COST REDUCTION STUDY OF AUTOMOTIVE PART USING DFA METHOD: REAR LAMP

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.

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Examiner Signature

COST REDUCTION STUDY OF AUTOMOTIVE PART USING DFA METHOD: REAR LAMP

MOHD HAFIZI BIN NAWI

Report submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering

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DECEMBER 2010

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this report and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledge. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Date : 6 DECEMBER 2010

To my Beloved Family and friends

ALLAHYARHAM NAWI BIN MOHAMED

TENGAH BINTI LONG

ZAHARI BIN NAWI

ZAILAH BINTI NAWI

AZMAN BINTI NAWI

NORHAFIZAH BINTI NAWI

AIZAM BIN NAWI

ASYRAF BIN NAWI

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ABSTRACT

This thesis deals with the study of assembly analysis of the rear lamp of a car by using Boothroyd Dewhurst DFA method and Hitachi AEM DFA method. The design for assembly of the rear lamp is analyzed based on design efficiency for both methods and the options available are suggested, analyzed and compared with the original design of the rear lamp. The project aimed to reduce the assembly cost of the rear lamp due to the production cost of the rear lamp in industries is high and the demand for the product is increased. From the result and discussion of this thesis, option 3 is the best option for the redesign of the rear lamp. For Boothroyd DFA method, design efficiency for option 3 is 65.7% while the original design efficiency is 48.9% and the design efficiency increased by 16.8%. Then, for Hitachi AEM DFA method, the design efficiency for option 3 is 83.3% while the original design efficiency is 75.7% and the design efficiency increased by 7.6%. The option of redesign with the higher percentage value of design efficiency is selected as the best design in term of its assembly efficiency.

ABSTRAK

Tesis ini berkaitan dengan kajian analisis pemasangan lampu belakang kereta dengan menggunakan kaedah DFA Boothroyd Dewhurst dan kaedah Hitachi AEM DFA.Rekabentuk untuk pemasangan lampu belakang dianalisis berdasarkan kecekapan rekabentuk untuk kedua-dua kaedah dan pilihan yang tersedia yang disarankan, dianalisis dan dibandingkan dengan rekabentuk asli lampu belakang. Projek ini bertujuan untuk mengurangkan kos pemasangan lampu belakang kerana kos pengeluaran lampu belakang dalam industri adalah besar dan permintaan produk meningkat. Daripada hasil dan pembahasan tesis ini, pilihan 3 adalah pilihan terbaik untuk merekabentuk kembali lampu belakang kereta.Untuk kaedah DFA Boothroyd, kecekapan rekabentuk untuk pilihan 3 adalah 65,7% sedangkan kecekapan rekabentuk asalnya adalah 48,9% dan kecekapan rekabentuk meningkat sebanyak 16,8%. Kemudian, untuk Hitachi kaedah DFA AEM, kecekapan rekabentuk untuk pilihan 3 adalah 83.3% sedangkan kecekapan rekabentuk asalnya adalah 75,7% dan kecekapan rekabentuk meningkat sebanyak 7.6%. Pilihan rekabentuk semula dengan nilai peratusan lebih tinggi kecekapan rekabentuk dipilih sebagai rekabentuk terbaik dalam kecekapan pemasangan.

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LIST OF SYMBOLS

E_{ma}	Design efficiency
Nmin	Theoretical minimum number of parts
Ta	Total assembly time
Tma	Estimated time to complete the assembly of the product
E	Assemblability evaluation score ratio
K	Assembly cost ratio
α	Rotational symmetry of a part about an axis perpendicular to its axis of insertion
β	Rotational symmetry of a part about its axis of insertion

LIST OF ABBREVIATIONS

NM	Theoretical minimum number of parts
TM	Total assembly time
DFA	Design for Assembly
DFM	Design for Manufacture
DFMA	Design for Manufacture and Assembly
AEM	Assemblability Evaluation Method
HR	Handling ratio

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter discussed about project background such as problem statement, objectives and scope of the project. This project is focused on replication DFMA (Design for Manufacture and Assembly) method to reduce assembly cost of car rear lamp. DFMA method is the combination of DFA (Design for Assembly) and DFM (Design for Manufacture). Design for manufacturability (DFM) is the general engineering art of designing products in such a way that they are easy to manufacture. DFM is intended to prevent product designs that simplify assembly operations but require more complex and expensive components, designs that simplify component manufacture while complicating the manufacture process and designs that are simple and inexpensive but are difficult or expensive to service and support.(Boothroyd *et al*., 1994)

Design for Assembly is a process by which products are designed with ease of assembly in mind. If a product contains fewer parts it will take less time to assemble, thereby reducing assembly costs. In addition, if the parts are provided with features which make it easier to grasp, move, orient and insert them, this will also reduce assembly time and assembly costs. The reduction of the number of parts in an assembly has the added benefit of generally reducing the total cost of parts in the assembly. This is usually where the major cost benefits of the application of design for assembly occur. (Boothroyd *et al*., 2002)

1.2 PROJECT BACKGROUND

At night, the vehicle need to be seen at night from the rear and it is provided by rear position lamps (also called tail lamps, taillights or tail lights). These are required to produce only red light, and to be wired such that they are lit whenever the front position lamps are illuminated including when the headlamps are on. Rear position lamps may be combined with the vehicle's brake lamps, or separate from them. In combined-function installations, the lamps produce brighter red light for the brake lamp function, and dimmer red light for the rear position lamp function. The tail and brake light functions may be produced separately and/or by a dual-intensity lamp.

The background of car rear lamp started from 1968 to 1971 with Ford Thunderbird could be ordered with additional high-mounted brake and turn signal lights. These were fitted in strips on either side of its small rear window. The Oldsmobile Toronado from 1971 to 1978, and the Buick Riviera from 1974 to 1976 had dual high-mounted supplemental brake lights or turn signals as standard, and were located just below the bottom of the rear window, visually aligned with the conventional rear tail lights/brake lights/turn signals just above the rear bumper. These innovations were not widely adopted at the time. (Taylor et al.,1981)

Automotive and lamp manufacturers in Germany experimented with dual high-mount supplemental brake lamps in the early 1980s, but this effort, too, failed to gain wide popular or regulatory support. Early studies involving taxicabs and other fleet vehicles found that a third stop lamp reduced rear end collisions by about 50%. The lamp's novelty probably played a role, since today the lamp is credited with reducing collisions by about 5%. In 1986, the United States National Highway Traffic Safety Administration and Transport Canada mandated that all new passenger cars have a CHMSL installed. A CHMSL was required on all new light trucks and vans starting in 1994. CHMSLs are so inexpensive to incorporate into a vehicle that even if the lamps prevent only a few percent of rear end collisions they remain a cost-effective safety feature. (Gaudean,1996).

To provide illumination to the rear when backing up, and to warn adjacent vehicle operators and pedestrians of a vehicle's rearward motion, each vehicle must be equipped with at least one rear-mounted, rear-facing reversing lamp (or "backup light"). These are currently required to produce white light by U.S. and international ECE regulations. However, some countries have at various times permitted amber reversing lamps. In Australia and New Zealand, for example, vehicle manufacturers were faced with the task of localizing American cars originally equipped with combination red brake or turn signal lamps and white reversing lamps.

Those countries' regulations permitted the amber rear turn signals to burn steadily as reversing lamps, so automakers and importers were able to combine the rear turn signal and reversing lamp function, and so comply with the regulations without the need for additional lighting devices. Both Australia and New Zealand presently require white reversing lamps, so the combination amber turn/reverse lamp is no longer permitted on new vehicles. The U.S. state of Washington presently permits reversing lamps to emit white or amber light. (Hitzemeyer et al., 1997)

Design for manufacture and assembly (DFMA) is a combination of design for assembly (DFA) and design for manufacture (DFM). The term DFMA is defined as a set of guidelines developed to ensure that a product is designed so that it can be easily and efficiently manufactured and assembled with a minimum labor effort, assemble time, and cost to manufacture the product. During a product development, DFMA method ensures that the transition from the design phase to the production phase is smooth and rapid as possible. (Boothroyd *et al*., 2002)

Generally, there are three DFA methods used to reduce the cost of the product. The first method are Boothroyd-Dewhurst DFA method, Lucas-Hull DFA method, and Hitachi Assembly Evaluation Method (AEM). These three methods are discussed further in Chapter 2. This project is about applying Boothroyd-Dewhurst DFA method and Hitachi AEM method to redesign the car tail lamp to make it better than the previous design in the aspect of assembly efficiency. This case study focused on redesigning the car tail lamp and the aim of the analysis is to evaluate the redesign of the car tail lamp in term of the assembly efficiency.

1.3 PROBLEM STATEMENT

The invention of car has change the world of transportations and the demand for the car is increased especially in the millennium of the new technologies of the car invention. The production of the car by the factories is increased due to the high demand from the customers and same case for the parts of the car produced by the factories. The cost of making the parts is high in the aspects of manufacturing and assembly the parts of the cars. In this project, the rear lamp of the car is investigated to reduce the assembly cost of the part. Car tail lamp consists of many components and parts from the bulb to the reflector of the lamp. In industries, the components of the lamp are assembled together to produce the final component of the car tail lamp. During assembly process, some intricate components are difficult to be assembled. This intricate component also need more time to be assembled and as a result, the cost to assemble the car tail lamp is increased. In solving the increasing cost of car tail lamp assembly, this project is done. The project also aims to minimize the difficulties encountered during assembly of the components of the lamp. At the same time cost of the car tail lamp also aimed to be reduced.

1.4 PROJECT OBJECTIVES

There are three objectives have been defined to be focused on and to simplify the project as stated below:

(i) To evaluate the design efficiency of the product using Boothroyd-Dewhurst DFA method and Hitachi AEM DFA method.
(ii) To make the suggestions to reduce assembly cost of car rear lamp.
(iii) To determine assembly cost of the rear lamp before and after improvements.

1.5 SCOPE OF STUDY

The following scopes of the project are determined in order to achieve the objectives of the project. Firstly, the original design and the improvements of the design are performed by using Solidworks 2010 software. Secondly, the analysis of the original design and the improvement of the design of car tail lamp is performed by using Boothroyd-Dewhurst DFA method and Hitachi AEM DFA method. Thirdly, the suggestions to reduce the assembly cost of the rear lamp are performed and the final scope of study is the assembly cost of the original design and the improvements of the design of the rear lamp is calculated and compared with the original design.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discussed about the DFA and its guidelines principle. The literature reviews gives a brief explanation about the functions and the principles of the DFA which is subcomponent of the DFMA method.

2.2 DESIGNS FOR ASSEMBLY (DFA)

Design for Assembly (DFA) is an approach to reduce the cost of the product and time of assembly by simplifying the product and process. The DFA method should be considered at all stages of the design process especially in the early stages (Boothroyd *et al*., 1994). It should give serious consideration to ease assembly of the product or subassembly. DFA tool is needed to effectively analyze the ease of assembly of the products or subassemblies it design and it should ensure consistency and completeness in evaluation of product assemblability. It should also eliminate subjective judgement from design assessment, allow free association of ideas, enable easy comparison of alternative design, ensure that solution are evaluated logically, identify assembly problems area and suggest alternative approaches for simplifying the product thus reducing manufacturing and assembly cost. (Boothroyd *et al*., 2002)

By applying a DFA tool, communication between manufacturing and design engineering is improved, and ideas, reasoning, and decisions made during the design process become well documented for future reference. (Baizura,2007)

2.3 General Design Guidelines for Manual Assembly

The process of manual assembly can be divided naturally into two separate areas, handling (acquiring, orientating and moving parts) and insertion and fastening (mating a part to another part or group of parts). The following design form manual assembly guidelines specifically address each of these areas.

2.3.1 Design Guidelines for Part Handling

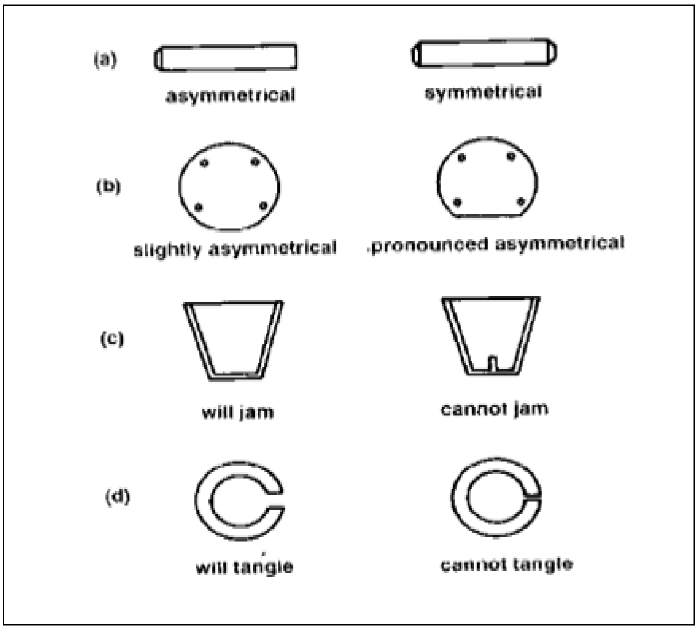


Figure 2.1: Geometrical features affecting part handling
Source: (Boothroyd *et al*., 2002)

(i) Design parts that have end-to-end symmetry and rotational symmetry about the axis of insertion. If this cannot be achieved, try to design parts having the maximum possible symmetry (see Figure 2.1)

(ii) Design parts that, in those instances where the part cannot be made symmetry, are obviously asymmetry (see Figure 2.1)

(iii) Provide features that will prevent jamming of parts that tend to nest or stack when stored in bulk. (see Figure 2.1)

(iv) Avoid features that will allow tangling of parts when parts stored in bulk. (see Figure 2.1)

(v) Avoid parts that stick together or a slippery, delicate, flexible, very small, or very large or that are hazardous to the handler (i.e. parts that are sharp, splinter easily, etc.).(see Figure 2.2).

