INTEGRATED APPROACH FOR IMPROVING PRODUCT DESIGN

MOSADDEQUE MAHMUD RIZWAN

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by

MOSADDEQUE MAHMUD RIZWAN

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Acknowledgement

Finally the long-term effort has come up to a conclusion through a successful write-up of this dissertation. I am extremely delighted for this long awaited moment of success in my life. I want to share my feelings with those whose contribution helped me to accomplish the work.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

AEM	Assembly evaluation method
CR	Customer requirement
DFM	Design for manufacture
DFA	Design for assembly
DFMA	Design for manufacture and assembly
DOE	Design of experiment
DP	Design parameter
E	Assemblability evaluation score ratio
FR	Functional requirement
K	Assembly cost ratio
p	Probability of success
PC	Physical concept
PV	Process variable
QFD	Quality Functional Deployment
RM	Ringgit Malaysia
S/N	Signal-to-noise ratio
$	United States Dollar

PENDEKATAN TERSEPADU UNTUK MENAMBAH BAIK REKABENTUK PRODUK

ABSTRAK

Pemasangan merupakan peringkat yang terpenting dalam pembangunan produk. Rekabentuk untuk pemasangan (DFA) adalah pendekatan terkini untuk menambahbaik rekabentuk produk agar lebih mudah dan mengurangkan kos dalam operasi pemasangan. Objektif utama projek penyelidikan ini ialah untuk membangunkan sistem DFA. Sistem ini sepatutnya menyokong teknik terbaru dalam DFA dan menyediakan peluang kepada pengguna untuk menilai dan mengurangkan kos pengeluaran; dengan mengurangkan masa pemasangan dan kos pada peringkat awal proses merekabentuk. Sistem ini diharap membolehkan perekabentuk mengurangkan bilangan komponen produk tanpa menjejaskan fungsi produk. Untuk menyempurnakan tugas yang penting ini, dua kaedah DFA terkini dipertimbangkan untuk menghasilkan rangka kerja analisis rekabentuk untuk keboleh pemasangan. Skop kajian termasuklah membangunkan analisis keboleh pemasangan sesuatu produk yang sistematik menggunakan aktiviti asas rekabentuk yang berturutan. Pengetahuan asas tentang prinsip dan peraturan DFA digunakan dalam kaedah saintifik menggunakan analisis keboleh pemasangan. Perisian 'PROPT' dibangunkan dalam kajian ini untuk memudahkan perekabentuk. Perisian ini menyediakan keputusan yang cepat dengan kejituan yang baik dan dapat menyimpan data rebentuk untuk rujukan pada masa depan. Dua kajian kes dipersembahkan mengguna perisian untuk menunjukkan kaedah yang dicadangkan dengan tujuan menentukan keberkesanannya dalam aplikasi sebenar.

ABSTRACT

Assembly is one of the most important stages of product development. Design for assembly (DFA) is a recent approach towards improving product designs for easier and less costly assembly operations. The main objective of the research work is to develop an improved DFA system. The system is supposed to support new techniques for design for assembly and to provide users opportunity to assess and reduce the total production cost by means of reducing assembly time and cost at the early stage of the design process. The system is expected to enable designers to minimize the number of components of a product without compromising the product functions. To accomplish such a crucial task, two most current DFA methodologies are reviewed in the current research work towards developing a framework for design for assemblability analysis. The scope of the work includes systematizing the assemblability analysis for a product through generic sequence of design activities with rational basis. The inherent knowledge of the DFA rules and principles are used in a systematic way throughout the assemblability analysis. The software 'PROPT' has been developed in this research work for the convenience of the designers. The software could facilitate quick result with best accuracy to be obtained and to preserve the design data for future reference. Two case studies have been performed using the software to illustrate the proposed method with a view to determine its effectiveness in actual application.

Chapter 1

INTRODUCTION

1.1 Background

In the early days up to 1960s, the manufacturing environment, both from the technological and operational points of view, was quite simple and international competition was of relatively mild and, thus, certain economic inefficiencies could be compromised. The product designer was probably justified then in assuming that the 'Production People' would tackle what they have designed. But things are completely different now; new products requiring new and demanding manufacturing techniques, are emerging almost every day. The scale of human activities has multiplied many folds, bringing with it enormous business opportunities. Today, progressive development of technology and diversification of customer needs (market pull and technology push, respectively) bring the marketplace into a very competitive environment (Rampersad, 1994). Increasing pressures from the marketplace are forcing industries to optimize products with competitive price, high quality and short delivery time. Industries, therefore, envisage new strategies to cope with the present situation of marketplace to optimize their product with respect to time and cost.

