA dan yang kedua bagaimana untuk membangunkan sistem penilaian untuk DFA. Pembaikan / peningkatan DFA dipengaruhi oleh prosedur kukuh untuk memperbaiki reka bentuk produk, kaedah yang boleh dipercayai untuk menyelesaikan masalah dalam aktiviti pemasangan dan keupayaan untuk meningkatkan idea dalam reka bentuk produk. Rangka kerja yang telah diintegrasi dan aplikasi perisian telah dibangunkan untuk merealisasikan objektif kajian ini. Teknik yang telah dibangunkan dinamakan Enhanced Design for Assembly 'EDFA' dan mengandungi prinsip yang disesuaikan daripada Hitachi AEM, sistem pembuatan maya dan prinsip dan penduan pemasangan. Daripada kajian kes yang menggunakan pendekatan EDFA menunjukkan pengurangan kerumitan pemasangan, pengurangan keseluruhan kos pemasangan dan pengurangan jumlah bilangan komponen dalam pembangunan dan pembaikan produk. Perisian EDFA mudah digunakan dan membantu kerja pereka bentuk dalam pembangunan dan pembaikan reka bentuk produk. Perbandingan antara kaedah EDFA dan Boothroyd-Dewhurst menunjukkan keupayaan EDFA yang lebih baik.

ABSTRACT

Assembly is the activity in which the activities of design, engineering, manufacturing, and logistics are brought together to create an object that performs a function. Design for Assembly (DFA) is an approach that addresses product structure simplification, where the total number of parts in a product is a key indicator of product assembly quality. The objective of this research is to develop a methodology to help the designer improve product design and development. The two main concepts that are central to the development of Design for Assembly (DFA) method are firstly how to make enhancement of DFA, and secondly how to develop an evaluation system for DFA. The enhancement of DFA is characterized by a robust procedure to improve product design, a reliable method to solve problems in design for assembly activities and the ability to increase ideas in product design. An integrated framework and a software implementation are developed in order to realize the research objective. The integrated approach is called 'Enhanced Design For Assembly' (EDFA) and consists of the principles adopted from the Hitachi AEM, virtual manufacturing system and assembly principles and guidelines. From the case studies that have been carried out using the EDFA approach the results showed that it can minimize assembly complexity, reduce the overall assembly cost and reduce the number of part and component in product development and improvement. The software 'EDFA' is easy to use and helps the designer's work in product design development and improvement. The comparison of EDFA method with Boothroyd-Dewhurst shows the capability of producing good results.

Chapter 1

INTRODUCTION

1.1 Introduction

New product development and product design and improvement are the important activities that manufacturing companies need to undertake in order to stay competitive. Generally, the main objective in product design and development is how to make the product more innovative and at the same time meeting the customer (market) requirements. Actually, customers and markets need a simple product design, high quality, friendly, and lower price (cheaper). Miles (1998) defined five major parameters that governs product introduction process:

1. Customer satisfaction – quality, reliability and value,
2. Market share and company image,
3. Product manufacturing cost – materials and process,
4. Time to market, and
5. Productivity - development and operations.

Fujita, et al (1999) defined three views for understanding and designing a product, mapping among customer, function and manufacturing, as shown in Figure 1.1.

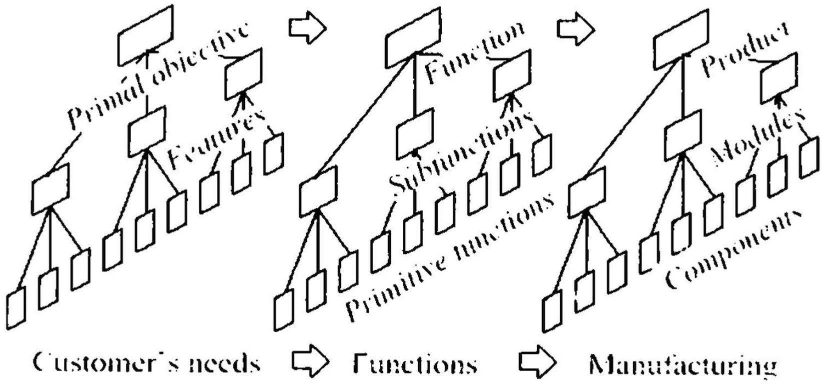


Figure 1.1 Relationship between customer needs, functions and manufacturing (Fujita et al. 1999)

The meaning of customer, function and manufacturing view are:

- *Customers view* ... Customer's needs and interests in customer's language. This view relates to subjective origins of a product.
- *Function view* ... Function structure that emerges and explains technological phenomena of an artifact, which may correspond to physical laws.
- *Manufacturing view* ... Structure or sequence in which a product is established from raw material through parts, components and modules.

The product life cycle, customer-needs activity in relation to other concept development activities following Ullrich et al. (2000) is shown in Fig. 1.2.

