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OPTIMIZATION OF THE MECHANICAL COMPONENT DESIGN USING DESIGN FOR ASSEMBLY TECHNIQUES

Ümit KOCABIÇAK

Sakarya University Engineering Faculty, Mechanical Engineering Department, Sakarya-TURKEY
Email : umit@esentepe.sau.edu.tr

ABSTRACT

Design For Assembly (DFA) is an important strategy for product design improvement. It lowers assembly and manufacturing costs, reduces overheads, improves quality and reduces time taken to bring the product to the market. Design for Assembly has been in wide use in industry for over fifteen years and has created a revolution in product design and development. There are several DFA methods of analyzing the ease of assembly of a product. These methods, however, must be used in the early stages of the design process to gain their full benefits. DFA tools help to make the designer more aware of the effects of his design choices on the ease of assembly of a product. This paper presents the redesign of the mechanical component based on Design for Assembly techniques.

I. INTRODUCTION

Design is the first step in manufacture and is an activity that traditionally starts with sketches of parts and assemblies and progresses to the drawing board or CAD workstation, where assembly and detail drawings are created. These drawings are often then handed to the manufacturing and assembly engineers, whose function is to optimize the processes used to produce the final product. Frequently, it is at this stage that the manufacturing and assembly problems are discovered and requests for change made.

Sometimes, these design changes result in considerable delays in the ultimate release of the product. In addition, the later in the development cycle the change occurs, the more expensive the change becomes. Therefore, not only is it important to take manufacturing and assembly into account during product design, but also, these considerations must occur as early as possible in the design cycle.

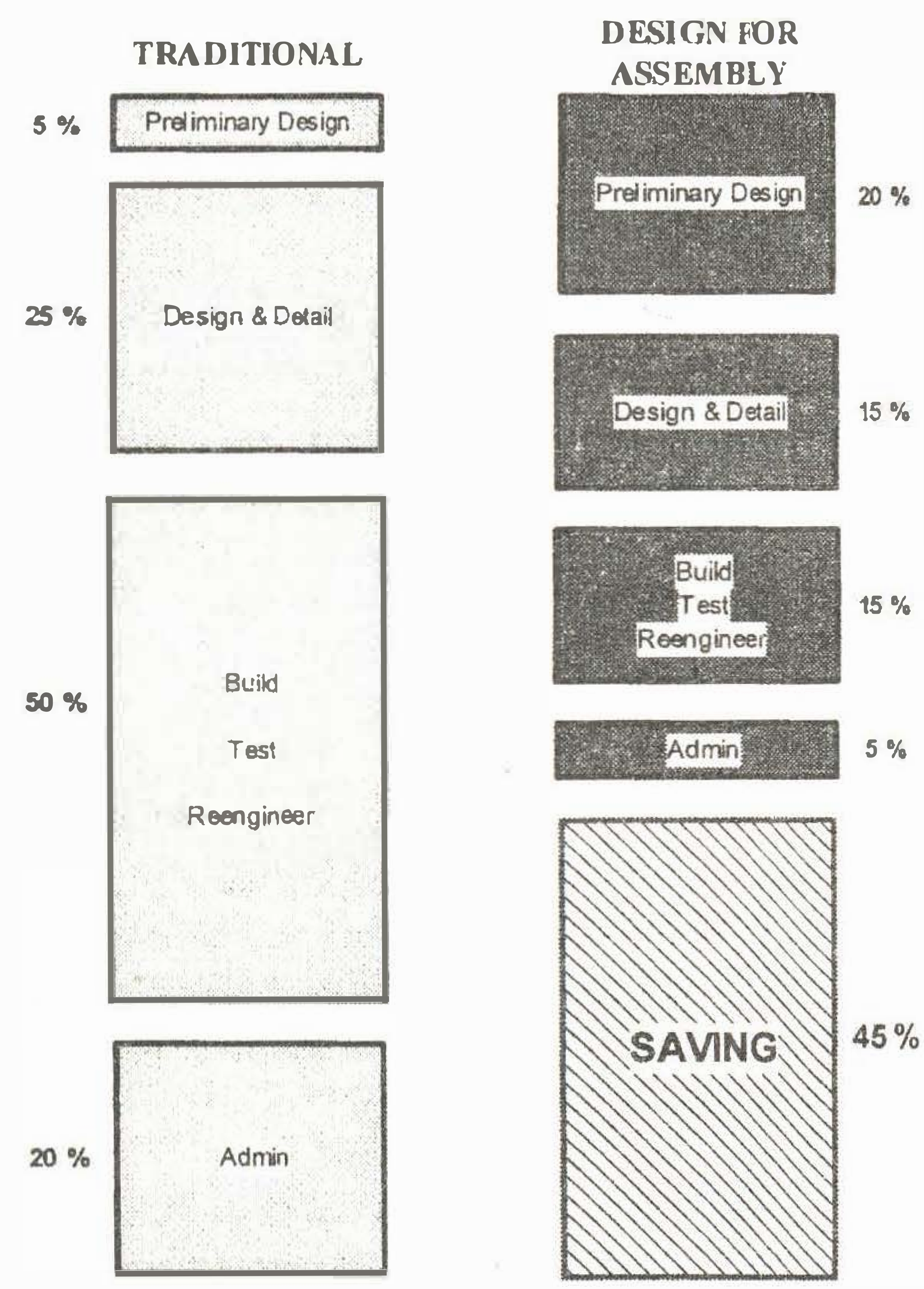

Figure 1. Comparison of the traditional (serial) engineering and employing design for assembly engineering.

As shown in Fig. 1, extra time spent early in the design stage is more than offset by the savings in time when modeling or prototyping takes place. Thus, in addition to reducing product costs, the application of Design for Assembly, shortens the time to bring the product to market.