Consumers are seeking new product with competitive price, high quality and reliability. So, companies are trying to uphold their market share by enforcing manufacturing team to develop new products or make product variety within a very short time with high quality, reliability and low cost. The consumers' demands are completely diversified. However, diversified needs of consumers lead to industries producing diversified products. Product diversity is strongly related to product life cycle. The following life phases of a product are distinguished in the market: pioneering phase, penetration phase, growth phase, satiation phase and decay phase as shown in Fig. 1.1.

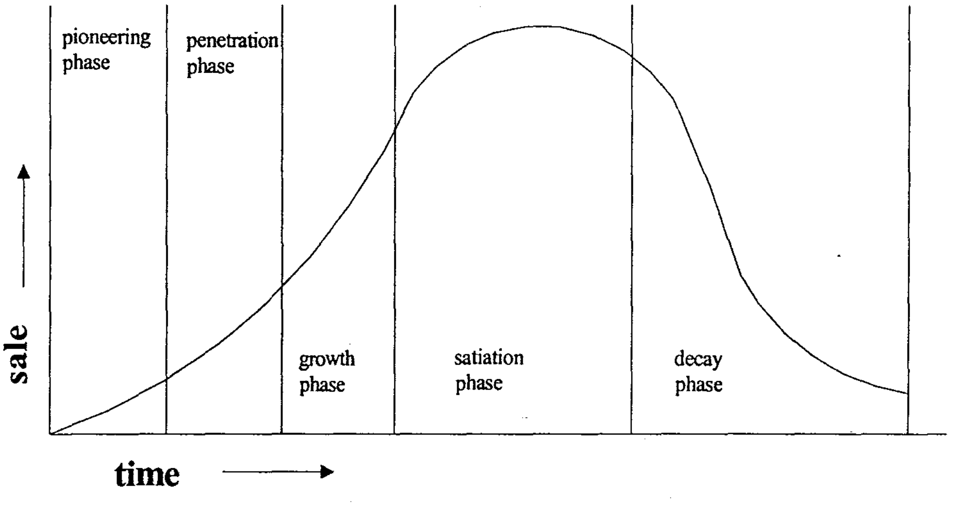

Figure 1.1 Life phases of a product (Rampersad, 1994)

A brief description of these life phases of a product is given as follows:

- Pioneering phase: a launching period when the product is introduced in the market.
- Penetration phase: a promotional period when the product is promoted through out the market and slowly brought on.
- Growth phase: a period when the product starts to sell well, and the sales rate increases rapidly.

- Satiation phase: a period where the product has lost its initial impetus, and sales grow slowly.
- Decay phase: a period of decline at the end of the life cycle.

The product life cycle indicates that product will disappear from the marketplace, owing to appearance of new products or removal of market needs. The life cycle (market life) of industrial products (e.g. electronics, automobiles etc.) has largely decreased over the recent time as shown in Fig. 1.2. The drastic change in product life cycle requires manufacturer to find new approaches and methodologies that can reduce the product design, manufacturing and assembly times.

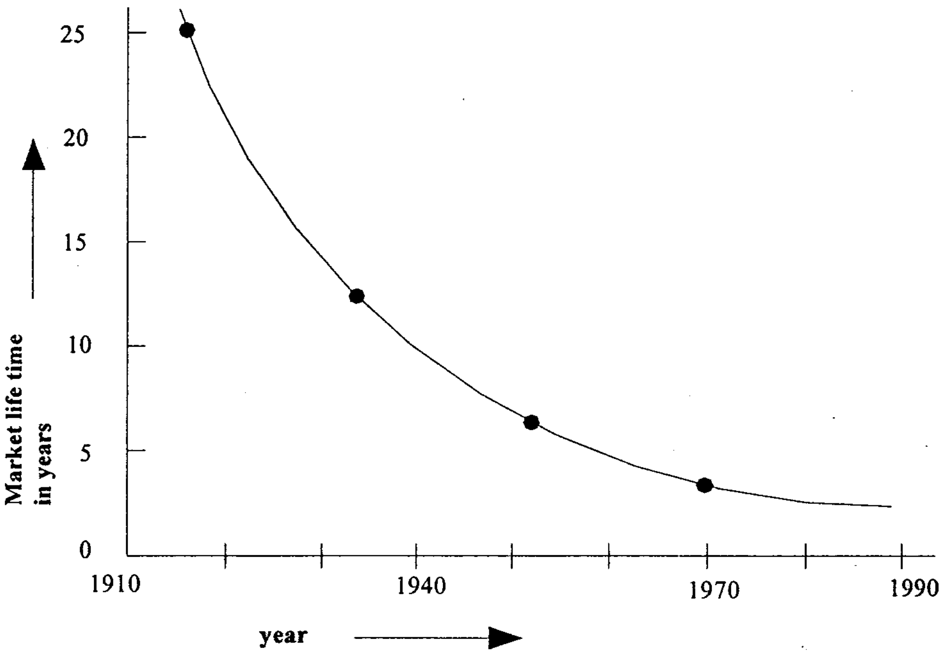

Figure 1.2 Market life of industrial products (Rampersad, 1994)