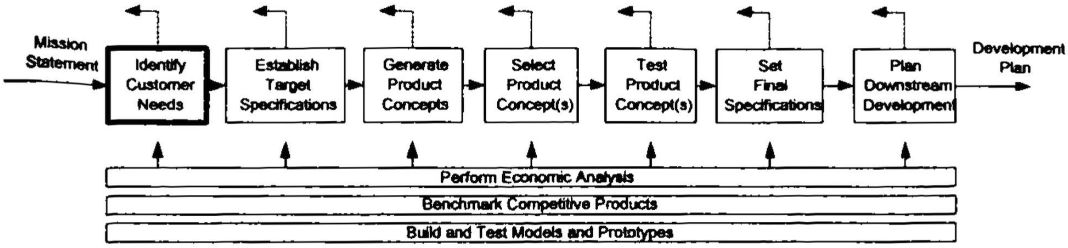


Figure 1.2 Customer-needs activity in relation to other concept development activities

Usually, product development activities follow and are based on market and customer needs. Development of characteristics of product design can be achieved by adopting developed concepts, methods, approaches, etc. Reducing of product complexity, minimize time to market cannot be solved by using traditional design method where design activities are performed sequentially. Instead, the whole design, manufacturing and assembly must be approached commontly. This will ensure the economic objectives of design and manufacturing can be achieved. Thus Design for Assembly (DFA) is on approach where assembly related aims are addressed during the design stage. Design for Assembly (DFA) has one important characteristic; it addresses product structure simplification, since the total number of parts in a product is a key indicator of product assembly quality (Redford and Chal, 1994). There are two main concepts that are central to the development of Design for Assembly (DFA) methods; firstly is how to make enhancement of DFA, and secondly is how to develop an evaluation system for DFA. Many solutions have been proposed to enhance and develop evaluation system for DFA. There are three main popular approaches to enhance and develop design evaluation system; the first is to apply one of the established methods such as apply Boothroyd-Dewhurst DFA method, the second is to integrate the established methods for example the integration of Value-Engineering and Lucas Engineering DFA method, the third is to integrate the established method with other method such as integration of Hitachi AEM DFA and Virtual Systems also Boothroyd Dewhurst and Disassembly Analysis (DIANA) (Hrinyak et al. 1996).

The background of methodology development is the need to make product design and development especially Design for Assembly (DFA) method more robust, effective and efficient. Green and Bonollo (2002) illustrated that design methodology includes the study of the principles, practice and procedures of design. Its primary focus is to develop a deep and practical understanding of the design process and how this process can be modified, made more effective and transparent, and be managed to achieve sustainable design outcomes.

The activities associated with the design process are grouped into four phases (Green and Bonollo, 2002) (Pahl and Beitz, 1988) and (Vliet et al. 1999):

1. Clarification of the task / product planning.
2. Conceptual design (generation of conceptual solutions by means of functions break – down, searching for working principles and combining them to working structures).
3. Embodiment design (initial design, product structure).
4. Detail design (drawings, process instructions).

The phases of the design process application in engineering design, industrial design and product development are shown in Table 1.1.

Table 1.1 Phases of the design process

Engineering Design	Industrial Design	Product Development
		Product planning
Clarification	Clarification	Clarification
Conceptualizing	Concept generation	Concept generation
Embodiment	Evaluation and refinement of design concepts	Evaluation / embodiment
Elaboration and detailing	Detailed design	Detailed design
	Communication of results	Communication of results
		Preparing for production

1.2 Objective of the Research

The main objective of this research is to develop a methodology to help the designer improves the product design such as to reduce assembly cost, assembly time and to reduce the number of part and component. It also consists of an evaluation system for design for assembly. The enhancement of DFA is characterized by:

1. Robust method to improve process and product design,
2. Robust method to solve problems in design for assembly activities,
3. Able to increase ideas in product design.

The second objective is to design and develop a software implementation of the methodology.

1.3 Research Methodology

In order to achieve the research objectives, the following research activities will be carried out:

1. Detailed review of the current DFA approaches,

2. Development of a concepts for integrating the principles from Hitachi DFA and VM,
3. Development of a software to implement the method,
4. Development of an evaluation system in DFA based on the proposed method,
5. Performing of two case studies to ascertain the consistency and completeness of the proposed method,
6. Comparison of performance of the proposed methodology with the more established method.

Figure 1.3 shows the flow chart of the research methodology.