In the past 15 years Design for Assembly has become an increasingly important concept in designing products for today's markets [1].

II. DESIGN FOR ASSEMBLY

Design for Assembly (DFA) is the process by which a product is designed to be easily assembled [2]. Product design is the critical first step in the manufacturing process. This first step decides the method of assembly, component tolerances, number of adjustments and type of fabrication tooling. Together, these decisions determine a great part of the manufacturing cost and total product cost. One way to ensure that a new product has been designed for economical production is to use the design for assembly (DFA) process.

Design for Assembly is a technique for reducing the cost of a product through simplification of its design. This cost reduction occurs by reducing the number of individual parts in the assembly and then ensuring that the remaining parts are easy to handle and assemble. By applying the DFA process, many leading companies such as Ford, Kodak, General Motors, IBM, NCR, Xerox and more have saved millions. Cost reductions of 20 percent to 35 percent are commonly achieved through the use of the DFA methodology [3-9].

DFA provides estimated assembly times, assembly costs, and operation times, as well as suggestions for redesign resulting in benefits such as reduced assembly time and cost. With this valuable information, engineers can then make design decisions based on concrete cost and times while ensuring that the assembly of the product is as efficient as possible.

How Does DFA Work?

By way of a example, Figure 2 represents a proposal for the design of a motor drive assembly that 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.

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 set screw. For a cover, an end plate is secured by two screws to two stand-offs screwed into the base. 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 represents the 'theoretical minimum number' needed to satisfy the constraints *without* considering practical limitations.

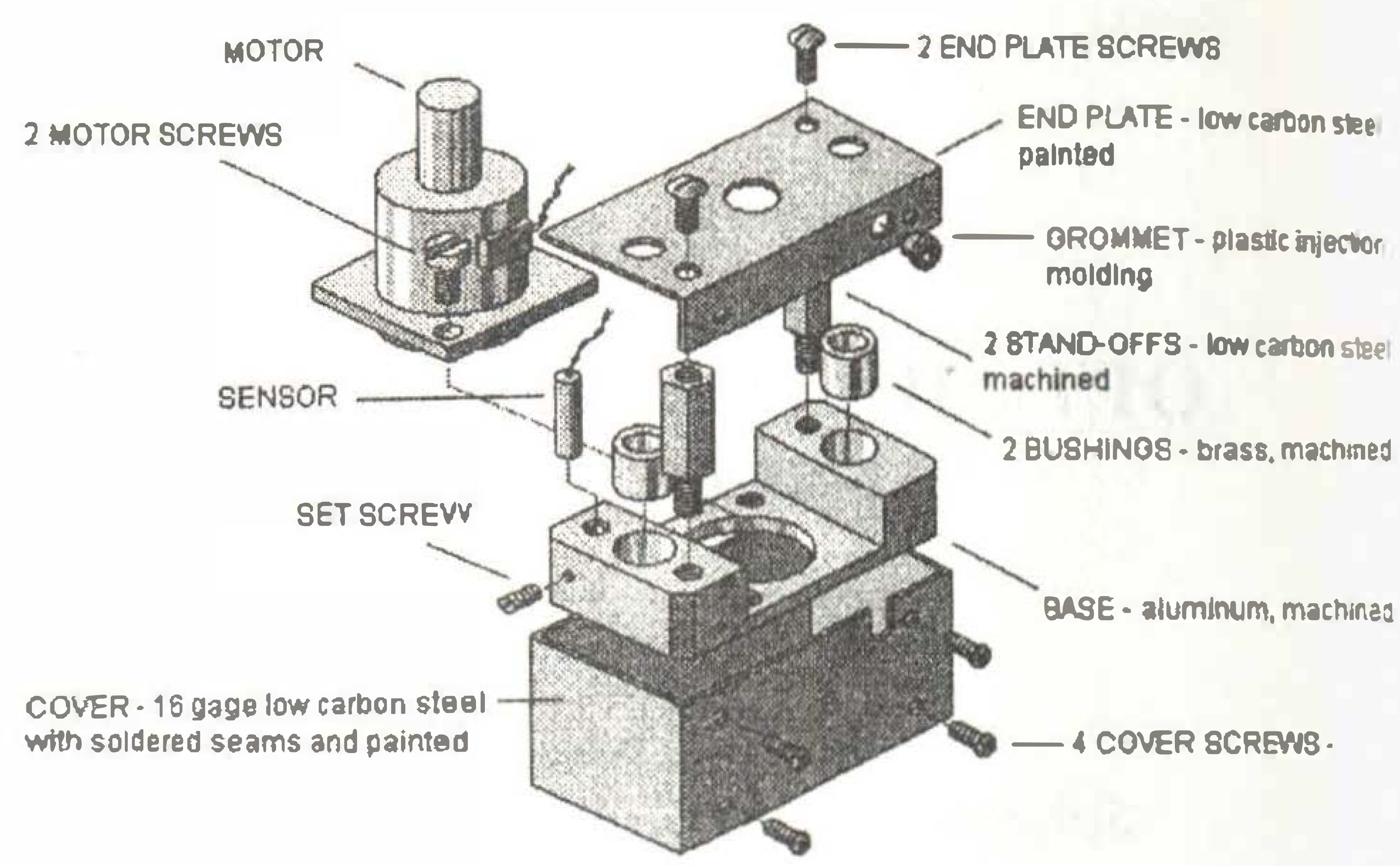

Figure 2. Current design of motor assembly (dimensions inches)

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 (Figure 3).

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 1). 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 [10].