2.3.2 Design Guidelines for Insertion and Fastening

(i) Design so that there is a little or no resistance to insertion and provide chamfers to guide insertion of two mating parts. (see Figure 2.3)

(ii) Standardize by using common parts, processes, and methods across all models and even across product lines to permit the use of higher volume processes that normally result in lower product cost. (see Figure 2.4)

(iii) Design so that a part is located before it is released. A potential source of problems arises from a part being placed where, due to design constrains. It must be released before it is positively located in the assembly. Under these circumstances, reliance is placed on the trajectory of the part being sufficiently repeatable to locate it consistently (see Figure 2.5)

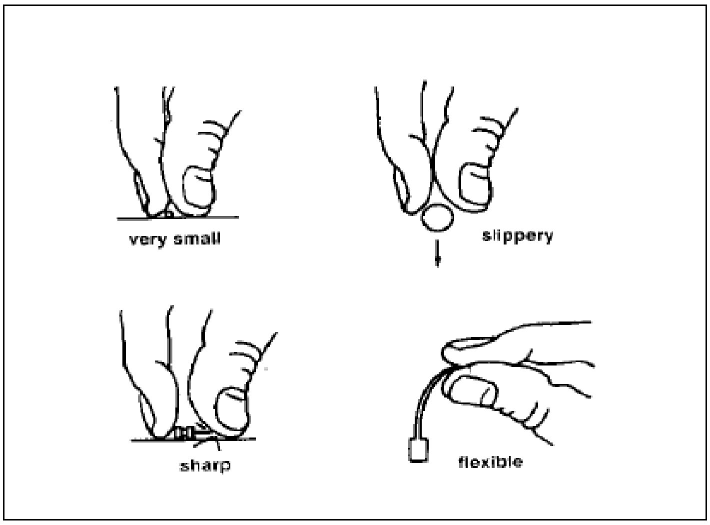


Figure 2.2: Geometrical features affecting part handling.
Source: (Boothroyd *et al*., 2002)

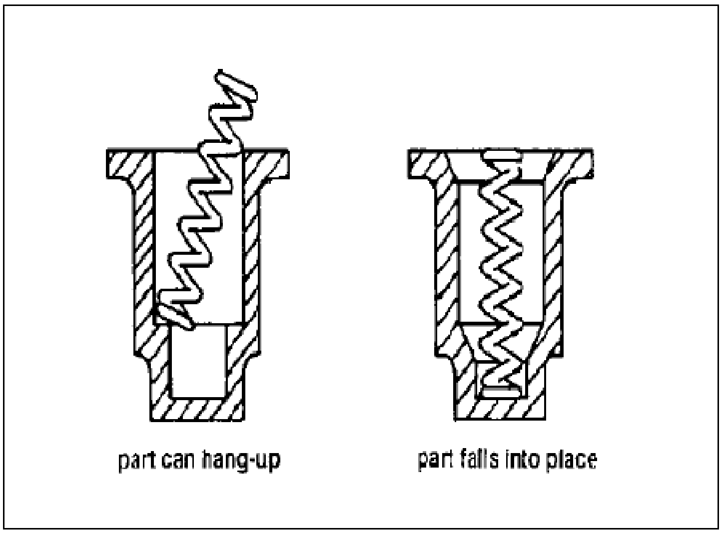


Figure 2.3: Provision of chamfers to allow insertion.
Source: (Boothroyd *et al*., 2002)

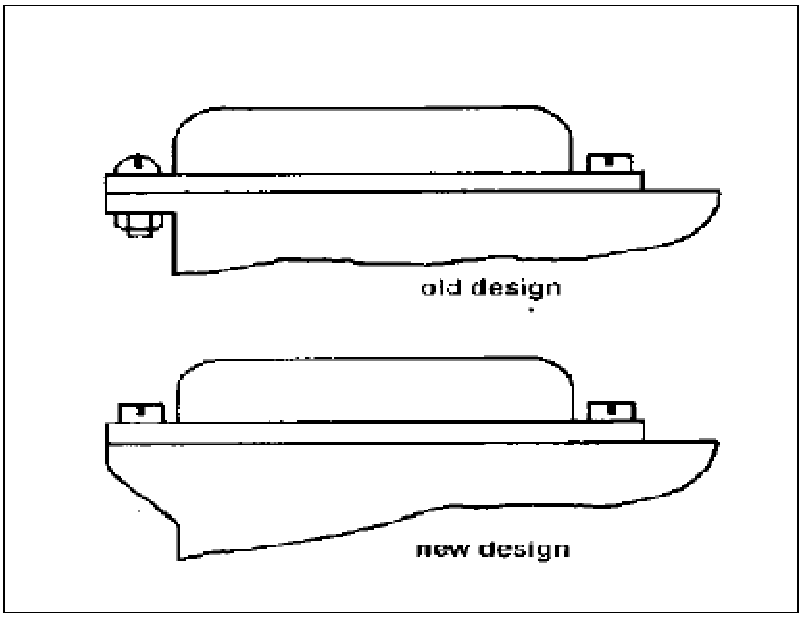


Figure 2.4: Standardize parts assembly

Source: (Boothroyd *et al*., 2002)

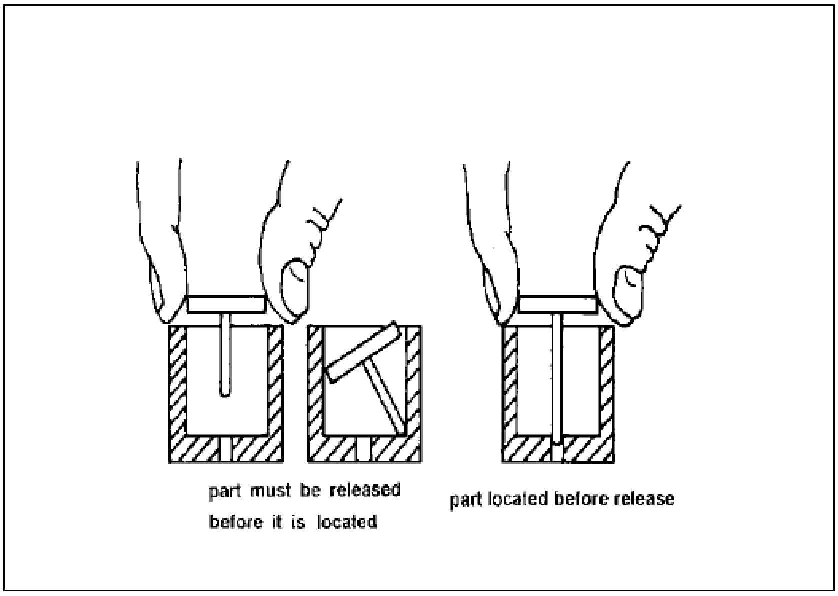


Figure 2.5: Design to aid insertion

Source: (Boothroyd *et al*., 2002)

The DFA guidelines are differ from the various source and it is insufficient for a number of reasons as stated below:

(i) The guidelines will not provide any means to evaluate a design
(ii) Quantitatively for its ease of assembly.
(iii) No relative ranking of all the guidelines that can be used to indicate which guidelines result in the greatest improvements in handling and assembly.
(iv) These guidelines are simply a set of rules which provide the designer with suitable background information to be used to develop a design that will be more easily assembled than a design developed without such a background

If a product contains fewer parts, it will take less time to be assembled, thereby reducing assembly costs. In addition, if the parts are easier to grasp, move, orient and insert, the parts can reduce the assembly time and assembly costs. The reduction of the number of parts in an assembly has benefit and generally reducing the total cost of parts in the assembly. This is usually where the major cost benefits of the application of design for assembly occur.

2.4 DESIGNS FOR ASSEMBLY METHOD

There are three methods that can be used for design for assembly (DFA):

(i) The DFA method exploited by Boothroyd-Dewhurst Inc, USA
(ii) The Hitachi Assemblability Evaluation Method (AEM) by Hitachi Ltd, Japan.
(iii) The Lucas Design for Assembly Methodology by Lucas-Hull, UK.

2.4.1 Boothroyd-Dewhurst DFA Method

In 1977, Geoff Boothroyd, developed the Design for Assembly method (DFA), which could be used to estimate the time for manual assembly of a product and the cost of assembling the product on an automatic assembly machine. Recognizing that the most important factor in reducing assembly costs was the minimization of the number of separate parts in a product, he introduced three simple criteria which could be used to determine theoretically whether any of the parts in the product could be eliminated or combined with other parts. These criteria, together with tables relating assembly time to various design factors influencing part grasping, orientation and insertion, could be used to estimate total assembly time and to rat the quality of a product design from an assembly viewpoint. (Baizura, 2007)

For automatic assembly, tables of factors could be used to estimate the cost of automatic feeding and orienting and automatic insertion of the parts on an assembly machine. Starting in 1981, Geoffrey Boothroyd and Peter Dewhurst developed a computerized version of the DFA method which allowed its implementation in a broad range of companies. In many companies, DFA is a corporate requirement and DFA software is continually being adopted by companies attempting to obtain greater control over their manufacturing costs. (Kader, 2008)

In this method, the manual assembly process can be divided into two separate areas which are handling (acquiring, orienting and moving the parts) and insertion and fastening (mating a part to another part or group of parts). Application of the manual method is straightforward using the subassembly worksheet and two pages of manual handling and manual insertion chart. The worksheet will be completed for each subassembly and for the final assembly.

For manual handling, the information that should be known and considered is listed down below. (Boothroyd *et al*., 2002).

(i) Alpha (α) - It is the rotational symmetry of a part about an axis perpendicular to its axis of insertion.

(ii) Beta (β) - It is the rotational symmetry of a part about its axis of insertion.

(iii) Thickness-It is the length of the shortest side of the smallest rectangular prism that encloses the part.

(iv) Size-It is the length of the longest side of the smallest rectangular prism that can enclose the part.

For manual insertion, below are the some of the knowledge that have to be known (Boothroyd *et al*., 2002).

(i) Holding down required - It means that the part will require gripping, realignment, or holding down before it is finally secured.

(ii) Easy to align and position - It means that insertion is facilitated by well designed chamfers or similar features.

(iii) Obstructed access - It means that the space available for the assembly operation causes a significant increase in the assembly time.

(iv) Restricted vision - It means that the operator has to rely mainly on tactile sensing during the assembly process.

The theoretical minimum number of parts is determined by answering to these three questions below (Boothroyd *et al.*, 2002).

(i) During the normal operating mode of the product, the part moves relative to all other parts already assembled. (Small motions do not qualify if they can be obtained through the use of elastic hinges).

(ii) The part must be of a different material than, or must be isolated from, all other parts assembled (for insulation, electrical isolation, vibration damping, etc.)

(iii) The part must be separate from all other assembled parts; otherwise the assembly of parts meeting one of the preceding criteria would be prevented.

If the answer to any of those questions is ‘yes’, then the part cannot be eliminated and it called as the theoretical minimum number of parts. The basic assembly time is the average time for a part that presents no handling, insertion, or fastening difficulties. The basic assembly time will be used in determining the design efficiency. The design efficiency is calculated using the formula below (Boothroyd *et al*., 1994).

$$\text{Design efficiency} = \frac{3 \times \text{Nm}}{\text{Tm}} \qquad (2.1)$$

Where;

Nm = theoretical minimum number of parts.

Tm = estimated time to complete the assembly of the product.

In general, adding a component to the assembly will involve some or all of the following basic functions (Boothroyd *et al*., 2002):

(i) Handling: the process of grasping, transporting, and orienting components.

(ii) Insertion: the process of adding components to the work fixture or partially built-up assembly.

(iii) Securing: the process of securing components to the work fixture or partially built-up assembly.

(iv) Adjustment: the process of using judgement or other decision- making processes to establish the correct relationship between components.

(v) Separate Operation: mechanical and non-mechanical fastening processes involving parts already in place but not secured immediately after insertion (eg. bending, upsetting, screw tightening, resistance welding, soldering, adhesive bonding, etc.).

(vi) Also other assembly operations such as manipulating of parts or subassemblies, adding liquids, etc.

(vii) Checking: the process of determining that handling, insertion, securing, and adjustment have been carried out properly.

Examples of DFA method by Boothroyd-Dewhurst

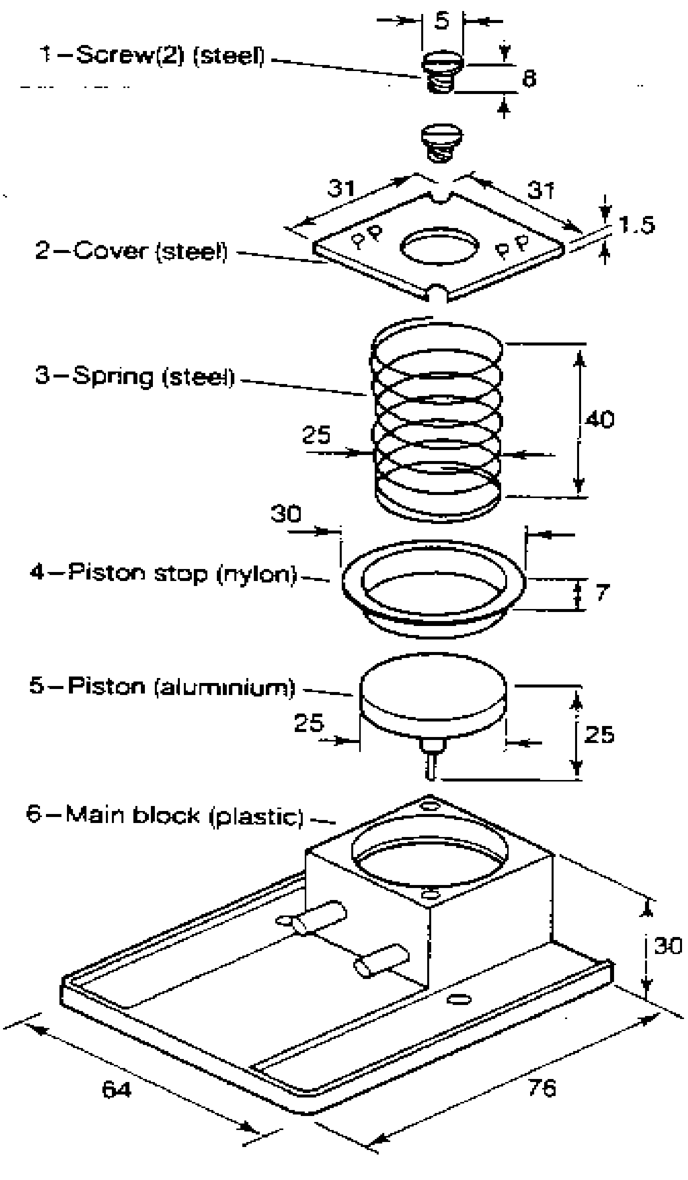


Figure 2.6: A piston assembly design

Source: (Boothroyd *et al.*, 1991)

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

Table 2.1: Table for computation of design efficiency

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

Source: (Boothroyd *et al*., 1991)

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

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

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

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

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

Table 2.2: Evaluating the design efficiency of a piston

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

Source: (Boothroyd *et al*., 1991)

Improving the design:

The following considerations are important:

STEP 1. Is the number in column 9 < the number in column 2 ?
If yes, there is an opportunity for reduction in number of parts.