1.2 The Design Process

By definition, design is considered as a process of transforming information that characterizes the needs and requirements for a product into knowledge about that product and its implied process (Magrab, 1997). Early design decisions are those that involve the initial definition of the products' design. These decisions are generally made during the engineering design process, which typically involves the following design activities (Stoll, 1999):

1. Clarification and definition of the requirements of the product or design.
2. Development of working principle or physical concept for fulfilling the required product functions.
3. Decomposition of the physical concept into subassemblies and components; determination of the geometric arrangement (layout) of the components; establishment of dimensional relationships between components.
4. Decision making of which components are standard and which must be designed.
5. Selection of general type of material (e.g. polymer, metal) and basic manufacturing process (e.g. casting, machining) to be used for each designed component, if not already determined.
6. Determination of the configuration (i.e. size, shape, external and internal geometric features) of each designed component.

7. Selection of specific material and manufacturing process for each designed component.
8. Establishment of dimensions and tolerances for each designed component.
9. Mobilization of additional dimensions, tolerances and detailed information required for manufacture and assembly of the components.

Virtually, the design process begins with conceiving a physical concept for the product based on customer needs and a product specification and creating a preliminary layout of the design that embodies the physical concept. This initial phase is often referred to as the conceptual design phase and typically involves activities 1 through 5 listed above. The preliminary layout represents a conceptual arrangement that embodies the physical concept. It is preliminary in the sense that the only key dimensions and relationships between parts have been specified; the actual size, shape, and detail features of the parts are to be undefined or only partly defined. Design concept is considered as the combination of physical concept and part decomposition (Stoll, 1999).

The basic premise of this study is that product cost can be realized, product delivery time can be shortened and eventually productivity can be increased, if the design can be investigated systematically with rational basis at the early design and planning phase. The principle of the prediction is to reduce the engineering changes by anticipating the manufacturing and assembly problems in the primitive stage of the design process. In order to handle such a difficult task, Design for Assembly (DFA) has emerged as a systematically implementing procedure to optimize design. Here, the word 'systematically' refers to complete methodology by which designers can optimize their product/products through step-by-step implementation of the process described in this report. To demonstrate the broad essence of DFA, the Axiomatic Approach and the Boothroyd-Dewhurst DFA method are reviewed in this study. The two methods provide a rational and systematic approach to achieve the product design goals and simultaneously to allow a comparative means to find the design improvement. In this study the axiomatic approach is used to analyze the product systematically. Axiomatic approach is used to translate the project goals or customer requirements (CRs) to functional requirements (FRs) and from FRs to physical concepts (PCs). It is the foundation of this study, where designer could introduce their innovative thoughts and sort out the best idea among the various ways the revealed problems can be solved. DFA are present here to provide a rational tools to help the designer to generate the idea and at the same time to screen out best alternatives. In contrast Boothroyd-Dewhurst methodology enables designer to evaluate the design. When evaluation is done, the result indicates the possibility of reducing the number of parts from the design and the design efficiency.

1.3 Objective

The objective of this project is to develop an improved methodology that will help the designer to analyze and evaluate the design in the early design phase. The approach should be simple and systematic so that it is easy to understand and implement. The developed methodology is expected to achieve the following sub objectives:

- To prioritize customer satisfaction
- To minimize redesign and engineering changes
- To reduce assembly complexity
- To shorten total assembly time
- To economize total assembly cost
- To improve product quality
- To improve product serviceability

1.4 Scope of Research

In order to accomplish the project objective, the following tasks are to be implemented:

- Detailed review of the current DFA approaches.
- Development of a framework for integrating the principles from selected current approaches.
- Illustration of the proposed framework in details so that it will be easy to understand.
- Development of a software to guide and facilitate the designers to implement the proposed method.
- Performing of two case studies to ascertain the consistency and completeness of the proposed method.