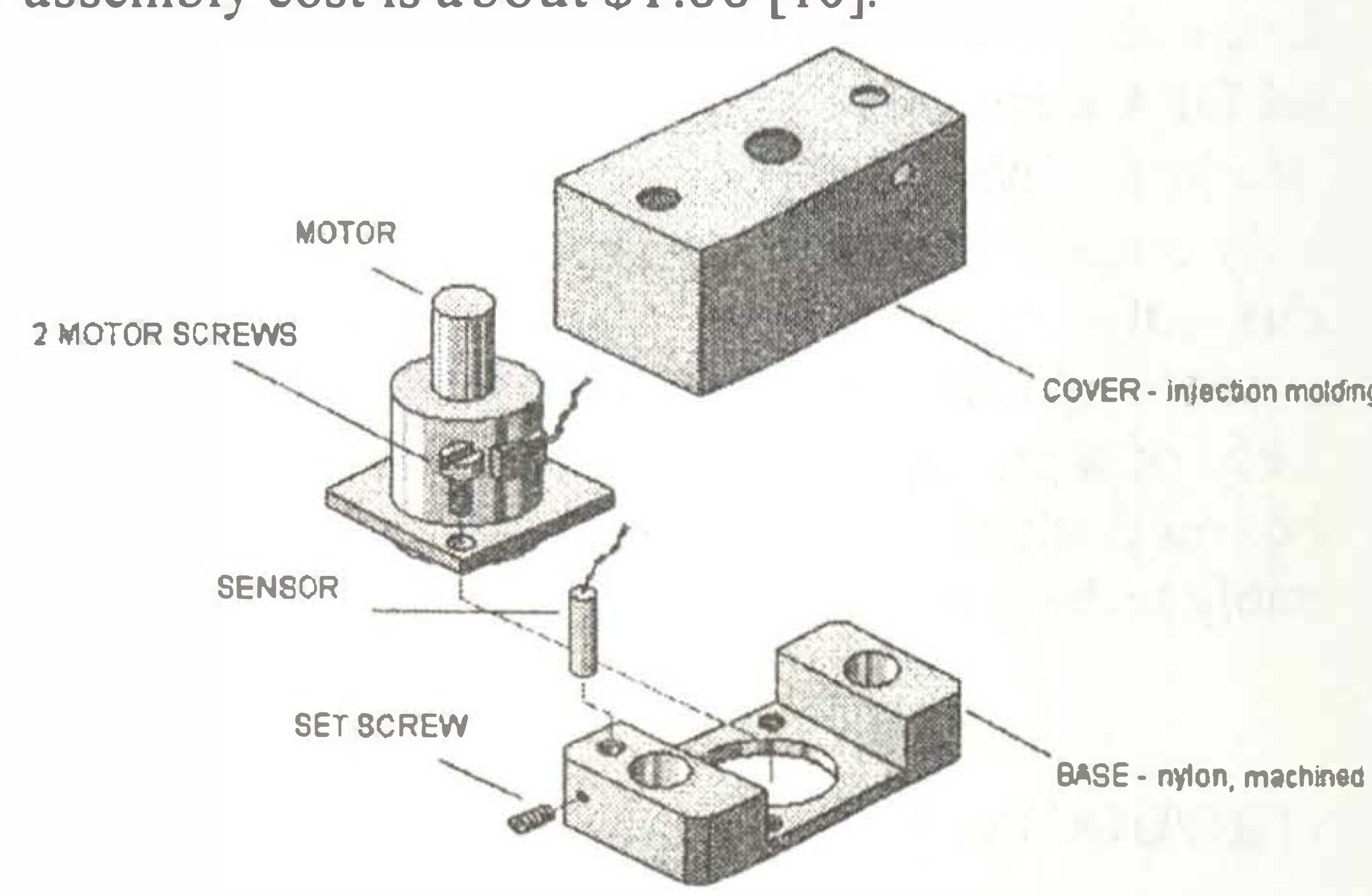

Figure 3. Redesign of motor assembly

Table 1. 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		

III. DESIGN FOR ASSEMBLY METHODS

A number of different DFA methodologies have been developed. Current DFA methodologies can be classified as being one of four basic types [11] :

- DFA systems using design principles and design rules : There are fundamental design principles or axioms, the use of which to guide and evaluate design decisions leads to good design.

- DFA systems employing quantitative evaluation procedures : Quantitative evaluation procedures allow the designers to rate the assemblability of their product designs quantitatively. These quantitative DFA methodologies are systematic. Each assembly operation is subject to a rating that measures how easily the process can be carried out by operators or assembly systems. For the product as a whole, quantitative measure is calculated which combines the individual ratings by a formula. The designer can improve the assemblability measure by redesigning those parts that caused bad ratings.

- DFA methods employing a knowledge-based approach : Knowledge-based systems are defined as those that provide new information-processing capabilities such as inference, knowledge-based management, search mechanisms, etc., combined with conventional computer capabilities. Knowledge-based processing for assembly has the following features :

  - Expressions can be stored to allow knowledge to accumulate and be used for problem-solving later.

  - Things can be described that are not known precisely in advance, i.e. it is possible to describe a hypothesis.

  - Advice on the consequences of design decisions on assembly costs can be obtained and suggestions for redesign given.

- Computer-aided DFA methods : DFA by conventional or knowledge processing involves sessions in which users have to reply to many questions on part geometry size, insertion processes, etc. Currently, to reduce user input, assemblability evaluation processes are being developed by which DFA systems are integrated with Computer-Aided Design (CAD).

IV. COMPUTER-AIDED DFA METHODS

Today naturally every product design is generated on a computer, PC or workstation, screen. The powerful CAD systems are normal tools for designers. Thus it has been quite obvious that also the DFA analysis methods are also coming to be computerized.

These PC based tools have been developed during the 80's on the work analysis theoretical calculations that were also published as manual methods. The manual handling of the mixture of very different work stages was too difficult to calculate by hand and they made their first success only after being in the computer program [11-15].