STEP 2. Examine columns 4 and 6.

These figures indicate potential for assembly time reduction. Based on these ideas, a redesign of the piston assembly is presented below. Notice how the new design presents a design efficiency of 90%.

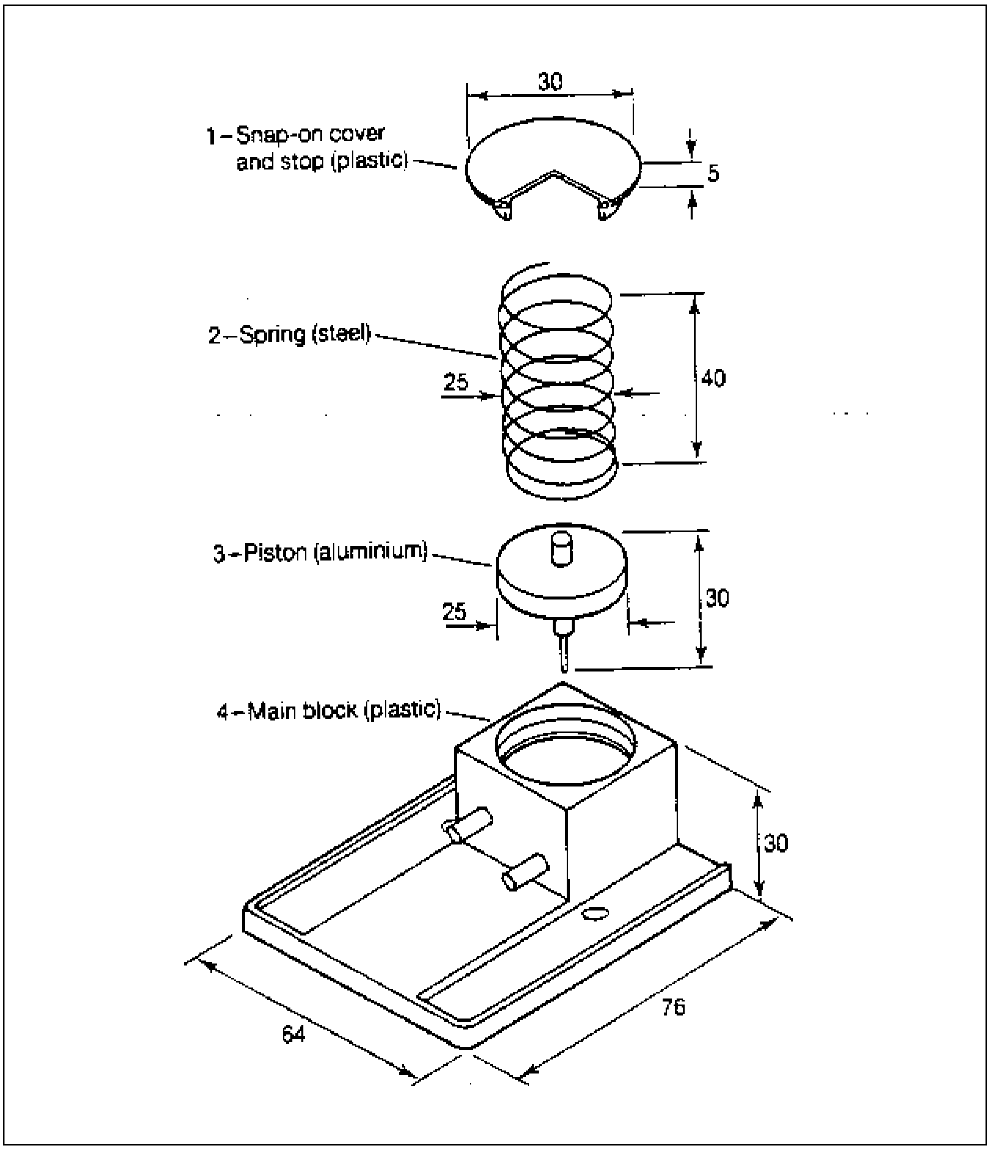


Figure 2.7: An improved piston design

Source: (Boothroyd *et al*., 1991)

Table 2.3: Evaluating the design efficiency of the new designed piston

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

Source: (Boothroyd *et al*., 1991)

2.4.2 Hitachi Assemblability Evaluation Method (AEM)

The Hitachi AEM analyses the motions and operations, called 'assembly operations', necessary to insert and secure each component of the product. A simple downward motion is considered to be the easiest and fastest assembly operation. Penalty points are awarded for every motion or operation that differs from, or is in addition to, this simple motion. This method makes use of assemblability and assembly cost ratio indices to identify the weak points of a design.

The Hitachi AEM DFA method based on the penalty given of the components that need to be assembled. For example, the parts that ready at a position to insert assigned penalty points to each part that are 100 points to a part for its existence and additional points depend on the difficulty of the assembly process. Then, the total points converted to the assembly time followed by the assembly efficiency.

The additional penalty points depending on the relative difficulty to insert the part such as:

(i) Direction of motion
(ii) Needs of fixture and forming
(iii) Method of joining and processing
(iv) Multiple operations

After that, the additional 15% penalty points per each operation for a second operation and beyond:

(i) Strong incentive for simpler assembly operation
(ii) More critical for automatic assembly

Symbol	Penalty Points	Description of Operation
↓	0	Straight downward
↑	30	Straight upward
← →	20	Move horizontally
↗ ↙	30	Move diagonally up/down
⊃ ∩	30	Turn like a screw
R	40	Turn or lift the whole assembly to insert a part

Figure 2.8: Direction of motion of a part

Source: (Hitachi AEM, 2002)

Symbol	Penalty Points	Description of Operation
f	20	Hold a part for next one operation
F	40	Hold a part for more than one next operations
G	40	Deform a soft/flexible part (O-ring, gasket)
P	20	Bend or cut (wires, ..)

Figure 2.9: Fixture & forming requirements

Source: (Hitachi AEM, 2002)

Symbol	Penalty Points	Description of Operation
B	20	Bond with adhesive or heat, or lubricate a part
W	20	Weld
S	30	Solder
M	60	Machine a part to join

Figure 2.10: Joining & processing requirements

Source: (Hitachi AEM, 2002)

Symbol	Penalty Points	Description of Operation
—	0	Base part for assembly
|	0	Pipe to keep track of assembly process

Figure 2.11: Other symbols without penalty points

Source: (Hitachi AEM, 2002)

Table 2.4: Hitachi AEM DFA method worksheet

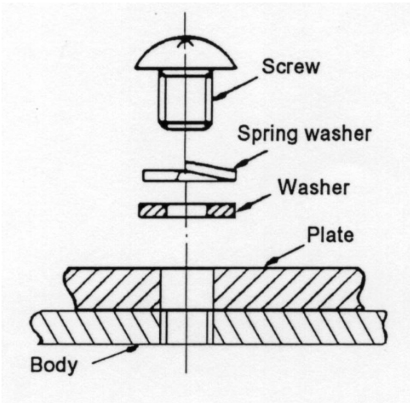
Part			Number of	Summation Method			
	Count	Operation	Operations	Total Penalty	M = 100 +	T = M * α	
Name	(n)	Symbols	(m)	(Σ Penalty)	Σ Penalty	(+15% add op)	T * n
						Σ T*n =	
						Assembly Time =	Tdown

Source: (Hitachi AEM, 2002)

$$\text{Design efficiency} = \frac{\sum part\ count}{\sum (assembly\ time\ in\ T\ down)} \text{ x } 100\%$$

$$= \frac{\sum n}{\sum T} \text{x}100\% \qquad (2.2)$$

Example of Hitachi AEM DFA method**:**



1. Position a body
2. Bring down a plate
3. Place and hold a washer
4. Place & hold a spring washer
5. Bring down and turn a screw

Figure 2.12: Assemble of a screw to a body

Source: (Hitachi AEM, 2002)

Table 2.5: Assemble of a screw to a body worksheet

Part			Number of	Summation Method			
Name	Count (n)	Operation Symbols	Operations (m)	Total Penalty (Σ Penalty)	M = 100 + Σ Penalty	T = M * α (+15% add op)	T * n
Body	1	base	1	0	100	100	100
Plate	1	down	1	0	100	100	100
Washer	1	down, f	2	20	120	138	138
Spring Washer	1	down, f	2	20	120	138	138
Screw	1	down, turn	2	30	130	150	150
						Σ T*n =	626

Source: (Hitachi AEM, 2002)

From the Eq (2.2):

Design efficiency = $\frac{\sum part\ count}{\sum (assembly\ time\ in\ T\ down)}$ x 100%

$= \frac{\sum n}{\sum T}$ x100%

$$= \frac{5}{6.3} \times 100\%$$

$$= 79.37\%$$

2.4.3 Lucas-Hull DFA Method

Lucas DFA method encompasses a functional analysis, a handling or feeding analysis and a fitting analysis. The method involves the assigning and summing of penalty factors associated with potential design problems similar to the Hitachi method but with the inclusion of handling (or feeding) as well insertion. These penalty factors are combined with an assembly sequence flow chart (Figure 2.12) and generate three assemblability scores.

The three scores; design efficiency, feeding/handling ratio and fitting ratio are generated in three stages of the analysis. All components of an assembly undergo functional analysis, categorising them into an A (essential) part or a B (nonessential) part. The design efficiency is derived from the ratio of essential parts to total parts (A/(A+B)).

A suggested target of 60% is to be aimed for. The feeding or handling analysis examines each component with respect to a knowledge base to determine a feeding index; these are then summed for the total assembly. The feeding index has a threshold of 1.5 indicating that any greater score be considered for redesign for feeding.

The feeding ratio is the ratio of feeding index total to number of essential components, and has its own threshold of 2.5. Fitting analysis follows the same formula as feeding, utilising a knowledge base, determining a fitting index, and finally a fitting ratio. These scores can then be compared to thresholds or values established for previous designs

2.5 COMPARISON OF DFA METHODS

2.5.1 Boothroyd Dewhurst's DFA Method

The advantages of this method is suitable to redesign the product based on the design efficiency calculation and the part that require high assembly time to assembly and unnecessary parts should be redesign or eliminate**.** The disadvantage is it does not show the evaluation of the whole assembly sequence and also there is no support on how to redesign the product and shows the poor results.

2.5.2 Lucas-Hull DFA Method

The advantage of the Lucas-Hull method is similar as the Boothroyd Dewhurst method. It is Suitable in develop new product design based on the design efficiency and also evaluated the parts of the product based on functional, handling and fitting analysis. The disadvantage is Lucas Hull DFA is classified into automated assembly and manual assembly only. The function analysis does not show why the part should exist.

2.4.3 Hitachi AEM Method

The advantage of this method is ease or the difficulty of insertion expressed in relative terms allowing applications to a wide range of products. The disadvantage is this method only focus on the insertion and fastening process only. Part handling considered not as important or considered separately. There was no part reduction step in the original Hitachi AEM method.

2.5.4 DFA Methods Comparison Table

Table 2.6: DFA methods comparison table

DFA Method	Advantage	Disadvantage
Boothroyd Dewhurst's	Redesign of product can be evaluated based on the design efficiency calculation.	Less support on how to redesign the product.
Hitachi AEM	Ease or the difficulty of insertion expressed in relative terms.	Focus on the insertion and fastening process only.
Lucas-Hull	Evaluated the parts of the product based on functional, handling and fitting analysis and suitable in developing a new product.	Categorized on automated and manual assembly only..

Source: (Faizal, 2007)

2.6 PREVIOUS RESEARCH OF BOOTHROYD DFA METHOD AND HITACHI AEM DFA METHOD

2.6.1 Concurrent Engineering Approach in Designing Pressure Vessel by A.R. Ismail, AH.A.A. Manap, D.A. Wahab, R. Zulkifli, N.K Makhtar and K. Sopian (2008)

A.R. Ismail, AH.A.A. Manap, D.A. Wahab, R. Zulkifli, N.K Makhtar and K. Sopian (2008) in journal titled "Concurrent Engineering Approach in Designing Pressure Vessel" study about the effect of implementation of the Design for Manufacture and Assembly (DFMA) in pressure vessel. Information such as design design and component development time was analysed and modelled to ensure the effect of the implementation of this approach to product development cycle and design efficiencies. By using Boothroyd-Dewhurst method, the existing design of pressure vessel was modified by incorporating the design for manufacture and assembly requirements. This approach enables a shorter product development cycle time through reduction in manufacturing and assembly time. Besides, the overall cost of the pressure vessel was reduced. The implementation of this method has improved manual assembly efficiency compare existing design. This improvement was trigger by reduction of component handling time and the design was simplified. The reduction of pressure vessel component was improving the assembly efficiency. Based on the manual assembly efficiency, the existing efficiency is 0.02% and after the DFMA approach implemented, there has been increased to 0.023% and this is quite good enough to give an impact on overall assembly time.