1.5 Significance of Findings

DFA (Design for assembly) is strategic tool to product optimization. It comprises various principles and guidelines for the optimizing process. There are several techniques and methodologies within the scope of DFA, which are studied in this research work. The essence of DFA lies in the successful implementation of these tools. If a product is investigated from the elementary design requirements to the design details with rational basis, the design of a product can be improved to its widest as possible. So, the industries will be encouraged to apply DFA to optimize their product. This research work suggests a unique methodology to systematize the application of DFA in a structured way.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter comprises a comprehensive literature survey that motivates the methodology presented in later chapter. Firstly, it states the history of this research work. The Design for Manufacture (DFM), the Design for Assembly (DFA) and its associated principles and guidelines are explained. Moreover, it provides description as well as a comparison table for the currently available DFA methodologies.

2.2 History

Traditionally, product and process used to be designed separately based on know-how and trial and error method. The introduction of new products tended to involve incremental changes to past models to improve resources utilization and reduce production costs. Design changes or improvements would be made after the problems encountered either by the production people or from the customer. The lack of consistent framework and resourceful information of design during the design process had posed insufficient to use for the follower. As a result the designer had to think again and again from scratch whenever the problem had exposed. This sequence of events was tedious, time consuming and eventually leads to productivity loss.

As early as the 1960s, several companies developed manufacturing guidelines for use during product design (Kuo et.al, 2001). The manufacturing data were accumulated into a large reference volume with the idea that designers would be able to acquire the manufacturing knowledge for efficient and effective design. However, the emphasis was only on design of individual parts for 'producibility' and very little attention was given to the manufacturing and assembly process (Kuo et.al, 2001). Beginning from the late 1970s, Boothroyd and Dewhurst conducted a series of study on design for assembly (DFA), which considers the assembly constraints (i.e. assembly method and cost) during the design stages (Kuo et.al, 2001). By using DFA, the estimated assembly time can be used as a guideline to find out the design changes that can lead to the reduction of the final assembly cost (Kuo et.al, 2001). Expanded from DFA, Stoll (1988a, b) developed the concept of design for manufacture (DFM) to simultaneously consider all the design goals and constraints for the products that will be manufactured (Kuo et.al, 2001). The implementation of DFA and DFM led to enormous benefits including simplification of products, reduction of assembly and manufacturing costs, improvement of quality, and reduction of time to market (Kuo et.al, 2001). More recently, environmental concerns required that disassembly and recycling issues should be considered during the design stages. In fact, the effort to reduce total life cycle costs for a product through a design innovation is becoming an essential part of the current manufacturing industry (Kuo et.al, 2001).

2.3 Design for Manufacture (DFM)

Design for manufacture (DFM) is the integration of product design and process planning into one common activity (Redford and Chal, 1994). It is sometimes called design for manufacturability or design for producibility (Vance, 1991). In the broad sense, DFM includes any step, method or system that provides a product design that eases the task of manufacturing and lower manufacturing cost (Bedworth et.al, 1991). The goal is to design a product that is easily and economically manufacturable. The concept of DFM is evolved on the understanding that (Corbett et.al, 1991):

- Design is the prime step in product manufacture.
- Every design decision, if not carefully considered, can cost extra manufacturing effort and an eventual productivity loss.
- The product design must be carefully matched to advanced flexible manufacturing, assembly, and quality control and material-handling technologies in order to fully realize the productivity improvements through integrated manufacturing systems.

Virtually, DFM embraces some underlying principles which help maintain communication between all elements of the manufacturing system and permit flexibility to adopt and modify the design during each stage of the product's realization. DFM focuses on designing individual components so that they are easy to manufacture. The idea of DFM is to identify features of a design that can be altered to reduce manufacturing cost without sacrificing reliability, functionality, or durability. Today, researchers have agreed that the greatest single opportunity for product design improvement using the concept of DFM has been in the area of assembly (Corbett et.al, 1991). This activity is widely known as design for assembly (DFA), and involves minimizing the number of parts to be assembled as well as designing the parts, which remain to be easy to assemble (Corbett et.al, 1991). DFM is often coupled with DFA, which is closely related (Vance, 1991). The integration of the two potential aspects (i.e. DFM and DFA) is often referred to design for manufacture and assembly (DFMA). Other areas of DFM include product design considerations, which impact material handling, in-process inspection, quality etc. (Corbett et.al, 1991).