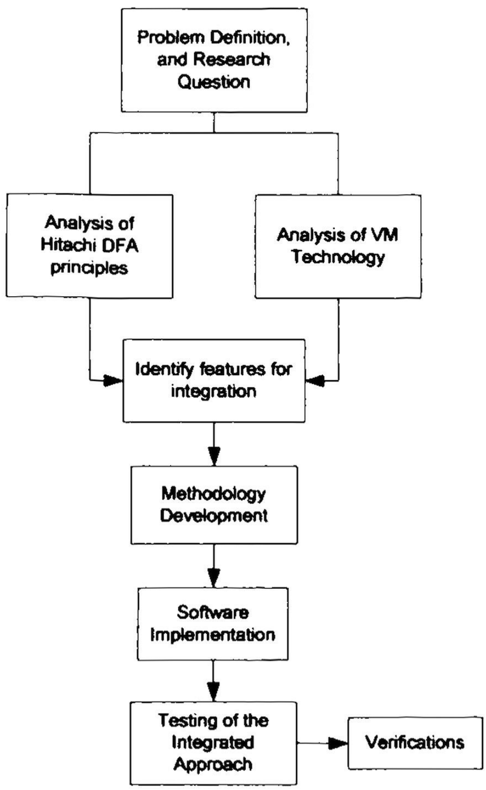


Figure 1.3 Research Methodologies

1.4 Significance of Findings

The integration of Hitachi AEM DFA, assembly principles and guidelines and virtual manufacturing has resulted in a robust system for product improvement and development. The integrated approach has the capabilities to reduce assembly time, reduce assembly cost and reduce the iterative step of design. The integrated approach has incorporated virtual technology to visualize the product design. The virtual technology can simulate, animate, and assemble virtually and as virtual prototype of the product design. The virtual prototype can reduce physical prototype, time, cost and design steps in product development.

1.5. Thesis Organization

The thesis is organized as follows:

Chapter 1 is introduces the need for design for assembly method. The research problem, research objective and research methodology are discussed in the chapter.

Chapter 2 is a review and discussion of the Design for Assembly methodologies, the justifications, the characteristics, the capability and the comparison of DFA method. Assembly principles and guidelines, the characteristics of Hitachi AEM and Virtual Manufacturing technology are also discussed in the chapter.

Chapter 3 describes the methodology development it covers the background of methodology development, justification for selecting Hitachi AEM and Virtual Manufacturing in the methodology development and the structure of the methodology development.

Chapter 4 is a discussion of software design and development, software implementation of the methodology, and application program language.

Chapter 5 is a discussion of the implementation of the methodology using the two case studies. The analysis of the improvement, evaluation of the improved product design and application of virtual manufacturing features for the case studies are also presented.

Chapter 6 discusses the results from the case studies.

Chapter 7 concludes the presentation of current research and suggests further work of the research.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Design for Manufacture and Assembly (DFMA) is an approach for making product design and development more efficient and effective. The aim is to reduce product development time and to reduce wastage of resources. Many tools and methods have been developed in order to implement the DFMA approach. This chapter reviews the various tools and methods of DFMA such as DFA, Hitachi AEM, and Virtual Manufacturing.

2.2 Design for Manufacture and Assembly (DFMA)

Design for Manufacture and Assembly (DFMA) is the integration of the separate but highly interrelated issues of manufacture and assembly processes. It aims to help companies make the fullest use of the manufacturing processes that exist, while keeping the number of parts in an assembly to a minimum (Kitsios, 2000). DFMA is an integration of techniques for Design for Manufacturability (DFM) and Design for Assembly (DFA) (Schrijver, 1994) (Boothroyd, 1999). DFMA contributes to the competitive success by matching product demands to manufacturability and assembly capability. The major characteristics of DFMA are:

- The efficiency of the design process is increased as both parts of manufacturing and assembly are taken into account in the optimization of the design, because by only considering one of these processes may lead to sub-optimization.
- The closed loop approach which means that product design, process planning and production equipment design are executed in parallel. Throughout the entire design process numerous decisions are taken which have consequences for production. By parallel execution the effect of a design decision on production can be evaluated, at-the-moment the decision is taken. This approach helps improve the product design quality and it helps in reducing time-to-market.
- Commitment to continuous product and process optimization is maintained

2.2.1 DFMA Applications

DFMA methods to improve product design and development have been implemented in many manufacturing industries. Batchelor and Schmidt (2000) showed that the DFMA procedure as preventive optimization process is profitable when a new product has to be designed and marketed or an existing one improved under new targets of costs and functions. A number of published international case studies have even shown a drastic simplification with the reduction of part counts, manufacturing costs and shorter time to market as shown in Table 2.1 (Batchelor and Schmidt, 2000). There is however no guarantee and no general recipe available to achieve those savings in all applications. The results of some industrial applications are described.