2.6.2 Product Design Enhancement By Integration Of Virtual Design And Assembly Analysis Tools By Choi And Prasanthi (2000)

Choi and Prasanthi (2000) in journal titled "Product design enhancement by integration of virtual design and assembly analysis tools" study about the assembly process for a computer mouse, using both the Boothroyd and Dewhurst design for assembly (DFA) and Tecnomatix's Dynamo software package. A mouse design in Unigraphics has been the product considered and the assembly process has been analysed. These software systems can help identify some of the technical problems that can possibly can be encountered in the real life production and can effectively be used to guide the design process. The Dynamo is concerned with finding the optimal sequence of assembly for a product while, DFA examines the mouse to evaluate its "fitness" for assembly, and where appropriate, to provide high-level suggestions to redesign the components so that they are easy to be assembled (Hsu et al., 1998).

2.6.3 Sub-Assembly Partitioning For Complex Assemblies Based On An Action-Count-Closure Criterion By Rhee (1996)

Rhee (1996) in his master degree thesis titled "Sub-assembly partitioning for complex assemblies based on an action-count-closure criterion" study about how DFA may be used successfully for such complex assemblies through subassembly repartitioning or minor redesign. Complex assemblies are generally characterized by having a large parts count with the assembly organized as a collection of subassemblies. Apart from that, a complex assembly may contain assembly moves in a large number of kinematic degrees of freedom (actions) and this must be fixed by using DFA during the assembly move in order to minimize the degree of freedom. The goal of this research was to develop the techniques and tools required to apply DFA to complex assemblies. This thesis presents one such computer-aided tool to aid in DFA of complex assemblies by allowing for rapid evaluation of assembly option by design changes and in assembly planning itself by suggesting subassembly partitions schemes along with assembly sequences.

2.6.4 DFMA Application On The Development Of Parts For The White Goods Industry By Canciglieri And Kovalchuk (2006)

Canciglieri and Kovalchuk (2006) in journal titled "DFMA application on the development of parts for the white goods industry" study about the applicability of the concepts of DFMA (Design for Manufacture and Assembly) and the Concurrent Engineering in the development of the product parts for White Goods industry (major appliances as refrigerators, cookers, and washing machines). By doing this DFMA to the product, it provided cost savings and reduction on the time to assembly the product.

2.6.5 A Product Architecture-Based Conceptual DFA Technique By Stone, Mcadams And Kayyalethekkel (2002)

Stone, McAdams and Kayyalethekkel (2002) in journal titled "A Product Architecture-Based Conceptual DFA Technique" study about DFA method with the

Boothroyd-Dewhurst DFA and the products evolution over the years. This study reveals the evolution of products into designs with smaller part counts, closely matching the modules identified by the conceptual DFA method.

2.6.7 Automatic Assembly Line For VTR Mechanisms By Toshijiro, Seii And Makato (1985)

Toshijiro, Seii and Makato (1985) in journal titled "Automatic Assembly Line for VTR Mechanisms" study about VTR mechanisms which was reviewed by using the Hitachi Assemblability Evaluation Method. Most of the operations could be performed by high-level robots but more preferred instead to perform such operation manually, both for reasons of cost-performance and quick line-up.

2.6.8 Extended Assemblability Evaluation Method (AEM) By Toshijio Ohashi, Minoru Iwata, Shoji Arimoto And Seii Miyakawa

The journal discussed about the Hitachi AEM DFA method to improve design quality for better assembly efficiency. Using this method, in the early design stages, assembly efficiency is highlighted. In addition, the effects of design improvements are confirmed with respect to assembly cost. Through these activities, design improvements are realized and the extended AEM has been developed to improve the functionality and the accuracy of the method to allow a wide variety of use. Based on a constructed product and process model, a new evaluation system has been developed and part-based cost estimation has been realized.

Table 2.7: Previous Research Of Boothroyd DFA Method And Hitachi AEM DFA Method

Author	Method	Product study	Results
Ismail, AH.A.A. Manap, D.A. Wahab, R. Zulkifli, N.K Makhtar and K. Sopian (2008)	Boothroyd-Dewhurst	Pressure Vessel	Based on the manual assembly efficiency, the existing efficiency is 0.02% and after the DFMA approach implemented, there has been increased to 0.023% and this is quite good enough to give an impact on overall assembly time.
Choi And Prasanthi (2000)	Boothroyd-Dewhurst	Computer mouse	DFA examines the mouse to evaluate its “fitness” for assembly, and where appropriate, to provide high-level suggestions to redesign the components so that they are easy to be assembled
Rhee (1996)	Boothroyd-Dewhurst	Sub-assembly partitioning for complex assemblies	DFA of complex assemblies by allowing for rapid evaluation of assembly option by design changes and in assembly planning itself by suggesting subassembly partitions schemes along with assembly sequences.

Table 2.7: Continued

Author	Method	Product study	Results
Canciglieri And Kovalchuk (2006)	Boothroyd-Dewhurst	Development of parts for the white goods industry	By doing this DFMA to theproduct, it provided cost savings and reduction on the time to assembly the product
Stone, Mcadams And Kayyalethekkel (2002)	Boothroyd-Dewhurst	Product Architecture	This study reveals the evolution of products into designs with smaller part counts, closely matching the modules identified by the conceptual DFA method.
By Toshijiro, Seii And Makato (1985)	Hitachi AEM	VTR Mechanisms	Most of the operations could be performed by high-level robots but more preferred instead to perform such operation manually, both for reasons of cost-performance and quick line-up.
Toshijio,Ohashi, Minoru Iwata, Shoji Arimoto And Seii Miyakawa	Hitachi AEM	The effects of design improvements are confirmed with respect to assembly cost	Based on a constructed product and process model, a new evaluation system has been developed and part-based cost estimation has been realized.

Source: Previous Research Of Boothroyd DFA Method And Hitachi AEM DFA Method

2.7 CONCLUSION

There are three different types of DFA methodologies: Boothroyd Dewhurst, Hitachi and Lucas which can be applied in a product. Each method had its own approach and function ability that refers to their principle. Knowledge and skills are important in using this method in order to get a good result. It is clear that the use of DFA method has a tremendous impact when it is properly applied in improving the product. The adaptation of DFA philosophy and cost quantification tools at the early stages of product design will gives greater benefits. For this project, Boothroyd Dewhurst's DFA and Hitachi AEM DFA method will be used to reduce the assembly cost of the car rear lamp.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discussed about the method that used in this final year project.. The flow chart of the Final Year project started with the project proposal and then the second step is the literature review. After that, the next step is the methodology regarding this project. The methods used including methods in project progress, methods in gathering information, methods in separating and measuring of the product, method in drawing of the product and methods of using manual calculations of Boothroyd DFA and Hitachi AEM DFA. Then, the next steps are the results and discussions of the project which is the analysis of the product by using Boothroyd DFA and Hitachi AEM DFA method. After that, the next step is the conclusions and recommendations and ended with the final report of the Final Year project.

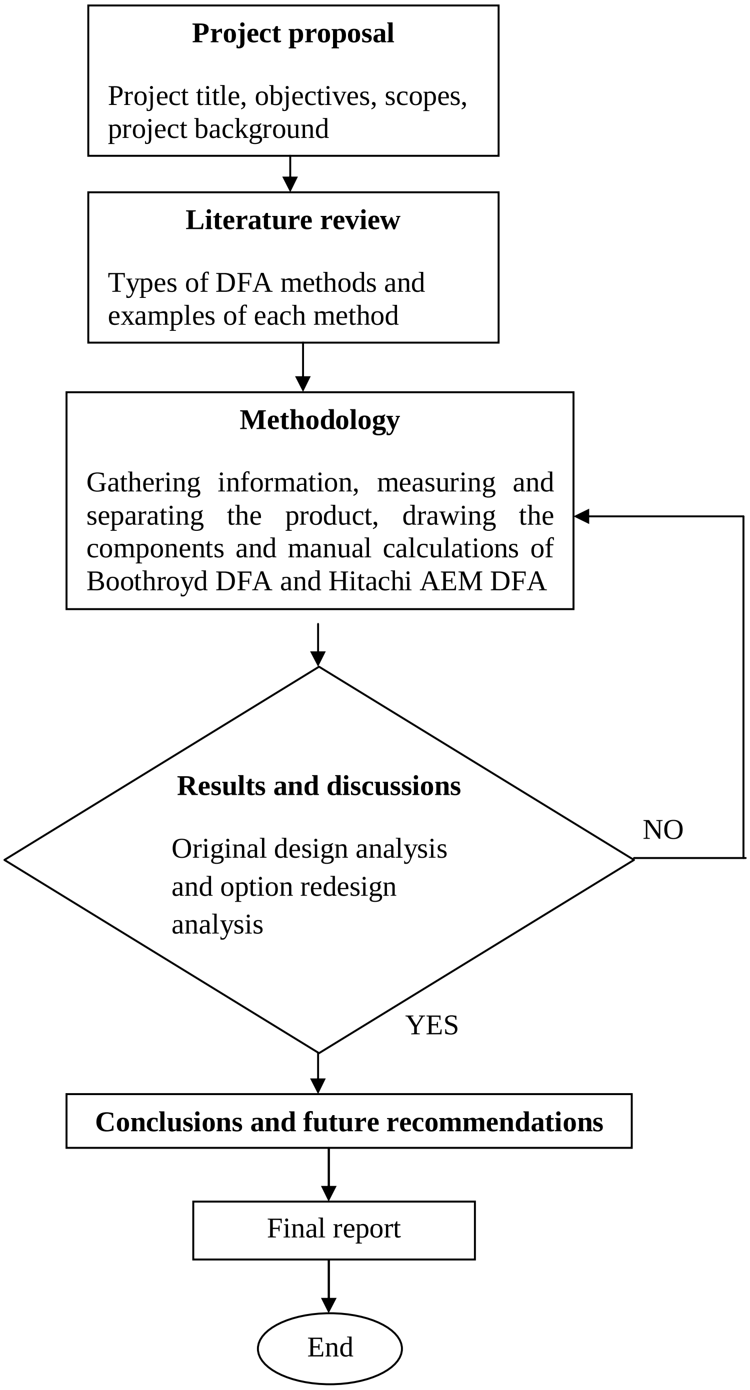


Figure 3.1: Flow Chart of the Final Year Project

3.2 METHOD IN GATHERING INFORMATION

The progress of the project is started with gathering information regarding the project title. Before that, an appointment with the supervisor has been made and the suggestion by the supervisor is to find the journal and reference book about DFMA method regarding the project title so that there will be a general idea on how to conduct the project. Other than that, the information regarding the project also obtained from websites and journals from the internet. Some journals are referred from the university's database such as the journals from previous project that have been done by the senior students. Several journals has been studied and kept as a future reference to be used later. Previous thesis of final year student also referred as a source of information while doing the project. Besides the journals from internet and reference books from library, the information of short interview with Deputy Dean of FKKP also considered the important information in understanding the method that will be used in this final year project.

3.3 METHOD IN SEPARATING AND MEASURING THE PRODUCT

Method in separating and measuring of the product which is the rear lamp of Proton Saga BLM is the most difficult method that need to be done because this method need a special expertise in separating and measuring the components of the rear lamp. The separating of the components of the lamp is easier than measuring the components. The components of the rear lamp can be separated by using hand and a screwdriver. The bulb socket can be removed from the main casing by rotating the socket anticlockwise and the cover of the main casing can be removed by using hand. The main casing connected with four screws that can be removed by using a screwdriver.

The most critical part in this method is to measure the dimensions of the components of the rear lamp. For this rear lamp, a vernier calliper is used to measure the small dimensions. For dimensions that greater than vernier calliper scale, a long ruler is used to measure the height and the length of the part of the rear lamp. Besides that, a small diameter rope also is used to measure intricate dimensions of the components of the rear lamp. Overall, the measurement of the products is not 100 percent precise due to the errors from the measurements tools and too mush intricate part of the rear lamp.

3.4 METHODS IN DRAWING OF THE PRODUCT

After all components of the rear lamp is separated and measured, each component is drawing back in solidworks software. The rear lamp consists of nine components which are three bulbs with difference size, a wire socket with bulb casing, a main casing and the cover and four screws. Then, all this part is drawing back in solidworks software with the dimensions from the previous method. After all the components are drawing back separately, all this parts will be assembled started with the bulb is connected to the bulb casing with the wire and socket. Then, the cover of the main casing is mated with the main casing and the four screws is connected to the main casing. The final assembly is the bulb with the socket wire is connected to the main casing and the final product of the rear lamp is finished.