2.4 Design for Assembly (DFA)

Design for assembly (DFA) is the central element of DFM (Redford and Chal, 1994). It is a simple approach to designing products with ease of manufacturing in mind. By making things easier to assemble, ultimate benefit is quick delivery time, high productivity and eventually low overall cost. Virtually, assembly is a key manufacturing operation and is used in manufacturing most discrete products (Liang and O'Grady, 1997). This particular assembly operation accounts for 50% or more of manufacturing costs, and also affects the product quality (Zha et.al, 2001). Therefore, DFA has been taken in consideration as the key element towards product optimization in this research work. The main motivation for considering the DFA is that the prospects of reducing cost and moreover the evidence suggests that the proper application of DFA can result in cost savings of between 15% and 70% (Liang and O'Grady, 1997). In addition, quality can be improved and lead times reduced. DFA is now an accepted technique and used widely throughout many large industries including Lucas, GEC, Mercedes Benz, NISSAN Motors, AMP, DEC, XEROX, FORD, NCR, and IBM (Daabub and Abdallah, 1999, Zha et.al, 2001). Besides the other benefits, it also concerns the environmental issues by considering disassembly in mind. Since disassembly is a critical process for the three end-of-life options (i.e. repair/reuse, remanufacturing, scrap material recycling), product design for easier disassembly has become important (Shu and Flowers, 1999). The goal of disassembly for recycling is to separate different materials to the greatest extent with least effort.

The basic idea in the DFA is to first reduce the number of components (parts, pieces) that must be assembled, and then to ensure that the remaining components are easy to assemble, are easy to manufacture (or purchase), reduce the total cost of the assembly, and, of course, satisfy the functional requirements (Magrab, 1997). The scope of DFA, thus, is very broad. The principles governing the DFA are discussed below to illustrate their global nature and to provide insight into how such principles can be used to aid the product development team (Bedworth et.al, 1991, Corbett et.al, 1991, Magrab, 1997).

2.4.1 Simplification, integration and reduction of the number of parts

Minimum number of parts means less of everything that is needed to manufacture a product. If a part is eliminated that means it does not cost to make, assemble, move, handle, orient, store, purchase, clean, inspect, rework and service. It never causes jams or interferes with automation. It never fails, malfunctions, or needs adjustment. It also reduces inventory management. But it does not mean that the minimization of part is the way to increase productivity because elimination of parts may lead to added cost and complexity to other parts to fabricate and assemble as well. Thus the best way to eliminate parts is to identify a design concept that requires fewer parts. Integral design, or the combining of two or more parts into one, could be another approach. Besides the advantages, integral design reduces the amount of interfacing information required, and decreases weight and complexity. The insight of the guideline, reducing number of parts, is expressed as a pictorial representation in Fig. 2.1 and Fig. 2.2.

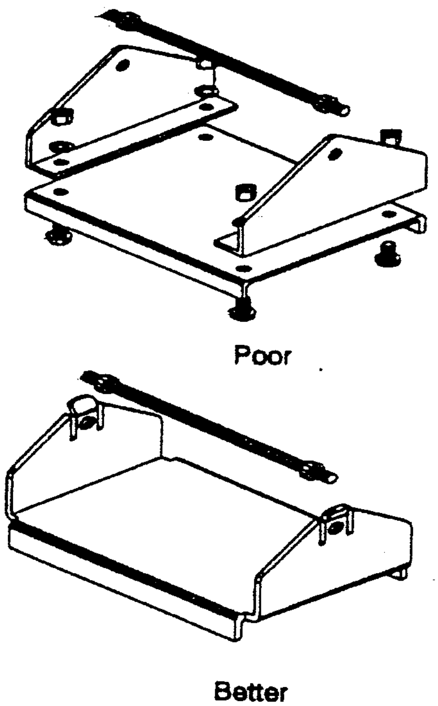

Figure 2.1 Examples of ways to reduce the overall number of components: a component with many parts redesigned to have only two parts (Magrab, 1997)

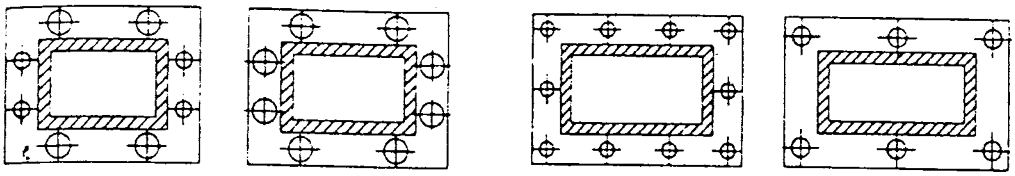

Figure 2.2 Reduce the number and type of parts (Magrab, 1997)

2.4.2 Designing of modular products to facilitate assembly

A module is a self-contained component having a standard interface to other components of a system. The main characteristics of the modules are that the interfaces are standardized, in view of the different combination possibilities of the modules into product variants. With proper interface correspondence, modules can be developed simultaneously.