In general the PC-based tools will have a simple consideration of complex technical problems. The approach to the problem is very systematical and almost independent on the user capabilities. The procedure leads the operator towards the goal and the real problem in the designed construction. The results are always documented also in the conceptual phase when no design really exists. The results are easy to reproduce and comparisons during time can be easily made, e.g. with competing products. These advantages are very obvious and thus the market for these PC-based systems is growing.

The best advantages of the systems are the numerical presentations. They provide evidence of the calculative criteria of the product design. That is of a great help for the participants of design reviews, in calculating the optimal solution.

On the negative side it is often argued that these PC based tools concentrate too much on the activities that can be easily calculated, e.g. in the number of parts. Its implication can be that it leads towards too complicated designs of parts that will be left on the developed and finalized product.

All commercial realisations of the PC-based systems have a different work analysis theory behind each other. There have been half a dozen different systems available, but nowadays there are only three systems widely commercially available. Those are Design For Manufacturability and Assemblability (DFMA) by Boothroyd&Dewhurst Inc, Assemblability Evaluation Method (AEM) by Hitachi Corp., and Design for Assembly Cost-effectiviness (DAC) by Sony Corp. and TeamSet by CSC Computer Sciences Ltd. These analysis methods have been on the market several years and they have gained a wide reputation by the designers. The written computer code has originally been for DOS-operating systems but is now in the transfer for more widely used Win3.x or Win9x operating systems.

Hitachi Assemblability Evaluation Method

Assemblability Evaluation Method, AEM, is developed by Hitachi Corp. Tokyo, Japan. The main objective of AEM is to facilitate design improvements by identifying 'weakness' in the design at the earliest possible stage in the design process, by the use of two indices : an assemblability evaluation score ratio, E, used to assess design quality by determining the difficulty of operations, and an assembly cost ratio, K, used to project elements of assembly cost[11, 12]. The procedure of the analysis in the AEM method is as follows (Figure 4):

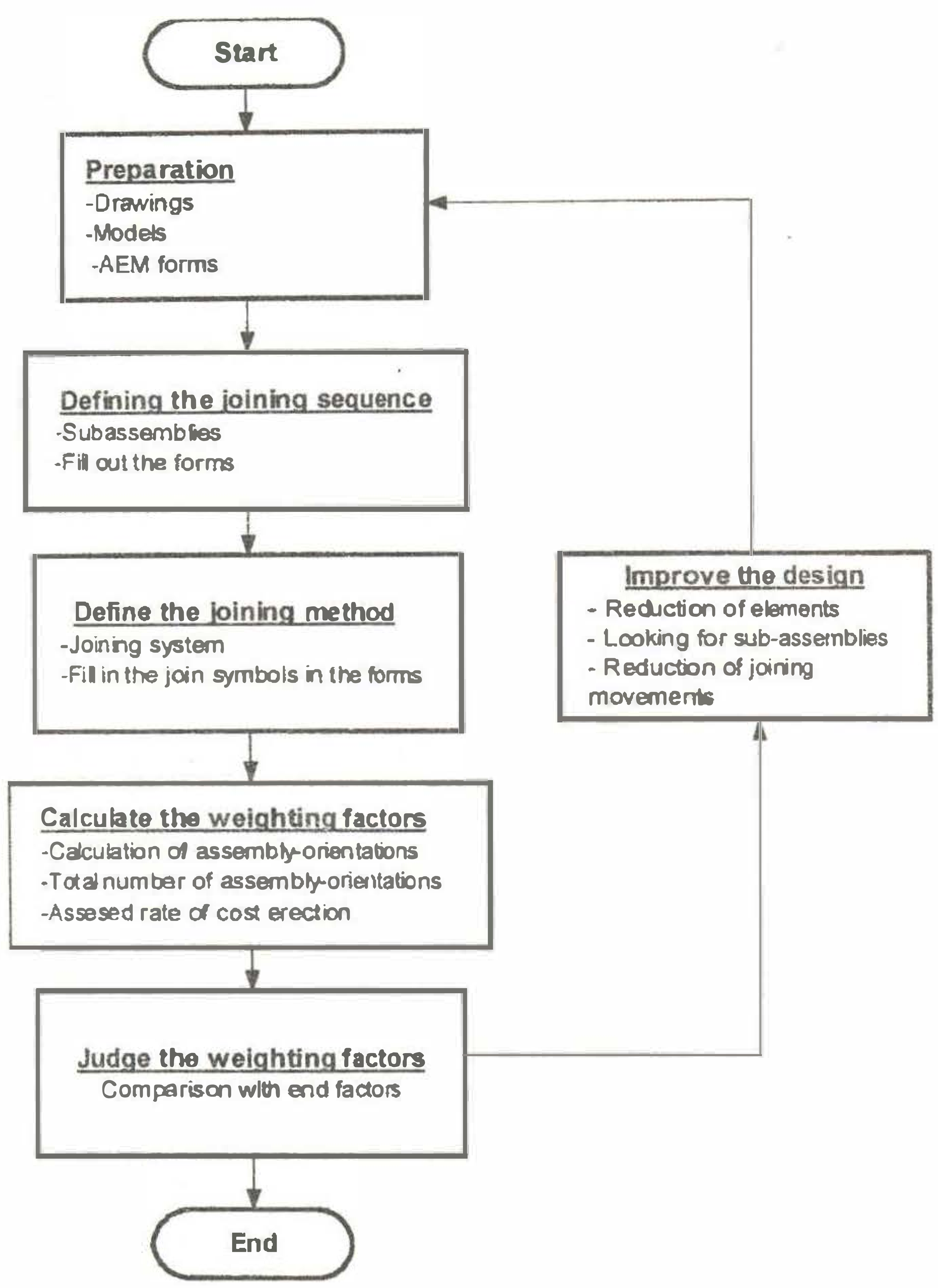

Figure 4. Assemblability evaluation and design improvement flow diagram

The total assemblability evaluation score for the product is defined as the sum of the assemblability scores for the individual tasks, divided by the number of tasks. This may be considered to be a measure of design efficiency where a score of 100 would represent a perfect design. Hitachi consider that an overall score E of 80 is acceptable and overall assembly cost ratio K of 0.7 is unacceptable.