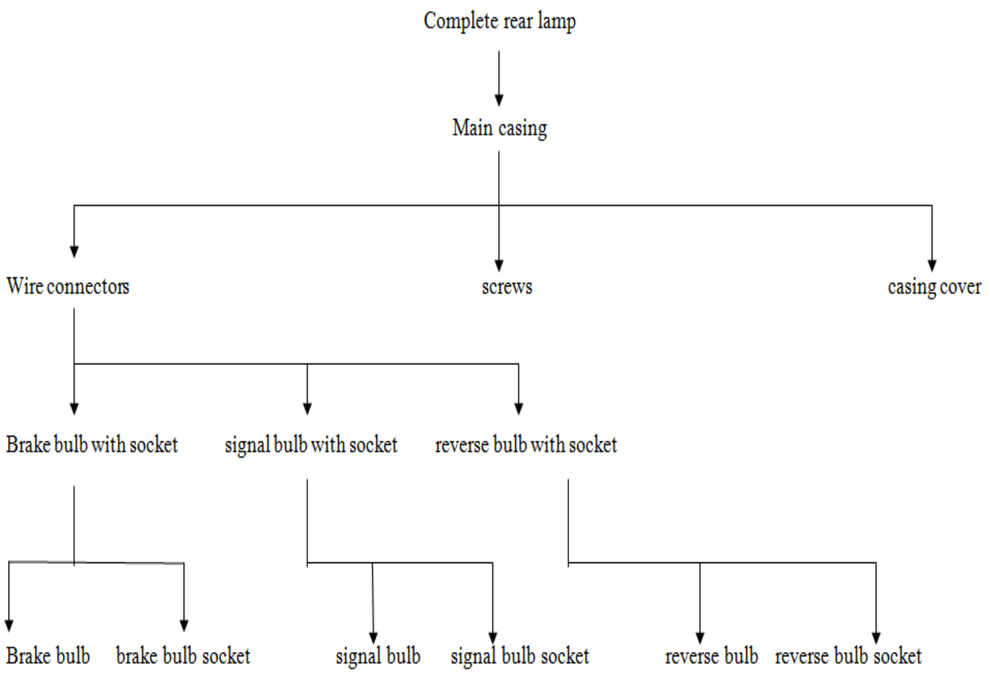


Figure 3.2: Product tree of the rear lamp

3.5 METHODS IN MANUAL CALCULATIONS OF BOOTHROYD DFA METHOD

The computation is done by systematically completing the data in the following table. The data requires several estimates for assembly efficiency of different components based on their characteristics.

Table 3.1: Table for computation of design efficiency

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

Source: (Boothroyd 91)

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

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

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

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

If the answer to any of these questions is YES, a 1 is entered in column 9 (except if there are multiple parts in column 2, in which case the minimum number of separate parts required is entered in column 9 and the design efficiency is calculated according to the equation (2.1)

3.6 METHODS IN MANUAL CALCULATIONS OF HITACHI AEM DFA METHOD

The computation is done by systematically completing the data in the following table. The data requires several estimates for assembly efficiency of different components based on their characteristics.

Table 3.2: Table for computation of design efficiency

Part			Number of	Summation Method			
Name	Count (n)	Operation Symbols	Operations (m)	Total Penalty (Σ Penalty)	M = 100 + Σ Penalty	T = M * α (+15% add op)	T * n
						Σ T*n =	
						Assembly Time =	Tdown

Source: (Hitachi AEM, 2002)

Then, the design efficiency of the Hitachi AEM DFA method is calculated according to the equation (2.2)

$$\text{Design efficiency} = \frac{\sum part\ count}{\sum(assembly\ time\ in\ T\ down)} \text{ x } 100\%$$

$$= \frac{\sum n}{\sum T} \text{ x}100\%$$

3.7 CONCLUSION

This chapter gives the important information regarding all the methods used in the project. Various methods have been used to get the information for the project such as methods in design for the project, methods in gathering information, method in separating and measuring the product, method in drawing of the product and method used when using the Boothroyd-Dewhurst DFA manual calculation and Hitachi AEM DFA method and steps taken in writing thesis. By referring to the flowchart in Figure 3.1, the flow of the project can be seen and understood easily.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter presents results of this project and further the results are discussed in detail. The results for the current design and redesign of the rear lamp are stated. In this project, the results are obtained by using Boothroyd Dewhurst DFA and Hitachi Assemblability method for DFA analysis and using SOLIDWORKS software for the redesign of the component rear lamp. The recommendations for this project will be discussed in the next chapter.

4.2 PRODUCT INFORMATION

The rear lamp of Proton Saga BLM is designed and manufactured by Automotive Lighting Malaysia Sdn Bhd and this company is the vendor for Proton to design and manufacture the rear lamp of the latest Proton car at that time which is the Proton Saga BLM. The function of the rear lamp is to alert the driver at the rear of the car especially during the night time driving.

The rear lamp of Proton Saga BLM consists of 10 components and the main component of this rear lamp is the main casing which is the most important part followed by the bulbs, sockets, wire connector, cover and screws. The rear lamp consists of 6 subassemblies and the operation involved during the assembly process including handling, insertion and tightening operation.

Figure 4.1: Location of rear lamp

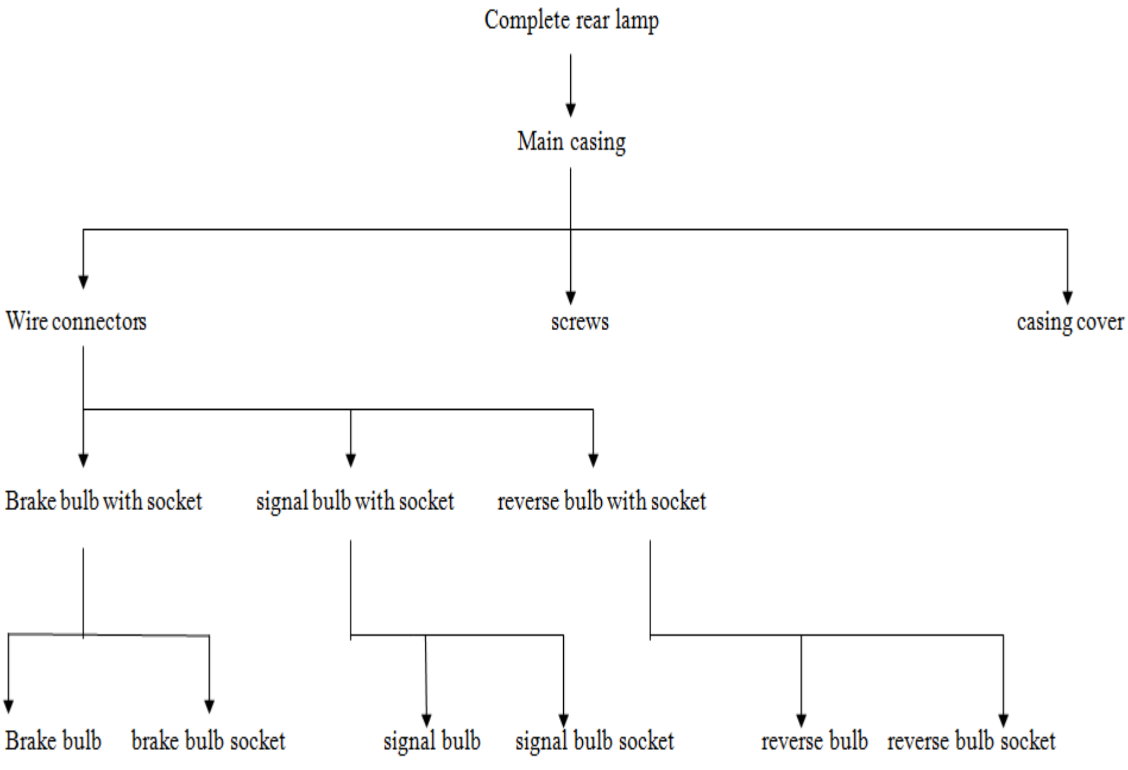


Figure 4.2: Product tree of the rear lamp

Figure 4.1 shows the product tree for the assembly process of the rear lamp of Proton Saga BLM that consists of the main assembly and sub-assemblies. The main assembly and six other subsystems are assembled together during assembly process to make the complete rear lamp. Below is the list of components assembled in the main assembly.

(i) Wire connectors
(ii) Screws
(iii) Cover

There are six sub-assemblies for the assembly process of the rear lamp and all of that is connected to the wire connector which is the main assembly for the rear lamp. Below are the sub-assemblies for the assembly process of the rear lamp.

(i) Brake bulb with socket
(ii) Signal bulb with socket
(iii) Reverse bulb with socket
(iv) Brake bulb and brake bulb socket
(v) Signal bulb and signal bulb socket
(vi) Reverse bulb and reverse bulb socket

4.3 PRODUCT DESIGN ANALYSIS FOR BOOTHROYD DFA METHOD

Table 4.1 showed the components of the rear lamp with the thickness and size and the value of α and β to analysis the design by using Boothroyd DFA method.

Table 4.1: The components of the rear lamp

Main casing 	α = 180° β = 0° Size = 372 mm Thickness = 246 mm
Brake bulb 	α = 180° β = 0° Size = 47 mm Thickness = 12.5 mm
Signal bulb 	α = 180° β = 0° Size = 47 mm Thickness = 12.5 mm
Reverse bulb 	α = 180° β = 0° Size = 35 mm Thickness = 7 mm

Table 4.1: Continued

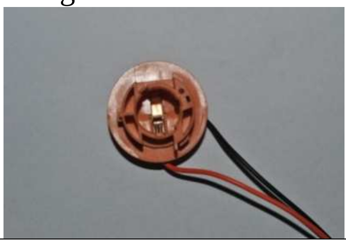
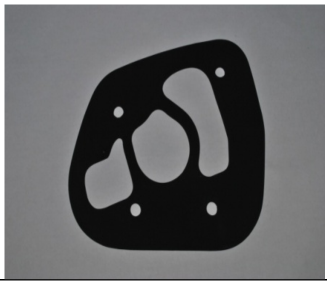
Wire connector 	α = 180° β = 0° Size = 33 mm Thickness = 19 mm
Brake bulb socket 	α = 180° β = 0 Size = 27 mm Thickness = 17.5 mm
Signal bulb socket 	α = 180° β = 0° Size = 27 mm Thickness = 17.5 mm
Reverse bulb socket 	α = 180 β = 0° Size = 29 mm Thickness = 12 mm
Reverse bulb with socket 	α = 180° β =360° Size = 52 mm Thickness = 12 mm

Table 4.1: Continued

Signal bulb with socket 	α = 180° β = 360 Size = 60 mm Thickness = 17.5 mm
Brake bulb with socket 	α = 180° β = 360° Size = 60 mm Thickness = 17.5 mm
Screw 	α = 180° β = 0° Size = 36 mm Thickness = 7.5 mm
Cover 	α = 360° β =360° Size = 207 mm Thickness = 5 mm

The original rear lamp design analysis is started after disassemble the entire rear lamp product component. Below are the steps in completing the whole analysis for the original design of the rear lamp:

(i) Decision has to be made on whether the rear lamp components can be considered as a candidate for elimination or redesign the components in the assembly.
(ii) Determine the theoretical minimum number of parts for the rear lamp components which is the minimum number of components necessary to perform the function.
(iii) Estimation of the time taken to grasp, manipulate, and insert each rear lamp component to its main assembly.
(iv) Calculate the total product assembly time and assembly cost.
(v) Calculate the design efficiency for the rear lamp product in percentage value

According to the step (Π) above, the theoretical minimum number of parts is obtained by answering 3 questions. If the answer to any of the questions is 'yes' then either a "1" is placed in the column. Otherwise, if all the answer for the 3 theoretical minimum number of parts questions is ‘n’ then put ‘0’ in the column (refer Table 4.2). Below is the 3 theoretical minimum numbers of parts questions:

(i) Does the part move relative to all other parts already assembled? (small motions where elastic hinges are possible can be ignored)
(ii) Does the part have to be in different material or be isolated from all other parts already assembled?
(iii) Does the part have to be separated from all other parts already assembled because of possible assembly or disassembly?

4.3.1 Original Design Analysis

Original rear lamp design consists of 10 different components including 4 screws and 3 different operations. The screws used in this original rear lamp design will be always a candidate for elimination. For original design, the total assembly time to assemble all the components is 73.61 seconds. On the other hand, total cost of assemble all the components of original rear lamp design is RM 0.10224

By observing the original design, the improvements in term of ease of assembly can be done. There are possible components for elimination from the original rear lamp design.

Other than that, certain components seem possible for combination with the already assembled components. In the redesign of the rear lamp, those elimination and combination will be considered.

Table 4.1 shows DFA worksheet for the original rear lamp design. The DFA worksheet is a sheet used to evaluate each components of the rear lamp in term of many aspects. The aspects that will be evaluated are shown below:

(i) Proper names are given for each component of the rear lamp.
(ii) Number of times the operation is carried out consecutively for each component is determined
(iii) Handling code and handling time for each component is determined from Manual Handling Chart.
(iv) Insertion code and insertion time for each component is determined from Manual Insertion Chart.
(v) Operation time for each component obtained by adding each component's handling and insertion time.
(vi) Operation cost for each component is calculated by costing assumption done for each component.
(vii) Finally the theoretical minimum number of part is obtained by answering three questions.

Table 4.2: Original design analysis by using Boothroyd DFA method

Part ID. No.	Number of times the operation is carried out consecutively	Manual Handling Code	Manual Handling Time	Insertion Code	Insertion Time	Operation Time	Operation Cost ($x10^{-3}$)	Theoretical Minimum Number of Part	Part Name
13	1	00	1.13	30	2.0	3.13	4.347	1	Main casing
12	1	30	1.95	30	5.0	6.95	9.653	1	Main casing cover
11	1	20	1.8	01	2.5	4.3	5.972	1	Reverse bulb with socket
10	1	00	1.13	-	-	1.13	1.569	1	Reverse bulb socket
9	1	00	1.13	30	2.0	3.13	4.347	1	Reverse bulb
8	1	20	1.8	01	2.5	4.3	5.972	1	Brake bulb with socket
7	1	00	1.13	-	-	1.13	1.569	1	Brake bulb socket
6	1	00	1.13	01	2.5	3.63	5.042	1	Brake bulb
5	1	20	1.8	01	2.5	4.3	5.972	1	Signal bulb with socket
4	1	00	1.13	-	-	1.13	1.569	1	Signal bulb socket
3	1	00	1.13	01	2.5	3.63	5.042	1	Signal bulb
2	1	00	1.13	-	-	1.13	1.569	1	Wire connectors
1	4	01	1.43	-	-	5.72	7.945	0	screws
	4	-	-	01 92	7.5	30.0	41.67	-	Tightening operation
						73.61 **TM**	102.238 **CM**	12 **NM**	**Design efficiency** 3 NM/TM = 0.489

4.3.2 Original Design Calculations

For the calculation part, design efficiency needs to be calculated in a percentage value. It is important to find the design efficiency for the original design and for the each redesign so that the assembly efficiency between the rear lamp designs can be compared and evaluated. Below are the costing assumptions that have been made to find the design efficiency for the original design.