It allows product diversity because it makes possible to be customized by using different combinations of standard components. Modular design prevents obsolescence and shortens the redesign cycle. It reduces significantly the number of various product parts. It makes possible simultaneous assembly and testing of units, that leads shorter delivery time. Ease of service and repair are enhanced as faulty parts can be quickly replaced resulting in lower cost. Most importantly, individual module as well as assembly can be fully checked prior to installation within the artificial environment. As modular design may add extra cost and complexity to manufacture because of extra fittings and interfaces connections required, its feasibility should be considered prior to implementation.

2.4.3 Standardization and using of common parts and materials

Use of standardized and common parts and materials facilitate design activities, minimize the inventory in the system and also standardize handling and assembly operations. A stock item is always less expensive than a custom-made item. Standard components require little or no lead-time and are more reliable because characteristics and weakness are well known. These can be available in any quantity at any time. They are easier to repair and find replacements. It also enables to improve inventory management, reduced tooling, and suitable for mass production even at low volume. In Fig. 2.2, it is shown that instead of different types of fasteners, common fasteners are used in favor of assembly operation.

2.4.4 Designing of parts to be multi-functional

Combining functions, wherever possible, leads to less assembly parts and results in faster and more accurate assembly operation, and fewer mistakes. It reduces inventory management, assembly time, material costs and moreover simplifies assembly operations. It can be done by reducing numbers and types of fasteners, cables etc. by building self-fastening features in the parent assembly parts. For example instead of screw fastening techniques, snap fasteners can substantially reduce the assembly time. An example is shown in Fig. 2.3.

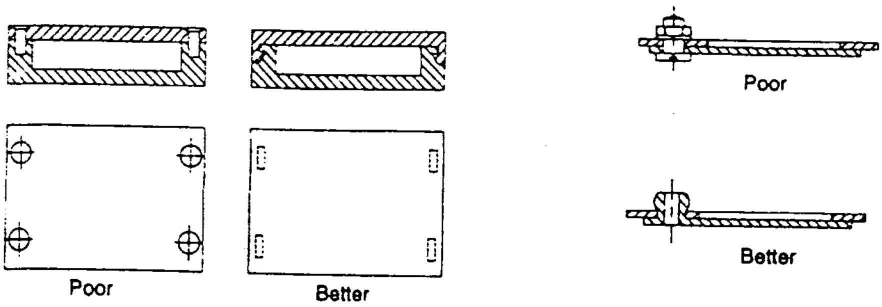

Figure 2.3 Use snap fasteners when possible (Magrab, 1997)

2.4.5 Designing of parts for multi-use

Many parts can be used for multi-use. For example, the same mounting plate can be designed to mount a variety of components. An example is shown in Fig. 2.1. Key to multi-use part design is identification of part candidates. One approach involves sorting all parts (or a statistical sample) manufactured or purchased by the company into two groups consisting of:

a. Parts, which are unique to a particular product or model (that is, crankshafts, housing etc.)
b. Parts, which are generally needed in all products and/or models e.g. shafts, flanges, bushings, spaces, gears, levers, etc.)

Each group is then divided into categories of similar parts (part families). Multi-use parts are then created by standardizing similar parts. In standardizing, the designer should sequentially seek to:

a. Minimize the number of part categories
b. Minimize the number of variations within each category

c. Minimize the number of design features within each variation

Once developed, the family of standard parts could be used wherever possible in existing products and used exclusively in new product designs. Also, manufacturing process and tooling based on a composite part containing all design features found in a particular part family should be developed. Individual parts can then be obtained by skipping some steps and features in the manufacturing process.

2.4.6 Mistake-proof product design and assembly

Product design should ensure that the assembly process is unambiguous. Components should be designed so that they can only be assembled in one way: they cannot be reversed. Fig. 2.4 shows an example of poor and better assembly motion. Notches, asymmetrical holes and stops can be used to mistake-proof the assembly process. Design verification can be achieved with simple go/no-go tools in the form of notches or natural stopping points. Product should be designed to avoid adjustments.

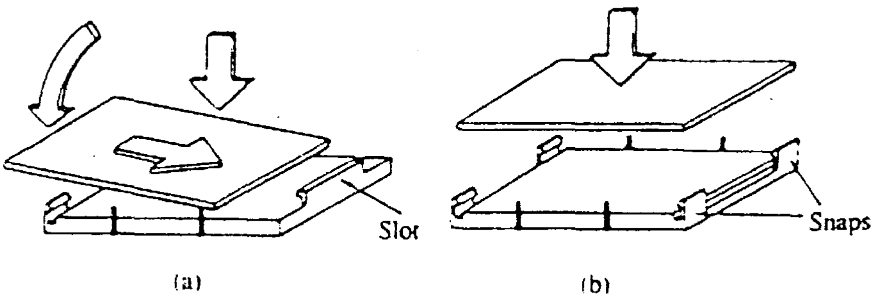

Figure 2.4 Simple assembly motions where (a) poor design and (b) better design (Redford and Chal, 1994)

2.4.7 Design for parts orientation and handling

Components should be designed so that they can be handled and oriented easily to minimize the effort and ambiguity in orienting and merging parts. Parts should be designed to orient themselves when fed into a process. Product design must avoid parts that can become tangled, wedged or disoriented. Part design should incorporate symmetry, low centers of gravity, easily identifiable features, guide surfaces and points for easy pick-up and handling. An example is shown in Fig. 2.5.