Redesign of a simple product using AEM

An illustration of a simple redesign procedure is shown in Fig. 5, 6 and 7.

Step 1: (Original Design) Here, it is necessary to attach a small block, B, to a chassis, A, and the initial method, shown in Fig. 6, involves the use of bolt, C.

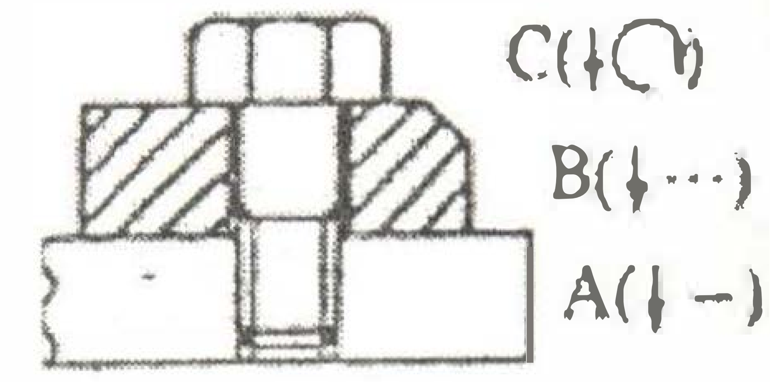

Figure 5. Original Design

Table 2. Evaluation score and the cost ratio of original design

	Part Assemblability Evaluation Score	E Assemblability Evaluation Score	K Assembly Cost Ratio
Set chassis A	100		
Bring down B and hold it to maintain is orientation	50	73	1
Fasten screw C	65		

Step 2: (Redesign 1) Examining original design, the holding down to maintain orientation is the worst individual evaluation score and the suggestion is that the need for holding is removed by spot-facing the chassis shown in Fig. 6. This gives an improved evaluation score and the cost ratio as a result of this (Table 3.).

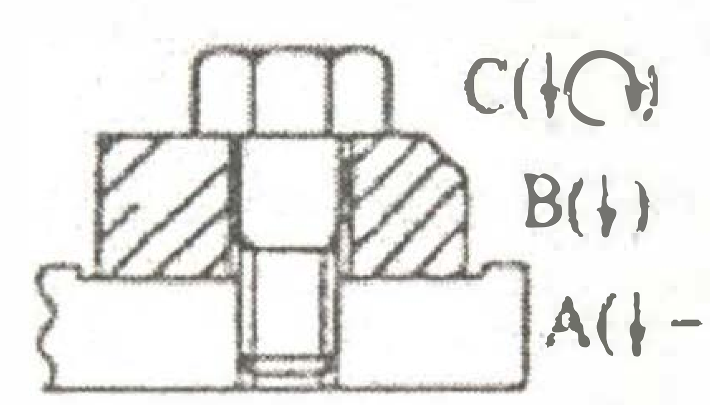

Figure 6. Redesign 1

Table 3. Evaluation score and the cost ratio of redesign 1

	Part Assemblability Evaluation Score	E Assemblability Evaluation Score	K Assembly Cost Ratio
Set chassis A	100		
Bring down B (orientation is maintained by spot-facing)	100	88	0.8
Fasten screw C	65		

Step 3: (Redesign 2) Here, the bolt has been removed and the block attached to the chassis by using a press fit. The assembly evaluation score for the press fit is less than that for simple block placement and reduces from 100 to 80 but, importantly, one part has been eliminated. As a result, although the product evaluation score has not

significantly improved (89 compared with 88), the assembly cost ratio has significantly improved because of the reduced number of parts (Figure 7 and Table 4).

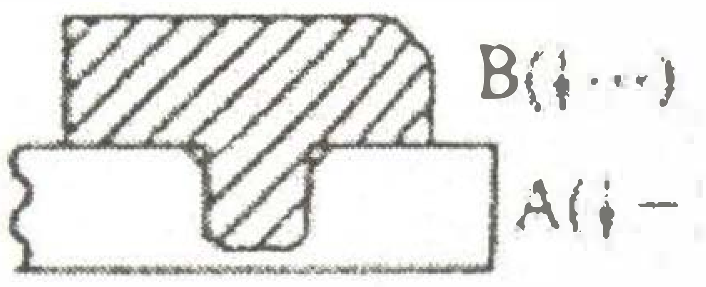

Figure 7. Redesign 2

Table 4. Evaluation score and the cost ratio of redesign 2

	Part Assemblability Evaluation Score	E Assemblability Evaluation Score	K Assembly Cost Ratio
Set chassis A	100		
Bring down and pressfit block B	80	89	0.5

DAC by Sony Corp

The DAC method, **D**esign for **A**ssembly **C**ost-Effectiveness, is developed by Sony Corp, Tokyo, Japan. Taking the economics of a single up or down operation a standard for evaluation, the shape of a part, the direction of assembly and any other factors causing a simple operation are evaluated. Factors for evaluation are classified into 30 keywords. The evaluation ranking is expressed on a diagram using a maximum 100 point system for each operation, making judgement at a glance easy. The evaluation point is calculated by selecting the keyword for each operation. By representing this point on a diagram, the work flow level can be confirmed. The ranking of the evaluation point takes always into account the automation rate of assembly operations guiding the sequences towards more automated assembly methods. Thus this analysis tool is mainly utilized in mass production factories [13].

Boothroyd-Dewhurst DFA Method

This methodology is based on the studies by Prof. Boothroyd on the handling and its difficulties in small parts handling and assembly [1, 12]. The set of analysis tools started in 1982 from the DFA package, but is nowadays a set of packages for different early cost estimation tools: injection moulding, machining, sheet metal working, die casting and powder metal parts.