Table 2.1 Improvements due to DFMA Applications (Batchelor and Schmidt, 2000)

	No. of Cases	Average Reduction (%)
Part count	55	57
Separate fasteners	12	72
Assembly operations	9	60
Assembly time	37	63
Assembly cost	16	45
Material cost	3	37
Product cost	15	51
Product development / time to market	4	50
Manufacturing cycle time	6	58
Work in process	1	31
Manufacturing process steps	3	45
Number of suppliers	3	55
Adjustments	2	94
Assembly defects	3	68
Service calls	2	78
Failure rate	1	80
Fixtures / assembly tools	7	72

In the automotive industry improvements brought about by the application of DFMA are shown in the case study of GM Power train in Strasbourg. The team used DFA in analyzing the current design of the overdrive system and was guided through the improvement process. The exercise increases the DFA-index from 13 to 28 and a reduction of the number of parts, operations and assembly time of 40 per cent. In a three-day workshop different teams analyzed the whole product in order to find new ideas - which formed a base for the overall potential for cost savings and the redesign. The same procedure was repeated again three months later in order to confirm quality and savings.

The DFMA methodology provides a systematic means of qualifying the existence of components in an assembly (Boothroyd, et al. 1994). In short, these qualifying criteria lead to a minimum part count design - which includes (Gauthier, et al. 2000):

- A stable chassis for assembly to begin
- Needed relative motion between parts

- Needed unique materials
- Required interfaces to make assembly possible

DFMA is utilized by many companies in an effort to cut down concurrent manufacturing and assembly time. The second example for DFMA applications is shown in Fig. 2.1. The application is on the design of Pilots Instrument Panel of the AH64D Helicopter (Herrera, 1997). The first assembly examined is the Pilot's Instrument Panel, which is comprised of a combination of sheet metal angles and extruded stiffeners. The panel itself is attached to an existing airframe structure with rivets. It consists of 74 parts with a weight of 3.00 Kilograms. The fabrication time for this instrument panel is 305 hours. This panel also requires a final assembly - tooling fixture in addition to tooling needed to form all brackets and angles. The use of DFMA has resulted in the redesign of the pilot's instrument panel, into only 9 parts. Subsequent analysis yielded data indicating that the fabrication time could be reduced to 20 hours. The total manufacturing and assembly time would be reduced from 697 hours to 181 hours, weight reduction to 2.74 Kilograms, and the total cost was reduced by 74%. Table 2.2 provides a summary of the estimated comparison for the Pilot's Instrument Panel.

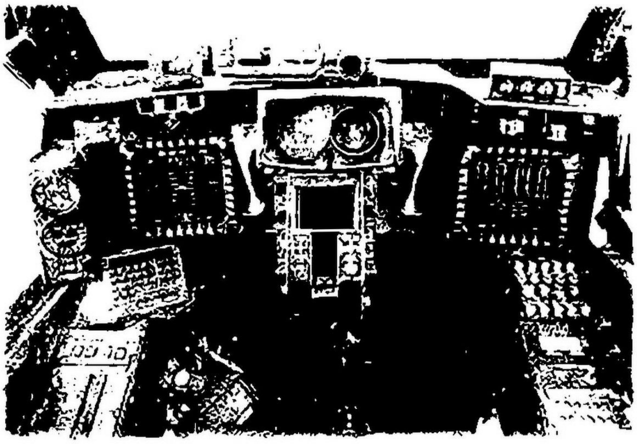


Figure 2.1 Pilot's Instrument Panel

Table 2.2 Pilot's Instrument Panel Estimate Summary (Herrera, 1997)

	Present Instrument Panel	DFMA Proposed Instrument Panel
Part Count	74 pieces	9 pieces
Fabrication Time	305 Hours	20 Hours
Assembly/Installation Time	149/153 Hours	8/153 Hours
Total Time	697 Hours	181 Hours
Weight	3.00 Kilograms	2.74 Kilograms
Cost	74% Reduction	

In addition, data were obtained for three other areas: The Co-Pilot Gunner (CPG) instrument panel was a good candidate for DFMA due to its assembly complexity, number of parts and rivets required to assemble it. It included the Up-Front Display (UFD) tray and the Multifunction Display (MFD) tray. These last two sub-assemblies of the CPG instrument panel made it very difficult to assemble and require extensive labor for the assembly activity and the final installation. The total original part count was 87 parts. Presently it has been reduced to 12 parts, where 7 are machined parts and 5 are sheet metal/composite parts. The original instrument panel is a combination of sheet metal parts representing more than 90% of the total parts and a few machine parts being fastened mechanically. Bench tooling is required to perform the sub-assemblies of the

UFD and MFD trays, making the task very difficult. With the simplified DFMA instrument panel, sub-assembly is minimal, representing a considerable amount of time and cost savings, as well as weight savings.

2.2.2 Design for Manufacture (DFM)

Design is an activity for converting specification descriptions to design description ready for implementation and, in general, includes within it the concerns of manufacturing (materials, processing, and equipment) and also concerns felt further down the life cycle of the product (e.g., maintenance and disposal) (Kannapan and Marshek, 1992). Design for manufacturing is defined as a method consisting of the following steps (Vliet et al. 2001):

1. Selection of an optimal combination of the material, geometry and manufacturing method for all parts of the product, suited to fulfill the functional requirements of the product.
2. A continuous evaluation of the manufacturability of the product design throughout the entire design process, via the stages verification and quantification.