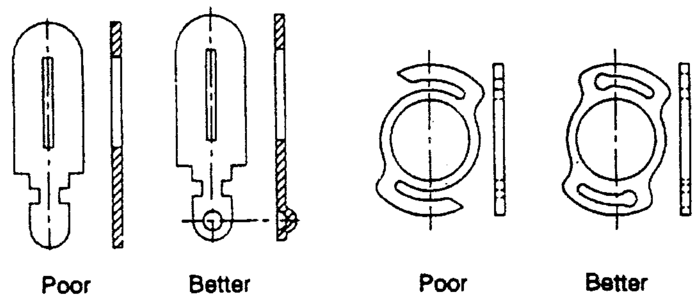

Figure 2.5 Design parts that can't tangle with themselves (Magrab, 1997)

2.4.8 Minimization of flexible part and interconnections

Components should be designed to avoid flexible and flimsy parts such as belts, gaskets, tubing, cables and wire harnesses. Their flexibility makes material handling and assembly more difficult, and these parts are more susceptible to damage. Interconnections such as wire harnesses, hydraulic lines, and piping are expensive to fabricate, assemble and service. Partition should be provided to the product to minimize interconnections between modules and place related modules adjacent to each other to minimize the routing of interconnections.

2.4.9 Design for ease of assembly

It will be done by utilizing simple pattern of movement. Parts should include such features as chamfers and tapers. The product's design should enable assembly to begin with a base component with a large relative mass and a low center of gravity upon which other parts are added. Assembly should proceed vertically with other parts added on top and positioned with the aid of gravity. This minimizes the need to re-orient the assembly and reduces the need for temporary fastening and more complex fixturing. A product that is easy to assemble manually frequently will be easily assembled with automation. An example is shown in Fig. 2.6.

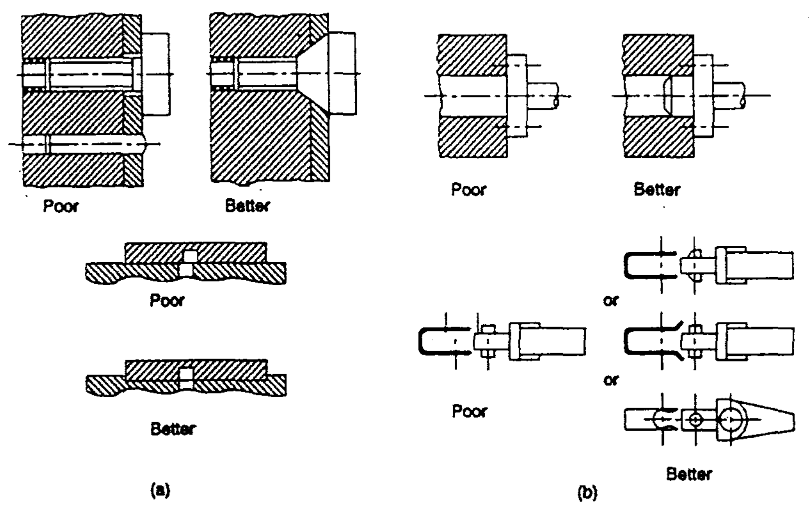

Figure 2.6. Provide for (a) self-adjustment, (b) guide features to ease assembly (Magrab, 1997)

2.4.10 Minimization of assembly directions

All parts should be assembled from one direction. Extra direction mean wasting of time and motion as well as more transfer stations, inspection stations and fixtures. This, in turn leads to increased cost and large number of wear and tear on equipment. The best possible way to assemble product parts in a top-down fashion that resembles z-axis insertion. Multi-motion insertion should be avoided. It reduces fatigue and repetitive motion problems and decrease assembly time. An example is shown in Fig 2.7.