Boothroyd-Dewhurst DFA method is based on three basic steps :

- to determine the appropriate assembly method
- to reduce the number of parts in a design
- to estimate handling and assembly costs in the assembly process.

The first step in Boothroyd-Dewhurst DFA method is to select the appropriate assembly method for the product. The designer must decide, from the values of the basic product and company parameters (number or parts, production volume, etc.), which assembly method is likely to be the most economic. The methods of assembly are classified into three basic categories.

1. Manual assembly
2. Special-purpose transfer machine assembly
3. Robot assembly

To apply step 2, it is necessary to determine the number of essential parts in the assembly. This is referred to as the theoretical minimum number of parts.

In step 3, cost figures should be determined for the assembly process.

In Boothroyd-Dewhurst DFA method, the design efficiency can be calculated. In the case of manual assembly, for example, the following equation should be evaluated

$$E_m = 3N_m / T_m$$

where

E_m = manual-assembly design efficiency
N_m= minimum number of parts
T_m= total assembly time

This equation represents the ratio of the ideal assembly time/part (3s) to the actual assembly time part, taking N_m, as the actual number of parts. It is assumed that each part is easy to handle and insert, and that one-third of the parts is secured immediately after insertion.

Redesign of a simple product using the Boothroyd-Dewhurst DFA method

Figure 8 shows a simple sub-assembly used in the construction of a gas-flow meter. The objective is to analyse the design using the Boothroyd-Dewhurst method with the intention of using the information obtained to create a new, easier-to-assemble, less expensive sub-assembly. In this analysis will be considered only manual assembly. For the redign of an existing product, it will be assumed that the functional parts must have the same dimensions and be made of the same materials.

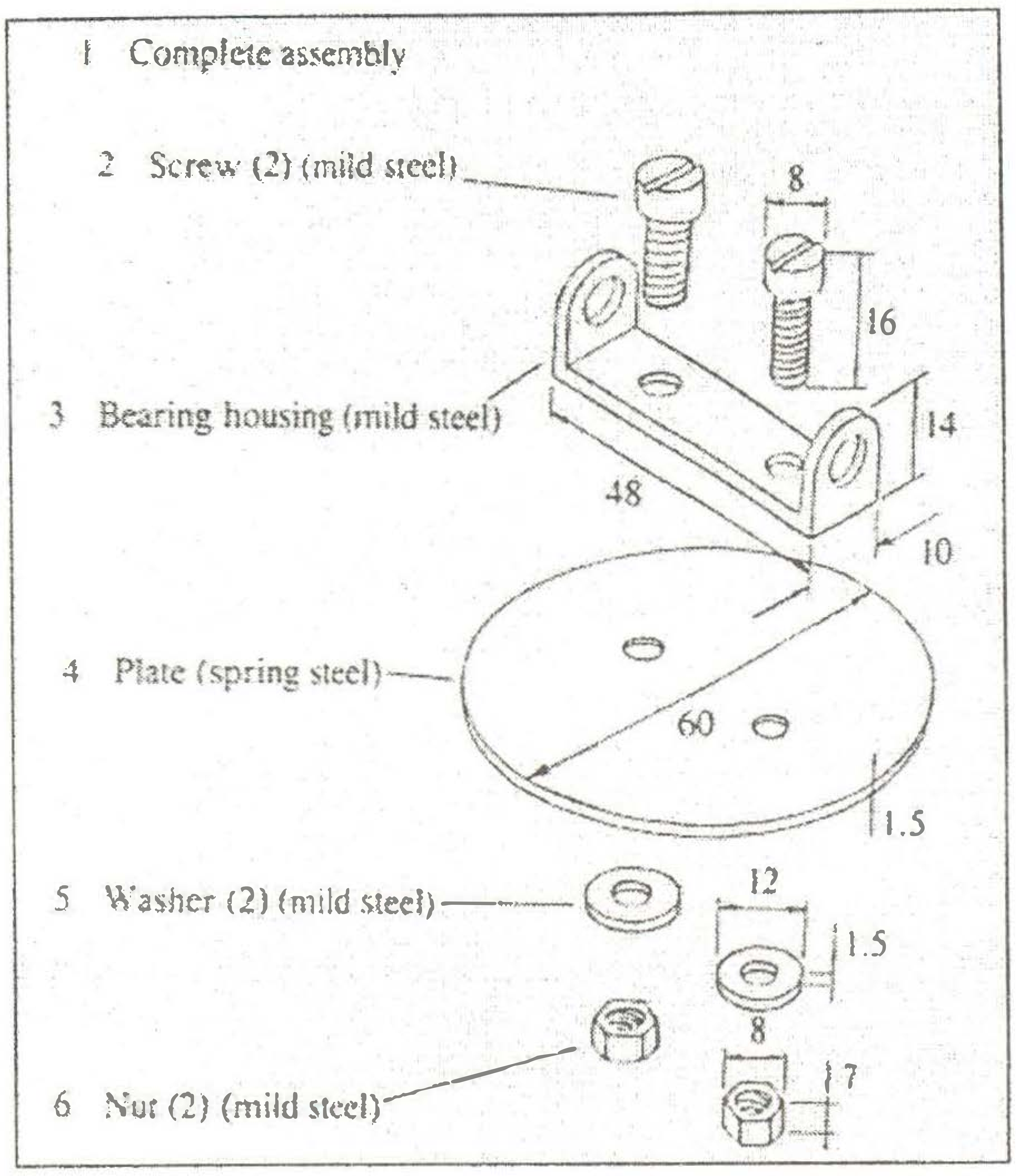

Figure 8. A simple product sub-assembly

Table 5 shows a design for manual assembly worksheet for the product shown in Fig. 8.