Design for manufacturing aims at improving the efficiency of the product realization process by explicitly considering the product manufacturability during the design stage. Design for manufacturing is one of the most integrative practices involved in product development. DFM utilizes information of several types, including (1) sketches, drawings, product specifications, and design alternatives; (2) a detailed understanding of production and assembly processes; and (3) estimates of manufacturing cost, production volumes, and rump-up timing. DFM therefore requires the contributions of most members of the development team as well as outside experts. DFM effort commonly draws upon expertise from manufacturing engineers, cost accountants, and production personnel, in addition to product designers. Many companies use structured, team-based workshop to facilitate the integration and sharing of views required for DFM. (Ulrich and Eppinger, 2000).

2.2.3 Design for Assembly (DFA)

Assembly is the activity in which all the upstream processes of design, engineering, manufacturing, and logistics are brought together to create an object that performs a function. Design for Assembly (DFA) as a central element of DFM has one important characteristic; it addresses product structure simplification, since the total number of parts in a product is a key indicator of product assembly quality (Redford and Chal, 1994). The aim of design for assembly (DFA) is to make processes of design, manufacturing and assembly more robust and to increase assemblability. Specifically, the results of assemblability analysis depend on how and which method is used in solving DFA problems. The assemblability of each part in the assembly is quantified into five categories (Boothroyd and Dewhurst, 1989; Matthew, et al, 1996):

1) Minimum number of parts criteria. The crux of the DFA methodology, the minimum number of parts criteria, embodies the belief that only a certain few parts really need to exist in an assembly. Each part is questioned as to its real need in an assembly. A part that is not theoretically required in the assembly is a candidate for elimination. The minimum number of parts criteria can be tricky to define for a given part, but with practice one can become proficient at it.

2) Part shape and size. The part shape and size questions are used to describe the general shape (either rotational or non-rotational) and volumetric envelope of a component. Part shape can be obtained visually and part size can be measured. Larger parts may incur additional assembly time penalties.

3) Part Symmetry. Part symmetry is a measure of how far a part must be rotated about its axis of insertion before it can be correctly inserted, and can be obtained by visual inspection of the part. Symmetry matters because, ideally, a part should not need to be oriented a specific way to be inserted; a part should be able to be assembled properly no matter how it is placed into an assembly.

4) Handling difficulties. Handling difficulties are used to describe any problems we encounter from the time we pick up a part from a bin to the time right before it is inserted into the assembly. Such problems might occur if parts are sticky, flexible, or sharp, etc. Handling difficulties can be obtained visually, but they can be better quantified if parts can be physically handled. Handling difficulties only increase assembly time.

5) Insertion difficulties. Insertion difficulties, like handling difficulties, add time to assembly. Insertion can be compromised if we have poor accessibility or a restricted view of the mating location, if there is resistance to insertion, if there are alignment problems, or if we have to hold the assembly down in any way. As with handling difficulties, insertion difficulties can be better quantified if parts can be physically inserted.

Many solutions are available to make assembly design more effective and efficient. One of it is how we can make assemblability more robust and one factor for it is we must solve attachment problem in assembly design. An example of design features effecting assembly is shown in Figure 2.2, where there are five different solutions for the same attachment problem taken from the gas flow meters. It can be seen that, on the left, the simplest method for securing the housing consist of a simple snap fit. In the examples on the right, not only does the assembly time increase but also both the number and cost of parts increases. This illustrates the two basic principles of design for ease of assembly of a product, namely, reduce the number of assembly operations by reducing the number of parts and make the assembly operations easier to perform (Boothroyd, 1999).

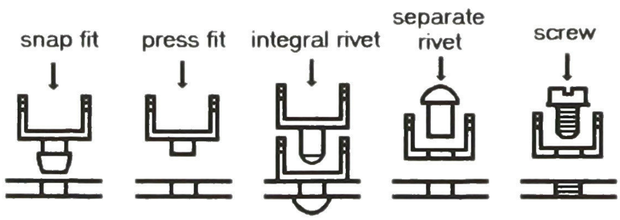


Figure 2.2 Examples of design features affecting assembly

Parallel with the developments described above there was much talk in the 1960s and 1970s about designing products so they could be manufactured more easily. Design guidelines and producibility rules were proposed. However, many of these could direct the designer in the wrong direction. As an illustration of a misleading recommendation, Fig. 2.3 shows a design guideline where the emphasis was on simplifying the individual parts (Pahl and Beitz, 1984).