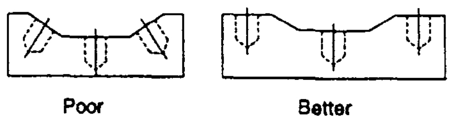

Figure 2.7 Design for assembly in one direction (Magrab, 1997)

2.4.11 Design for efficient joining and fastening

Threaded fasteners (screws, bolts, nuts and washers) are time-consuming to use in assembly and difficult to automate. Where they must be used, should be standardized to minimize variety, by using fasteners such as self-threading screws and captured washers. Even in manual assembly the cost of fixing a screw can be 10 times the cost of the screw. So one of the easiest things could be done to eliminate fasteners in the assembly is by using tabs or snap-fits. At the same time joints (welding, soldering, riveting etc.) should be minimized to avoid extra incorporation of equipment and after-work quality inspection for those joints. If the fasteners or joints must be applied, minimizing the number, size and variations applied can significantly reduce cost as well as quality risks. An example is shown in Fig. 2.3.

2.5 DFA methodologies

A number of DFA methods are available to optimize design in the early stage of the design phase. The currently recognized DFA methodologies are the Axiomatic design approach, the Boothroyd-Dewhurst DFA method; the Lucas DFA evaluation method; the Hitachi Assemblability Evaluation Method (AEM); Taguchi Method (on robust design); Value Analysis and so forth. A brief description of the above listed methodologies and a comparison among those methodologies are presented in this report.

2.5.1 Axiomatic Approach

In the axiomatic approach, the design process consists of few steps as follows (Albano and Suh, 1994, Harutunian, et.al, 1996, Wallace and Suh, 1993):

- Establish design objectives to satisfy a given set of customer attributes
- Generate ideas to create plausible solutions
- Analyze the solution alternatives that best suits to the design objectives
- Implement the selected design

Axiomatic approach guides to the execution of the above activities is based on the following key concepts as developed by Suh (1990) and mentioned in Yang and Zhang (2001):

1. There exist four domains in the design world, customer domain, functional domain, physical domain and process domain. The needs of the customer are transformed into required functionality of a product. Design parameters that satisfy the functional requirements are gathered, and finally transformed into process variables based on how the product will be produced. The whole design process involves the continuous progress and processing of information between and within four distinct domains.

2. The alternative decisions are generated by mapping the requirements specified in one domain to a set of characteristic parameters in the adjacent domain. The mapping between the customer and functional domains can be said as concept design; the mapping between functional and physical domains can be said product design; the mapping between the physical and process domains corresponds to process design.

3. The mapping process can be mathematically expressed in terms of the characteristic vectors that define the design goals and design solutions.

4. The output of each domain reveals from abstract concepts to detailed information in a top-down or hierarchical manner. Hierarchical decomposition in one domain cannot be

performed independently of the other domains, i.e., decomposition follows zigzagging and mapping between adjacent domains.

5. Two design axioms provide a rational basis for evaluation of proposed solution alternatives and the subsequent selection of the best alternative. The two axioms are:

Axiom1 (independence axiom): that entails in maintaining independence of functional requirements.

Axiom2 (information axiom): that entails in minimizing the information content required achieving functional requirements.

The decomposition starts from top-level functional requirement and mapping is done following two questions 'what is required?' i.e. functional requirements (FRs) and 'how to achieve it?' i.e. design parameters (DPs). During decomposition and subsequent mapping between adjacent domains, they need to follow the axioms. The four-domain structure is schematically illustrated in Fig. 2.8.

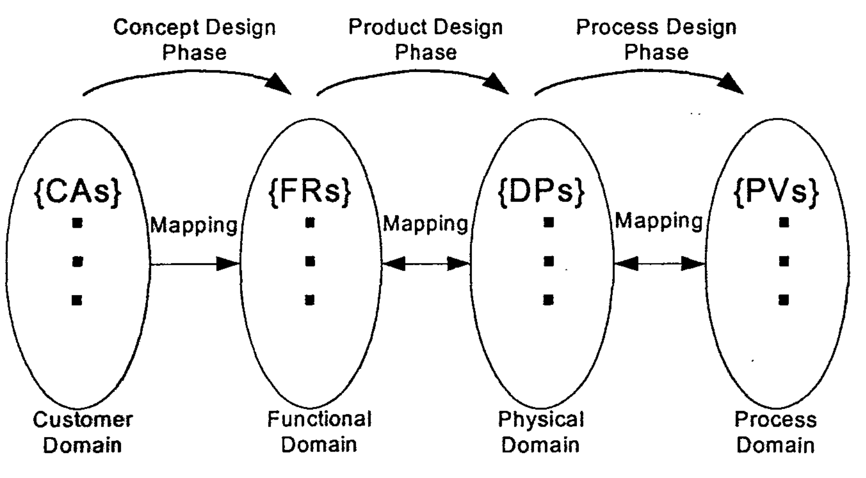

Figure 2.8. Four domains in the design world (Yang and Zhang, 2000)