(i) Labor cost per month for one labor to produce the product is assumed RM 800.
(ii) Working day per week for one labor is assumed 5 days.
(iii) Working hour per day for one labor is assumed 8 hours.
(iv) Working hour per month for one labor is:
(4 weeks x 5 days x 8 hours) = 160 hours
(v) Labor cost per hour per month for one labor is:
RM 800 /160 hours = RM 5.00
(vi) Labor cost per second for one labor is RM 0.001389

Below are steps of calculation to find the design efficiency for the original rear lamp design by using Eq (2.1):

$$\text{Design efficiency} = \frac{3\times \text{Nm}}{\text{Tm}}$$

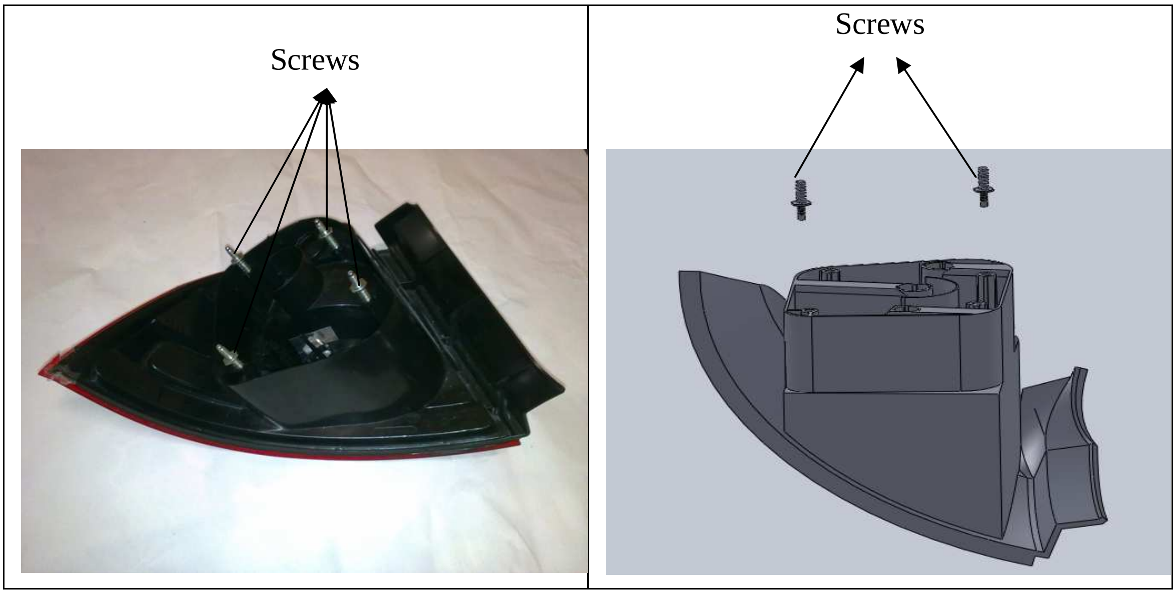
$$= \frac{3\times 12}{73.61}$$

$$= 0.489$$

From the calculation, the result of design efficiency for the original rear lamp design has been obtained. The value of design efficiency for the original design is 48.9%.

4.3.3 Option 1 Analysis

From the original design analysis, the main parts that contribute to most of the assembly time of the rear lamp are the screws that connected to the main casing. The original designs of the rear lamp consist of four screws that connected the main casing to the car body. From the analysis of the original design, the screws is the main parts that need to be eliminated to produce a better design efficiency of the rear lamp but the overall screws cannot be eliminated because the function of the screws is important in maintenance process. Besides that, the design of the screws are not satisfied the rule of the elimination of the part. So, the option of redesign 1 will reduce the number of screws from four screws to two screws to produce better design efficiency and reduce the operation cost. The option 1 analysis is shown in table 4.3.



(Before) (After)

Figure 4.3: Option 1 of redesign

Table 4.3: Boothroyd Dewhurst DFA worksheet for option 1 analysis

Part ID. No.	Number of times the operation is carried out consecutively	Manual Handling Code	Manual Handling Time	Insertion Code	Insertion Time	Operation Time	Operation Cost (x10^-3)	Theoretical Minimum Number of Part	Part Name
13	1	00	1.13	30	2.0	3.13	4.347	1	Main casing
12	1	30	1.95	30	5.0	6.95	9.653	1	Main casing cover
11	1	20	1.8	01	2.5	4.3	5.972	1	Reverse bulb with socket
10	1	00	1.13	-	-	1.13	1.569	1	Reverse bulb socket
9	1	00	1.13	30	2.0	3.13	4.347	1	Reverse bulb
8	1	20	1.8	01	2.5	4.3	5.972	1	Brake bulb with socket
7	1	00	1.13	-	-	1.13	1.569	1	Brake bulb socket
6	1	00	1.13	01	2.5	3.63	5.042	1	Brake bulb
5	1	20	1.8	01	2.5	4.3	5.972	1	Signal bulb with socket
4	1	00	1.13	-	-	1.13	1.569	1	Signal bulb socket
3	1	00	1.13	01	2.5	3.63	5.042	1	Signal bulb
2	1	00	1.13	-	-	1.13	1.569	1	Wire connectors
1	2	01	1.43	-	-	2.86	3.972	0	screws
	2	-	-	01 92	7.5	15.0	20.835	-	Tightening operation
						55.75	77.43	12	**Design efficiency** 3 NM/TM = 0.645
						TM	**CM**	**NM**	

Table 4.3 shows Boothroyd Dewhurst DFA worksheet for the option 1 of the rear lamp. Improvement has been done to the original design of the rear lamp and resulting in option 1 of the rear lamp. By redesigning the original rear lamp, the total assembly time that has been reduced is 17.86 seconds and the total assembly cost reduced is RM 0.0248.

4.3.4 Option 1 Calculations

Below are the costing assumptions that have been made to find the design efficiency for the redesign 1.

(i) Labor cost per month for one labor to produce the product is assumed RM 800.

(ii) Working day per week for one labor is assumed 5 days.

(iii) Working hour per day for one labor is assumed 8 hours.

(iv) Working hour per month for one labor is:
(4 weeks x 5 days x 8 hours) = 160 hours

(v) Labor cost per hour per month for one labor is:
RM 800 /160 hours = RM 5.00

(vi) Labor cost per second for one labor is RM 0.001389

Below are steps of calculation to find the design efficiency for the option 1 of the rear lamp design by using Eq (2.1):

$$\text{Design efficiency} = \frac{3 \times \text{Nm}}{\text{Tm}}$$
$$= \frac{3 \times 12}{55.75}$$
$$= 0.645$$

From the calculation, the result of design efficiency for the option 1 rear lamp design has been obtained. The value of design efficiency for the option 1 is 64.5%.

4.3.4 Option 2 Analysis

From the original design analysis, the bulbs that we used to assemble the components of the rear lamp are the reverse bulb, brake bulb and the signal bulb. The original design of the reverse bulb is inserted and fit to the socket while the original design of the brake bulb and the signal bulb are insert and rotate the bulb to fit the socket of the bulbs. From the original design of the reverse bulb, the handling time, insertion time and the operation cost of the reverse bulb is lower than the brake bulb and the reverse bulb. The improvements that have been made to the original design of the brake bulb and the signal bulb with the socket is to redesign them according to the original design of the reverse bulb and the socket of the rear lamp. The option 2 analysis is shown in the table 4.4.

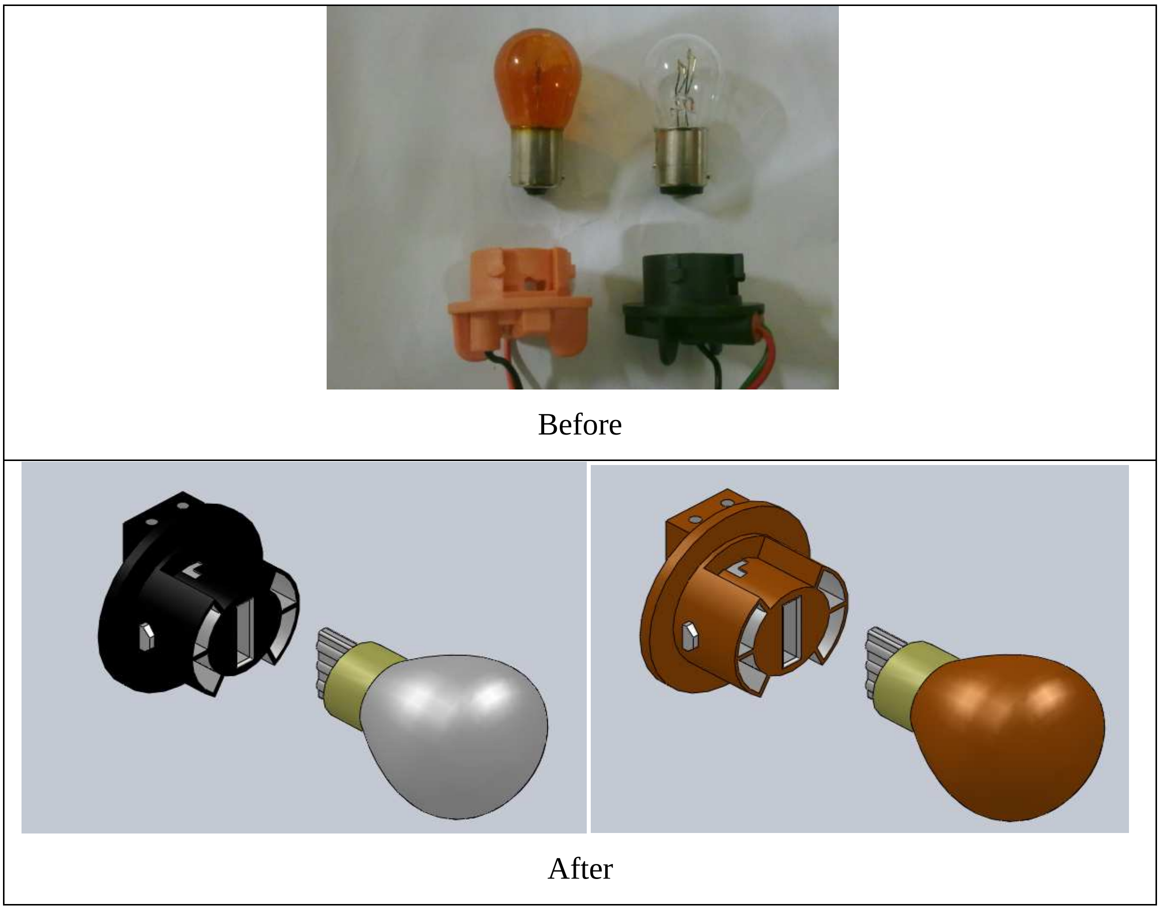


Figure 4.4: Option 2 of redesign

Table 4.4: Boothroyd Dewhurst DFA worksheet for option 2 analysis

Part ID. No.	Number of times the operation is carried out consecutively	Manual Handling Code	Manual Handling Time	Insertion Code	Insertion Time	Operation Time	Operation Cost ($x10^{-3}$)	Theoretical Minimum Number of Part	Part Name
13	1	00	1.13	30	2.0	3.13	4.347	1	Main casing
12	1	30	1.95	30	5.0	6.95	9.653	1	Main casing cover
11	1	20	1.8	01	2.5	4.3	5.972	1	Reverse bulb with socket
10	1	00	1.13	-	-	1.13	1.569	1	Reverse bulb socket
9	1	00	1.13	30	2.0	3.13	4.347	1	Reverse bulb
8	1	20	1.8	01	2.5	4.3	5.972	1	Brake bulb with socket
7	1	00	1.13	-	-	1.13	1.569	1	Brake bulb socket
6	1	00	1.13	30	2.0	3.13	4.347	1	Brake bulb
5	1	20	1.8	01	2.5	4.3	5.972	1	Signal bulb with socket
4	1	00	1.13	-	-	1.13	1.569	1	Signal bulb socket
3	1	00	1.13	30	2.0	3.13	4.347	1	Signal bulb
2	1	00	1.13	-	-	1.13	1.569	1	Wire connectors
1	4	01	1.43	-	-	5.72	7.945	0	screws
	4	-	-	01 92	7.5	30.0	41.67	-	Tightening operation
						72.61	100.848	12	**Design efficiency** 3 NM/TM = 0.495
						TM	**CM**	**NM**	

Table 4.4 shows Boothroyd Dewhurst DFA worksheet for the option 2 of the rear lamp. Improvement has been done to the original design of the rear lamp and resulting in option 1 of the rear lamp. By redesigning the original rear lamp, the total assembly time that has been reduced is 1 seconds and the total assembly cost reduced is RM 0.0014.

4.3.5 Option 2 Calculations

Below are the costing assumptions that have been made to find the design efficiency for the redesign 2.

(i) Labor cost per month for one labor to produce the product is assumed RM 800.
(ii) Working day per week for one labor is assumed 5 days.
(iii) Working hour per day for one labor is assumed 8 hours.
(iv) Working hour per month for one labor is:
(4 weeks x 5 days x 8 hours) = 160 hours
(v) Labor cost per hour per month for one labor is:
RM 800 /160 hours = RM 5.00
(vi) Labor cost per second for one labor is RM 0.001389

Below are steps of calculation to find the design efficiency for the original rear lamp design by using Eq (2.1):

$$\text{Design efficiency} = \frac{3\times \text{Nm}}{\text{Tm}}$$
$$= \frac{3\times 12}{72.61}$$
$$= 0.495$$

From the calculation, the result of design efficiency for the option 2 rear lamp design has been obtained. The value of design efficiency for the option 2 is 49.5%.