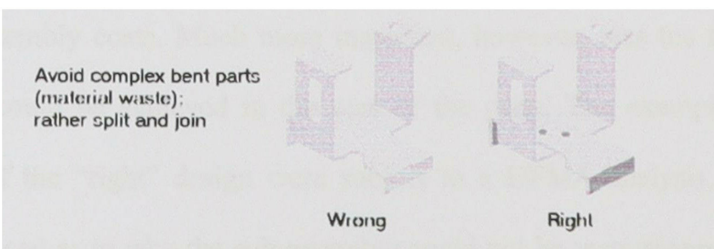


Figure 2.3 Misleading producibility guideline

Boothroyd (1999) mistakenly assumed that several simple-shaped parts are inherently less expensive to manufacture than a single complex part and that any assembly costs are more than offset by the savings in part costs. Table 2.3 shows the results of a cost analysis of the two designs.

Table 2.3 Estimated costs in dollars for the designs in Fig. 2.3

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

(Product Life Volume = 100,000)

Even ignoring assembly cost, the two parts in the "right" design would be significantly more expensive than the single part in the "wrong" design-even the piece part costs (neglecting tooling costs) would be greater. Taking assembly costs into account and ignoring storage, handling, quality and paperwork costs, the "right" design is estimated to be 50% more costly than the "wrong" design!

Once methods for analyzing assembly difficulties were developed, the conflict between producibility and DFMA became apparent. It was found that simplifying products by reducing the number of separate parts through DFA could easily achieve substantial reductions in assembly costs. Much more important, however, was the fact that even greater savings could be achieved in the cost of the parts. The example in Fig. 2.3 illustrates this. If the "right" design were subject to a DFMA analysis, the designer would be challenged as to why the sub-assembly could not be manufactured as a single part thereby eliminating an assembly cost of 20 cents. Further analysis would show additional savings of 17 cents in part costs (Table 2.3).

2.2.3.1 Justification of DFA

A better decision for solving problems in design and assembly activities is how we can choose and apply a relevant and familiar method for solving it. We can reduce time, cost and also make design activity more economic if we have the capability for it. Generally, the problems in product design and development can be solved by applying one of the established methods DFA. Several factors are involved in choosing a methodology in design for assembly problem, and is dependent on cases, experiences, and targets. Fig. 2.4 shows the comparison of the traditional (serial) engineering and the approach employing design for assembly engineering. Tables 2.4 and 2.5, compare the tools, ability and techniques on quality, cost and time between DFA and others methods.

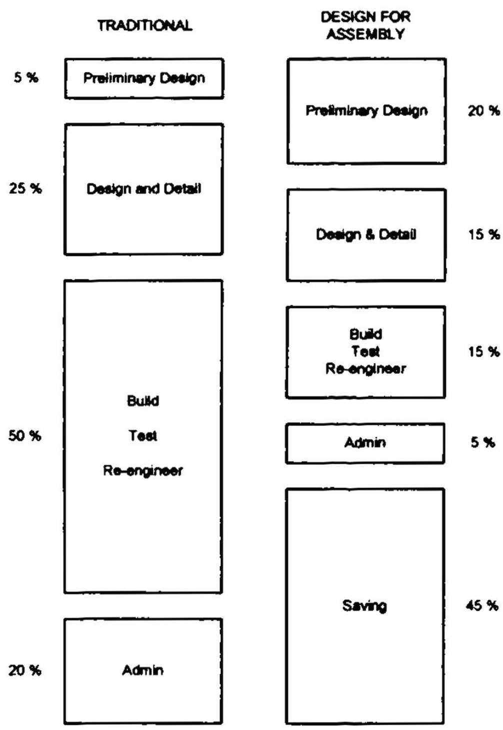
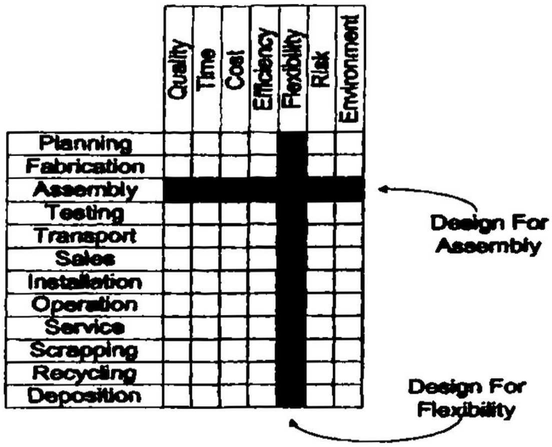


Figure 2.4 Comparison of the traditional (serial) engineering and employing design for assembly engineering (Kocabicak, 1999)

Table 2.4 The impact of tools & techniques on quality, cost and time (Miles, 1998)

O Medium • Strong		QFD	Con-Con	DFA	MA	FMEA	DTC	DOE
Quality	Robust design	O	O	O	O	O		•
	Customer satisfaction	•	O			•		•
	Right first time	•	•	O	O	•		O
Cost	Low cost manufacture		O	•	•		O	O
	Low investment cost		O	•	•		O	
	Achieve target cost		O	O	O		•	
Time	Minimize lead-time	O		•	O	O		

Table 2.5 DFX as lifecycle oriented or ability oriented (Andreasen, 1993)



DFA method has significant capabilities in design improvement and was adopted in many companies. Table 2.6 shows an example of result obtained after using DFA technique in German companies. DFA-index, assembly time, production and tooling costs are used as indicators.