Table 5. Original design

part no	number repeats	total assembly time	manual assembly cost	min. number parts	Remarks
6	2	6	1.2	0	Nut
5	2	6	1.2	0	Washer
4	1	4	0.8	1	Plate
3	1	3	0.6	0	Bearing Housing
2	2	20	4	0	Screw
1	-	-	-	-	Complete Assembly
		39	7.8	1	

Design efficiency = 3 * min parts / assembly time = 3 * 1 / 39 = 0.077

If at least two parts are now necessary, these would have to be the bearing housing and the plate; these are both functional and all the others are merely fasteners. There are many possibilities for joining the bearing housing to the plate using integral fastening-one proposed solution is by the use of integral rivets as shown in Fig. 9. The worksheet for this solution is shown in Table 6.

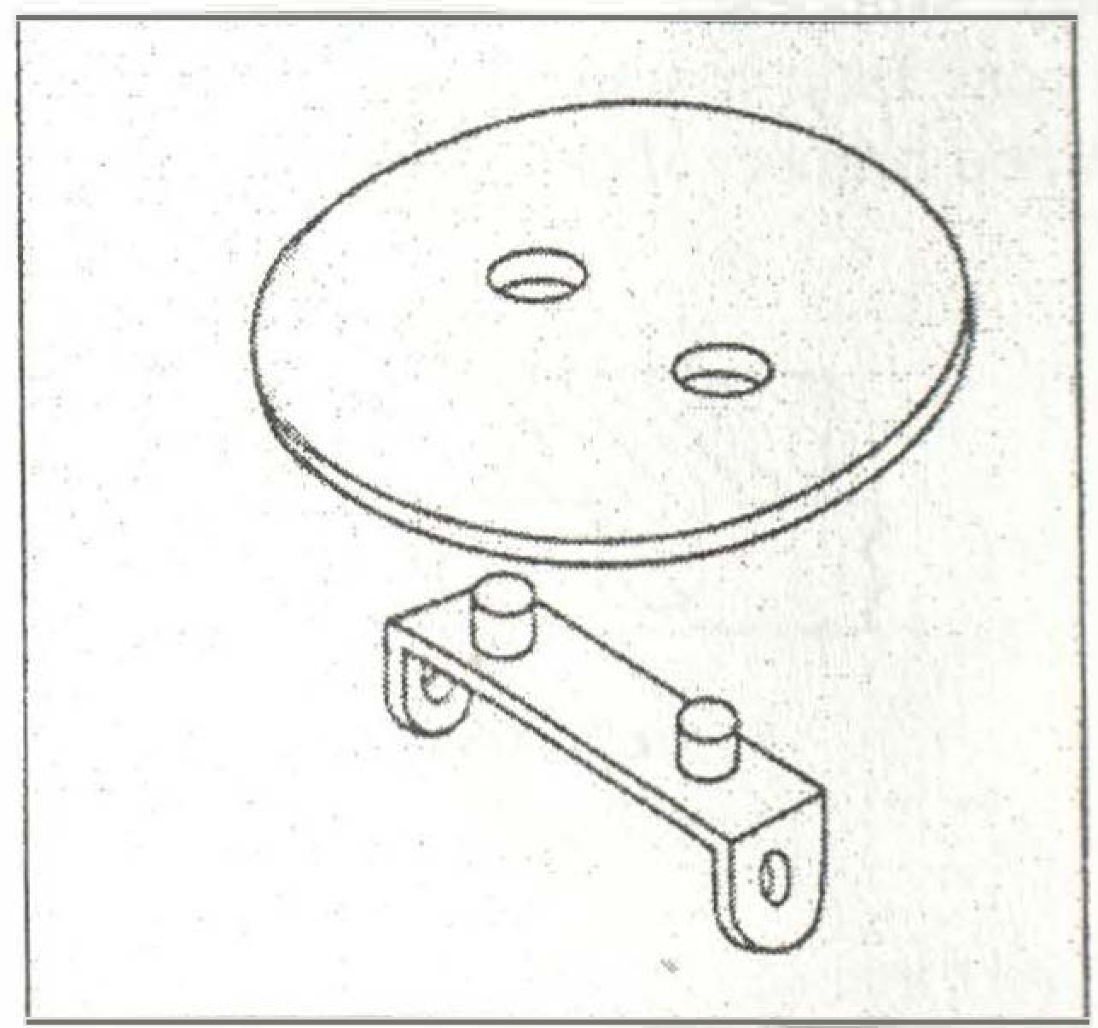

Figure 9. Redesign solution using an integral fasteners

Table 6. Redesign to minimize parts

part no	number repeats	total assembly time	manual assembly cost	min. number parts	remarks
3	1	3	0.6	1	Bearing house
2	1	4	0.8	0	Plate
1	-	-	-	-	Complete assembly
		7	1.4	1	

Design efficiency = 3 * min parts / assembly time = 3 * 1 / 7 = 0.428

The plate can be placed either way up, but it does ha rotational asymmetry and is 'thin'; one solution, is have one axi-symmetric integral fastener as shown Fig. 10. For this solution, the bearing housing cannot improved since it still needs to be assembled one w up, one of two ways round, but the plate is now easier handle; the worksheet for this solution is shown Table 7.