4.3.6 Option 3 Analysis

From the option 1 and the option 2, the improvements that performed is reduced of the amount of the screws and redesign back the signal bulb, brake bulb and the sockets according to the original reverse bulb with the socket. All improvements that performed are considered the option 3 which is the combination of the improvement from the option 1 and option 2. From the improvements that have been made, the option 3 will have the most efficient design efficiency due to the combination of the option 1 and option 2. Table 4.5 showed the redesign analysis of the option 3 by using Boothroyd DFA method.

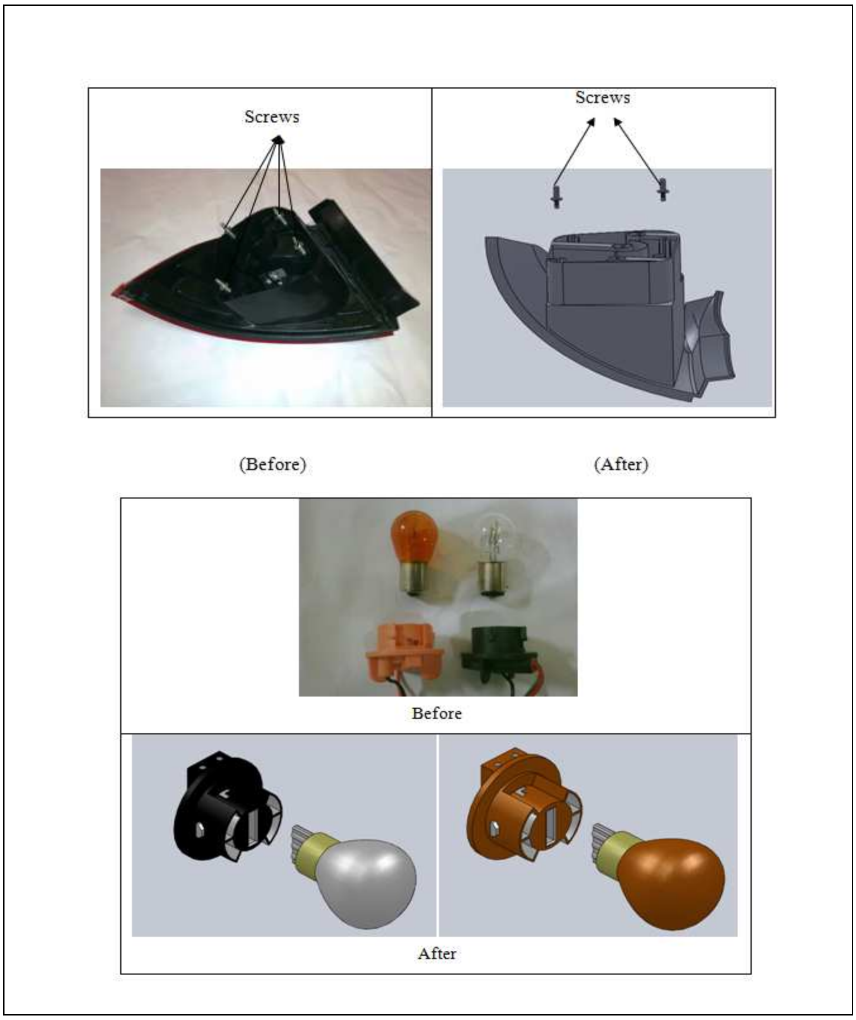


Figure 4.5: Option 2 of redesign

Table 4.5: Boothroyd Dewhurst DFA worksheet for option 3 analysis

Part ID. No.	Number of times the operation is carried out consecutively	Manual Handling Code	Manual Handling Time	Insertion Code	Insertion Time	Operation Time	Operation Cost ($x10^{-3}$)	Theoretical Minimum Number of Part	Part Name
13	1	00	1.13	30	2.0	3.13	4.347	1	Main casing
12	1	30	1.95	30	5.0	6.95	9.653	1	Main casing cover
11	1	20	1.8	01	2.5	4.3	5.972	1	Reverse bulb with socket
10	1	00	1.13	-	-	1.13	1.569	1	Reverse bulb socket
9	1	00	1.13	30	2.0	3.13	4.347	1	Reverse bulb
8	1	20	1.8	01	2.5	4.3	5.972	1	Brake bulb with socket
7	1	00	1.13	-	-	1.13	1.569	1	Brake bulb socket
6	1	00	1.13	30	2.0	3.13	4.347	1	Brake bulb
5	1	20	1.8	01	2.5	4.3	5.972	1	Signal bulb with socket
4	1	00	1.13	-	-	1.13	1.569	1	Signal bulb socket
3	1	00	1.13	30	2.0	3.13	4.347	1	Signal bulb
2	1	00	1.13	-	-	1.13	1.569	1	Wire connectors
1	2	01	1.43	-	-	2.86	3.972	0	screws
	2	-	-	01 92	7.5	15.0	20.835	-	Tightening operation
						54.75	76.04	12	**Design efficiency** 3 NM/TM = 0.657
						TM	**CM**	**NM**	

Table 4.5 shows Boothroyd Dewhurst DFA worksheet for the option 3 of the rear lamp. Improvement has been done to the original design of the rear lamp and resulting in option 3 of the rear lamp. By redesigning the option 3 rear lamp, the total assembly time that has been reduced is 18.86 seconds and the total assembly cost reduced is RM 0.0262

.4.3.6 Option 3 Calculations

Below are the costing assumptions that have been made to find the design efficiency for the option 3.

(i) Labor cost per month for one labor to produce the product is assumed RM 800.
(ii) Working day per week for one labor is assumed 5 days.
(iii) Working hour per day for one labor is assumed 8 hours.
(iv) Working hour per month for one labor is:
(4 weeks x 5 days x 8 hours) = 160 hours
(v) Labor cost per hour per month for one labor is:
RM 800 /160 hours = RM 5.00
(vi) Labor cost per second for one labor is RM 0.001389

Below are steps of calculation to find the design efficiency for the option 3 of the rear lamp by using Eq (2.1);

$$\text{Design efficiency} = \frac{3 \times \text{Nm}}{\text{Tm}}$$

$$= \frac{3 \times 12}{54.75}$$

$$= 0.657$$

From the calculation, the result of design efficiency for the option 3 rear lamp design has been obtained. The value of design efficiency for option 3 is 65.7%.

4.4 PRODUCT DESIGN ANALYSIS FOR HITACHI AEM DFA METHOD

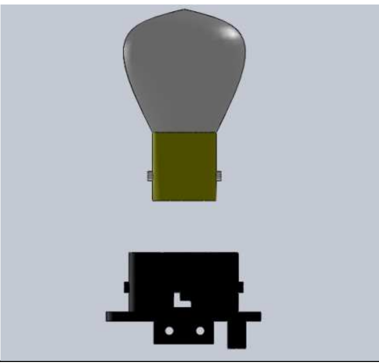
The Hitachi AEM analyses the motions and operations, called 'assembly operations', necessary to insert and secure each component of the product. A simple downward motion is considered to be the easiest and fastest assembly operation. Penalty points are awarded for every motion or operation that differs from, or is in addition to, this simple motion. This method makes use of assemblability and assembly cost ratio indices to identify the weak points of a design.

The procedure begins by entering the motions and operations necessary for assembly onto an AEM form. From drawings (detailed or conceptual) or samples, the analyst completes an AEM form by entering the part names and numbers in the same order that assembly takes place The form is used to compare the assembly processes to the optimum, and given a penalty from the synthetic assembly data.

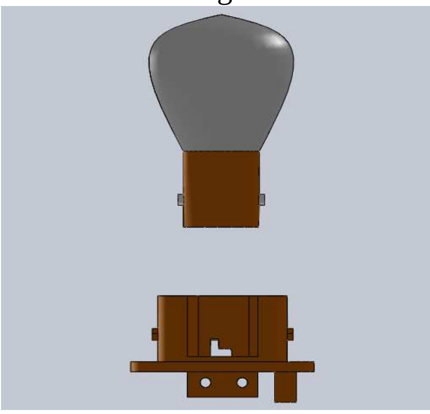
4.4.1 Original Design Analysis

The assembly sequences of the original rear lamp are shown in the table 4.6. The total assembly time for the original design is 25.07T down and the original design efficiency is 75.78%.

Table 4.6: Assembly sequences of the original rear lamp

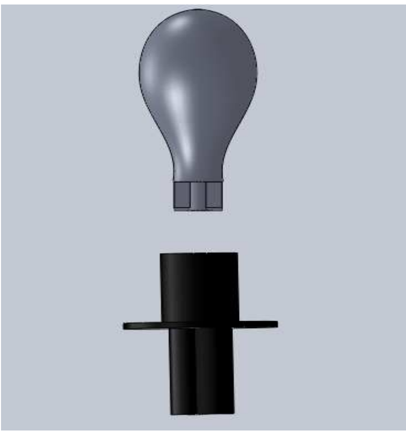
Assembly process	operation
1. Brake bulb 	1. Position a brake bulb socket as a base 2. Bring down a brake bulb 3. Press and twist the brake bulb to the bulb base

2. Signal bulb



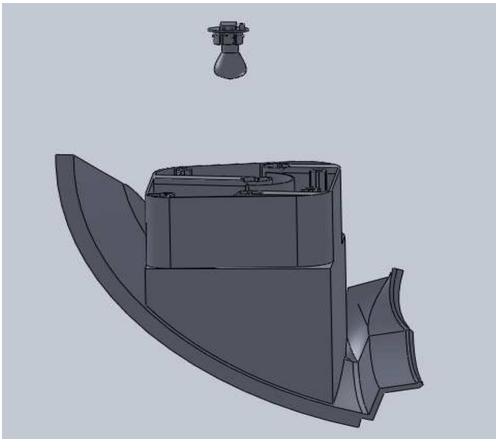
1. Position a signal bulb socket as a base
2. Bring down a signal bulb
3. Press and twist the signal bulb to the bulb base

3. Reverse bulb



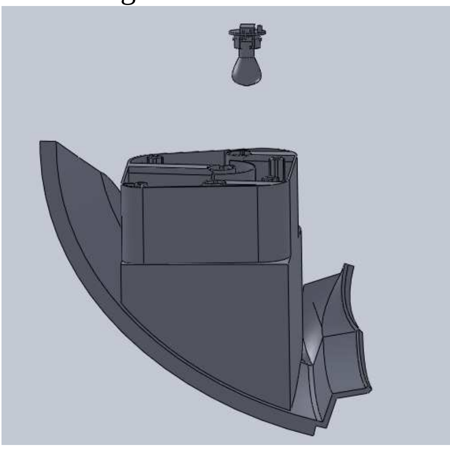
1. Position the reverse bulb socket as a base
2. Bring down the reverse bulb and insert the bulb to the bulb base

4. Brake bulb with socket



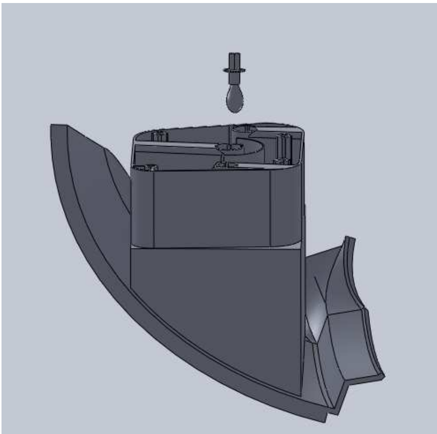
1. Position a main casing as a base
2. Bring down and turn the brake bulb with the socket to the main casing

5. Signal bulb with socket



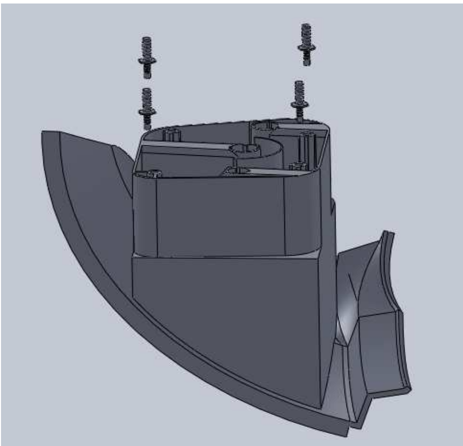
1. Position a main casing as the base
2. Bring down and turn the signal bulb with the socket to the main casing

6. Reverse bulb with socket



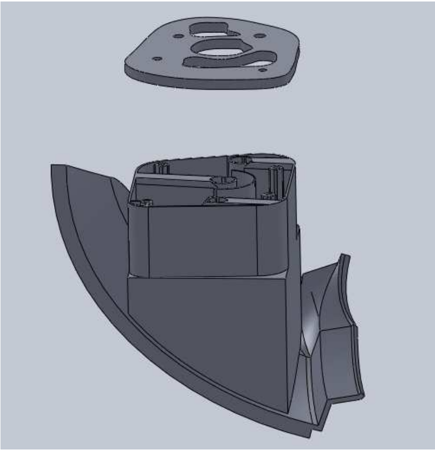
1. Position a main casing as the base
2. Bring down and turn the reverse but with the socket to the main casing

7. Screws



1. Position the main casing as the base
2. Bring down and turn the screws at the main casing

8. Cover



1. Position the main casing as the base
2. Bring down and insert the cover to the main casing

Table 4.7: Hitachi AEM for original design analysis

Part			Number of	Summation Method			
Name	Count (n)	Operation Symbols	Operations (m)	Total Penalty (S Penalty)	M = 100 + S Penalty	T = M * a (+15% add op)	T * n
main casing	1	base	1	0	100	100	100
cover	1	down	1	0	100	100	100
main casing	1	base	1	0	100	100	100
screws	4	down, rotational	2	65	165	189.75	759
main casing	1	base	1	0	100	100	100
brake bulb with socket	1	down, clinching	2	30	130	149.5	149.5
Main casing	1	base	1	0	100	100	100
Signal bulb with socket	1	down, clinching	2	30	130	149.5	149.5
Main casing	1	base	1	0	100	100	100
Reverse bulb with socket	1	down, clinching	2	30	130	149.5	149.5
brake bulb socket	1	base	1	0	100	100	100
brake bulb	1	down, clinching	2	30	130	149.5	149.5
Signal bulb socket	1	base	1	0	100	100	100
Signal bulb	1	down, clinching	2	30	130	149.5	149.5
Reverse bulb socket	1	base	1	0	100	100	100
Reverse bulb	1	down	2	0	100	100	100
	19					S T*n =	2506.5
						Assembly Time	= 25.07 Tdown

From the original design of the rear lamp, the total assembly time for the design is 25.07T down and the screws will be the best candidates to be reduced to increase the design efficiency of the rear lamp.