Table 2.6 Results of DFA-project (Womack and Jones, 1996)

	Without DFA	**With DFA**
DFA-index (per cent)	3,9	18,3
Total assembly time (sec.)	146,6	31,4
Total production costs (DM)	2,44	0.52
Total assembly weight (kg)	0,38	0,36
Total tooling costs (DM)	500.000	350.000

Several DFA methods are available, as shown in Table 2.7 (Egan, 1997). Other related tools of DFA are presented in Table 2.8 (Baiter, et al. 2000).

Table 2.7 Commercially available DFA methods (Egan, 1997)

DFA method	Authors	Country of origin
Assemblability Evaluation Method (AEM)	Ohashi, Yano	Japan
Boothroyd-Dewhurst DFMA	Boothroy, Dewhurst	USA
A systematic approach to Design For Assembly	Miles, Swift	UK
A designers guide to optimize the assemblability of the product design (DGO)	Hock	USA
ASSEMBLY	DeWinter, Machiels	Belgium
Assembly Oriented Product Design (AOPD)	Bassler, Warnecke	Germany
Assembly SYStem (ASSYST)	Arpino, Gropetti	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

Table 2.8 Related Tools of DFA (Beiter, et al. 2000)

Name of Tool	Organization
Hinckley Assembly Complexity factor	Stanford
Assembly Evaluation Method	Hitachi
Modified Westinghouse DFA	GE Aircraft Engines
Sony Standard Time Assembly Method	Sony Electronics
Design for Assembly	Boothroyd & Dewhurst
Westinghouse DFA	R. Sturges

The contents of commercially available DFA methods and related tools of DFA as shown in Tables 2.7 and 2.8 are same as DFA tools. Actually, Table 2.7 is commercial perspective of DFA and Table 2.8 is related tool perspective of DFA.

Fig. 2.5 illustrates how DFA is applied in practice Kocabicak (1999). The current design of a motor drive assembly must sense and control its position on two steel guide rails. The motor needs to be fully enclosed for aesthetic reasons but have a removable cover for sensor adjustments.

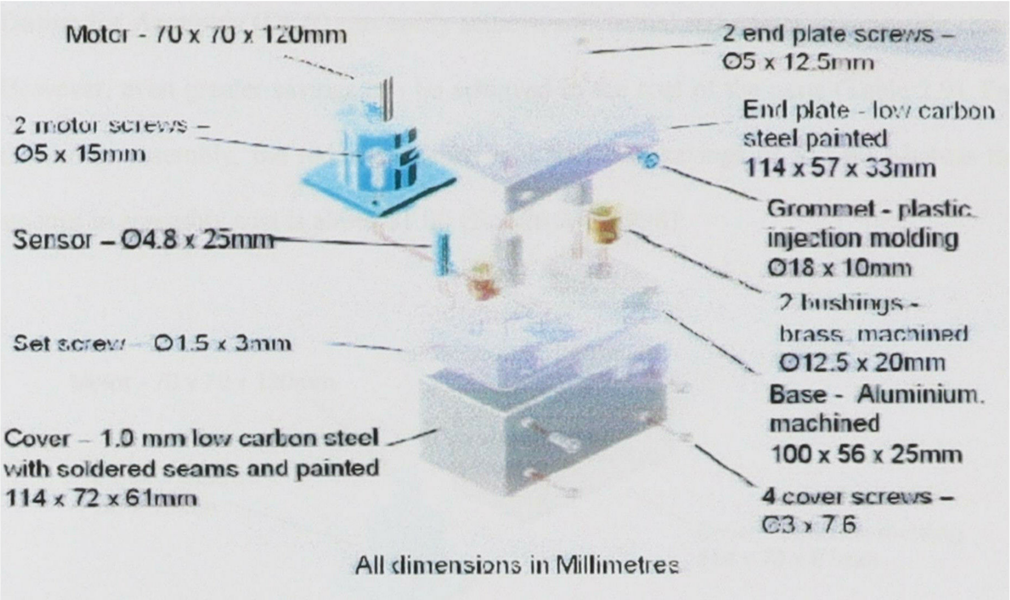


Figure 2.5 Current design of motor assembly

The base is provided with two bushes to provide suitable friction and wear characteristics. The motor is secured to the base with two screws and a hole in the base accepts the sensor, held in place with a setscrew. For a cover, two screws to two stand-offs screwed into the base secure an end plate. The end plate is fitted with a Plastic Bush through which wires pass. A box-shaped cover slides over the whole assembly secured by four screws. In brief, there are 2 subassemblies a motor and a sensor, which are essential items and 8 additional parts, and 9 screws making a total of 19 items.