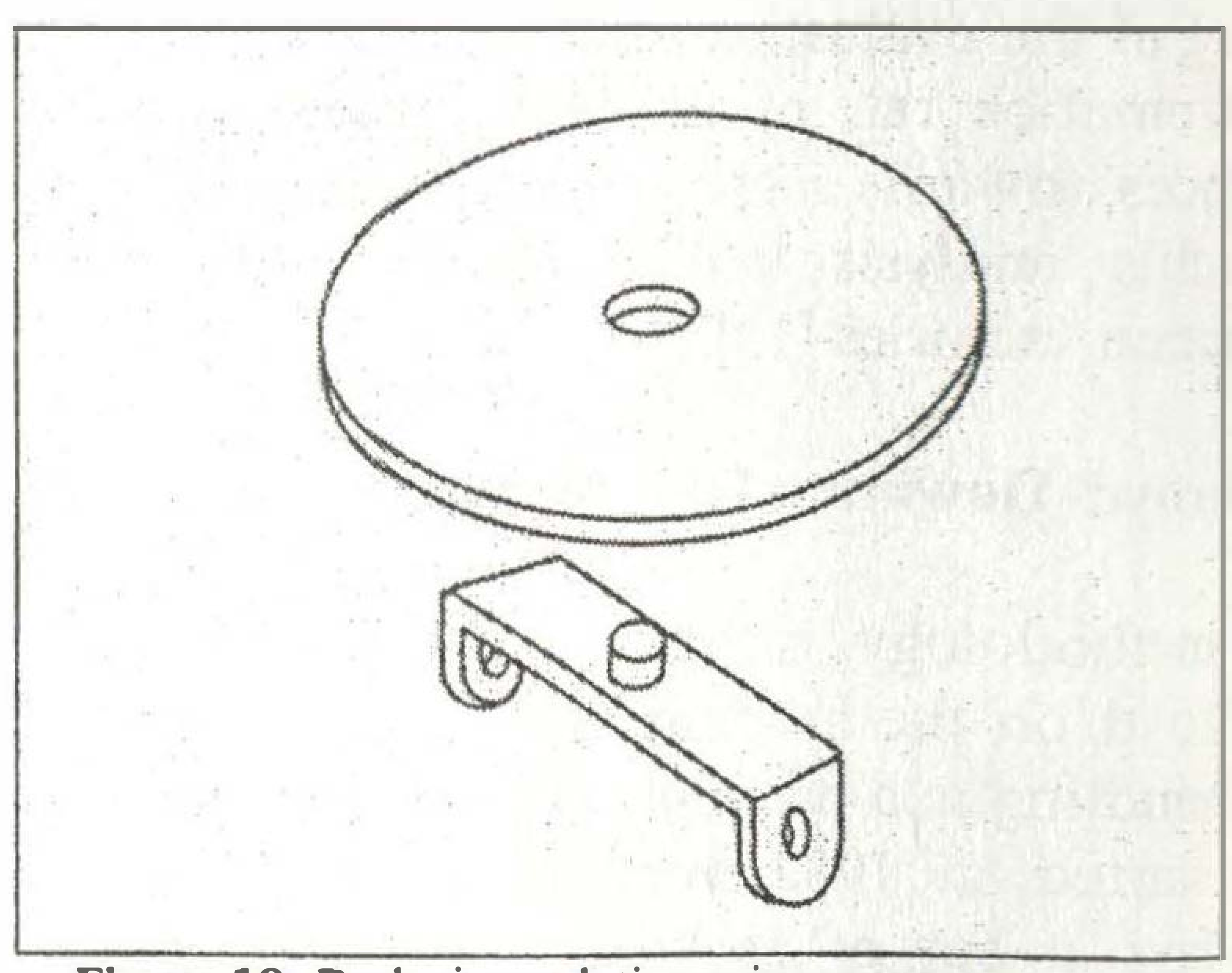

Figure 10. Redesign solution using more symmetry

Table 7. Redesign to reduce handling and insertion difficulties

part no	number repeats	total assembly time	manual assembly cost	min. number parts	remarks
3	1	3	0.6	1	Bearing house
2	1	3	0.6	0	Plate
1	-	-	-	-	Complete assembly
		6	1.2	1	

Design efficiency = 3 * min parts / assembly time = 3 * 1 / 6 = 0.5

The Boothroyd-Dewhurst DFA Software

To facilitate the use of this approach, Boothroyd and Dewhurst have developed DFA software that, by requesting the relationship between parts, helps the designer determine an efficient assembly sequence for a new product starting from a sketch.

Design for Assembly (DFA) software breaks down the traditional wall between manufacturing and design by providing designers with assembly information in the concept stage of product development.

TeamSET, concurrent engineering business solution

TeamSET is an evaluation software tool for new product introduction and redesign at the pont of conceptual design. It is a product of CSC Computer Sciences Ltd, of Solihull, UK. Formerly the product was developed by Lucas. It works by letting design teams test and compare design concepts up-front before manufacturing to ensure that the selected design is simple to manufacture and assemble, has a minimum of non-essential parts, keeps tooling costs down and meets customer needs.

The six-module tool set shares a common database which allows cross-pollination of information an d enables *"what-if" scenarios* from multiple aspects of design process. The package is a PC-Windows software. and highly graphical.

Comparison Of Design For Assembly Methods

Table 8 shows a comparison table for design –for-assembly methodologies.

Table 8. Comparison table for design-for-assembly methodologies

Criteria in the existing systems	DFMA	AEM	Teamset	DAC
parts reduction analysis	+	+	+	-
Handling analysis	+	+	+	+
Insertion analysis	+	+	+	+
Suitability for different kinds of assembly	+	-	+	+
Complexity of analysis method	medium	high	medium	high
Training effort	medium	high	medium	high
Cost of software	medium	high	medium	high
Assembly system investment calculation	-	-	-	+

V. CONCLUSION

Design for Assembly techniques, if used properly, can result in great savings in production costs and increases in productivity. These methods, however, must be used in the early stages of the design process to gain their full benefits. DFA provides estimated assembly times, assembly costs, and operation times, as well as suggestions for redesign resulting in benefits such as reduced assembly time and cost. With this valuable information, engineers can then make design decisions based on concrete costs and times while ensuring that the assembly of the product is as efficient as possible.

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