In this simple analysis, the two subassemblies could be arranged to snap or fasten into the base and a cover designed to snap on, then there would only be 4 separate items instead of 19. These 4 items represent the 'theoretical minimum number' needed to satisfy the constraints *without* considering practical limitations. In this example, it can be argued that two motor screws are needed, and one screw to hold the sensor because alternatives are impractical for a low volume item such as this (Fig. 2.6).

Design for Assembly (DFA) can easily achieve substantial reductions in assembly costs. However, even greater savings can be achieved in the cost of the parts (Table 2.9). For the motor assembly, the redesign results in a part cost savings of $12.80 whereas the savings in assembly cost is about $1.00 (Boothroyd, 1998).

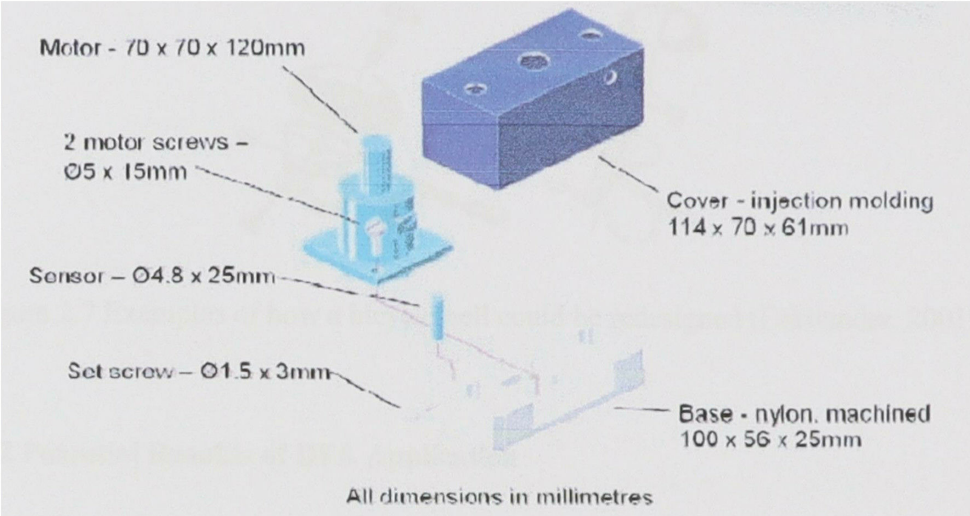


Figure 2.6 Redesign of motor assembly

Table 2.9 Part and Tooling costs for motor assembly

Current design	Cost ($)	Redesign	Cost ($)
Base (aluminium)	15.29	Base (nylon)	13.04
Bushing (2)	3.06	Motor screw (2)	0.20
Motor screw (2)	0.20	Set screw	0.10
Set screw	0.10	Plastic cover	8.66
Stand-off (2)	9.74	(includes tooling)	
End plate	2.26		
End plate screw (2)	0.20	Total	22.00
Plastic grommet	0.10		
Cover	3.73	Tooling cost for plastic	
Cover screw (4)	0.40	Cover - $8k	
Total	35.08		

Figure 2.7 illustrates another example on how part reduction may be achieved. The redesigned bicycle bell is not an ideal product since the fastener of the bell onto the bicycle is not the best. However, it is a good example of how assembly may be simplified with the use of DFA. Part count is reduced from ten to three.

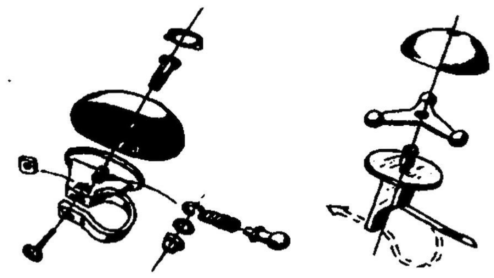


Figure 2.7 Examples of how a bicycle bell could be redesigned (Eskilander, 2001)

2.2.3.2 Potential Benefits of DFA Application

The application of DFA methodology in assembly and manufacturing projects has many benefits. Generally, the method can reduce time, cost, part, etc. and also can support assembly and manufacturing more effective. Some of the DFA benefits are summarized below (Andreason, et al. 1983):

- *High profitability.* Decrease in manufacturing cost always represents a very high percentage increase in profit. Statistical surveys show that 20 to 30% of assembly cost can be eliminated if company successfully implements of DFA.
- *High productivity.* The aim of DFA method is to simplify product design through minimizing the number of parts, so that less operation is needed to assemble a complete product. This would reduce assembly time and increase productivity at the same time.
- *High quality.* Assembly is extremely sensitive to alternations and variation in the quality of components. As a result, testing and checking of components is a