4.4.2 Original Design Calculations

For the calculation part, design efficiency needs to be calculated in a percentage value. It is important to find the design efficiency for the original design and for the each option so that the assembly efficiency between the rear lamp designs can be compared and evaluated. Below are the costing assumptions that have been made to find the design efficiency for the original design.

(i) Labor cost per month for one labor to produce the product is assumed RM 800.
(ii) Working day per week for one labor is assumed 5 days.
(iii) Working hour per day for one labor is assumed 8 hours.
(iv) Working hour per month for one labor is:
(4 weeks x 5 days x 8 hours) = 160 hours
(v) Labor cost per hour per month for one labor is:
RM 800 /160 hours = RM 5.00
(vi) Labor cost per second for one labor is RM 0.001389

From Eq (2.2):

$$\text{Design efficiency} = \frac{\sum part\ count}{\sum(assembly\ time\ in\ T\ down)} \text{ x } 100\%$$

$$= \frac{\sum n}{\sum T} \text{x}100\%$$

$$= \frac{19}{25.07} \text{ x } 100\%$$

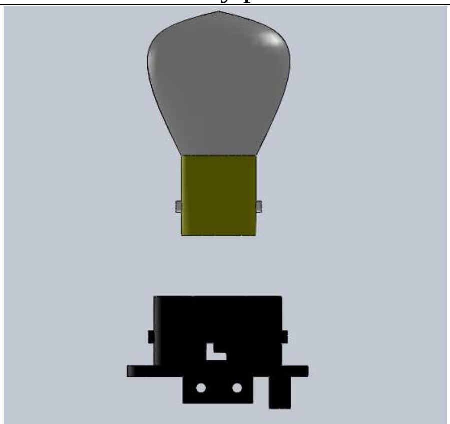
$$= 75.787\%$$

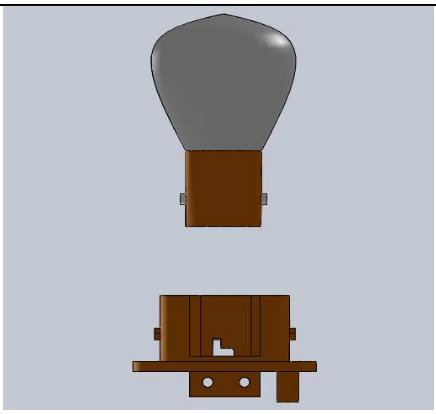
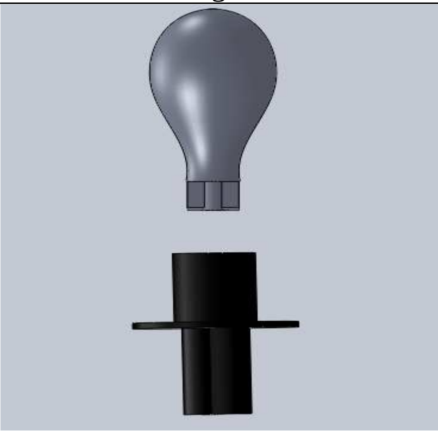
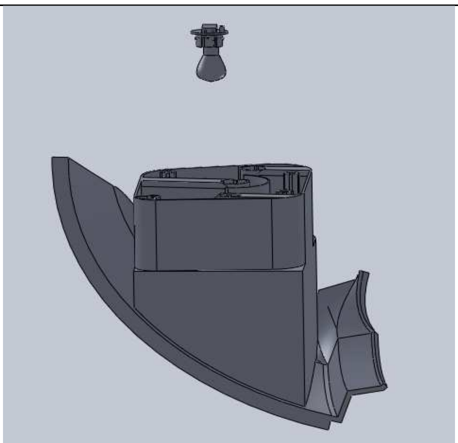
From the calculation, the result of design efficiency for the original rear lamp design has been obtained. The value of design efficiency for the original rear lamp is 75.787%

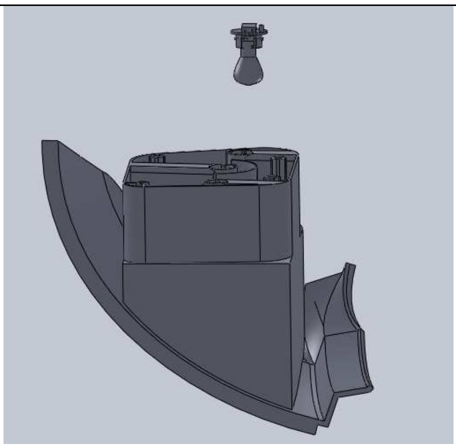
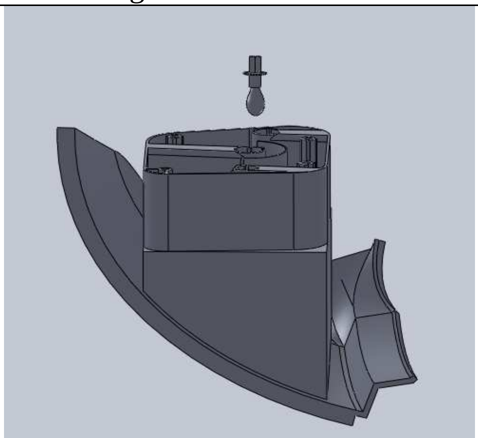
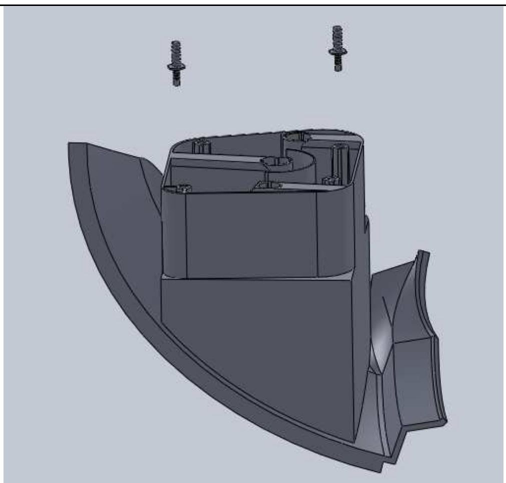
4.4.3 Option 1 Analysis

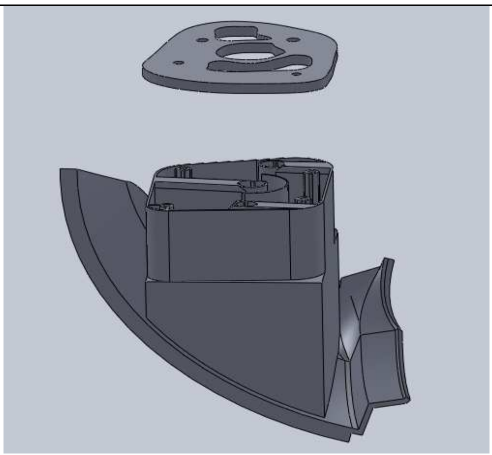
From the original design analysis, the main parts that contribute to most of the cost of the rear lamp are the screws that connected to the main casing. The original designs of the rear lamp consist of four screws that connected the main casing to the car body. From the analysis of the original design, the screws is the main parts that need to be eliminate to produce a better design efficiency of the rear lamp but the overall screws cannot be eliminated because the function of the screws is important in maintenance process. So, the option 1 will reduce the number of screws from four screws to two screws to produce better design efficiency and reduce the operation cost. Table 4.8 shown the option 1 assembly sequences of the rear lamp by using Hitachi AEM DFA method

Table 4.8: Assembly sequences for redesign 1 analysis

Assembly process	operation
 1. Brake bulb	1. Position a brake bulb socket as a base 2. Bring down a brake bulb 3. Press and twist the brake bulb to the bulb base

 2. Signal bulb	1. Position a signal bulb socket as a base 2. Bring down a signal bulb 3. Press and twist the signal bulb to the bulb base
 3. Reverse bulb	1. Position the reverse bulb socket as a base 2. Bring down the reverse bulb and insert the bulb to the bulb base
 4. brake bulb with socket	1. Position a main casing as a base 2. Bring down and turn the brake bulb with the socket to the main casing

 5. signal bulb with socket	1. Position a main casing as the base 2. Bring down and turn the signal bulb with the socket to the main casing
 6. Reverse bulb with socket	1. Position a main casing as the base 2. Bring down and turn the reverse but with the socket to the main casing
 7. Screws	1. Position the main casing as the base 2. Bring down and turn the screws at the main casing



8. Cover

1. Position the main casing as the base
2. Bring down and insert the cover to the main casing

Table 4.8: Hitachi AEM DFA method for option 1 analysis

Part			Number of	Summation Method			
Name	Count (n)	Operation Symbols	Operations (m)	Total Penalty (S Penalty)	M = 100 + S Penalty	T = M * a (+15% add op)	T * n
main casing	1	base	1	0	100	100	100
cover	1	down	1	0	100	100	100
main casing	1	base	1	0	100	100	100
screws	2	down, rotational	2	65	165	189.75	379.5
main casing	1	base	1	0	100	100	100
brake bulb with socket	1	down, clinching	2	30	130	149.5	149.5
Main casing	1	base	1	0	100	100	100
Signal bulb with socket	1	down, clinching	2	30	130	149.5	149.5
Main casing	1	base	1	0	100	100	100
Reverse bulb with socket	1	down, clinching	2	30	130	149.5	149.5
brake bulb socket	1	base	1	0	100	100	100
brake bulb	1	down, clinching	2	30	130	149.5	149.5
Signal bulb socket	1	base	1	0	100	100	100
Signal bulb	1	down, clinching	2	30	130	149.5	149.5
Reverse bulb socket	1	base	1	0	100	100	100
Reverse bulb	1	down	2	0	100	100	100
	17					S T*n =	2127
						Assembly Time	= 21.27Tdown

From the option 1 of the rear lamp, the total assembly time for the design is 21.27T down after the elimination of two screws and the assembly time is reduced to 3.8 Tdown.

2.4.4 Option 1 Calculations

Below are the costing assumptions that have been made to find the design efficiency for the option 1 design.

(i) Labor cost per month for one labor to produce the product is assumed RM 800.
(ii) Working day per week for one labor is assumed 5 days.
(iii) Working hour per day for one labor is assumed 8 hours.
(iv) Working hour per month for one labor is:
(4 weeks x 5 days x 8 hours) = 160 hours
(v) Labor cost per hour per month for one labor is:
RM 800 /160 hours = RM 5.00
Labor cost per second for one labor is RM 0.001389

From the Eq (2.2):

$$\text{Design efficiency} = \frac{\sum part\ count}{\sum(assembly\ time\ in\ T\ down)} \text{ x } 100\%$$

$$= \frac{\sum n}{\sum T} \text{ x}100\%$$

$$= \frac{17}{21.27} \text{ x } 100\%$$

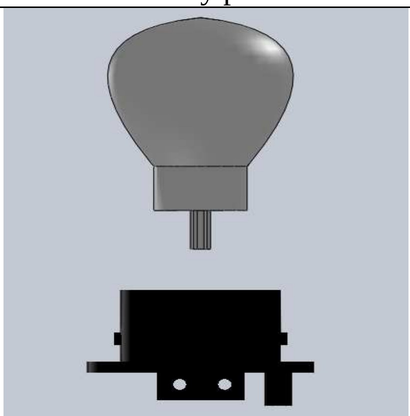
$$= 79.925\%$$

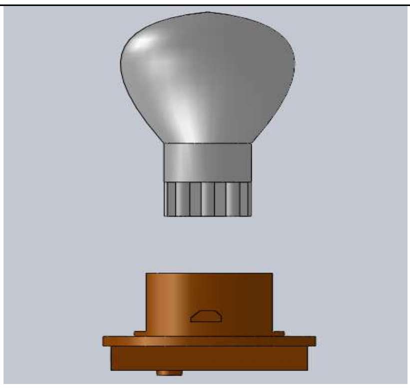
From the calculation, the result of design efficiency for the option 1 rear lamp design has been obtained. The value of design efficiency for the option 1 of the rear lamp is 79.925%.

4.4.4 Option 2 Analysis

From the original design analysis, the bulbs that we used to assemble the components of the rear lamp are the reverse bulb, brake bulb and the signal bulb. The original design of the reverse bulb is inserting and fit to the socket while the original design of the brake bulb and the signal bulb are insert and rotate the bulb to fit the socket of the bulbs. From the original design of the reverse bulb, the handling time, insertion time and the operation cost of the reverse bulb is lower than the brake bulb and the reverse bulb. The improvement that have made to the original design of the brake bulb and the signal bulb with the socket is to redesign them according to the original design of the reverse bulb and the socket of the rear lamp**.** Table 4.9 shown the assembly sequences for option 2 analysis.

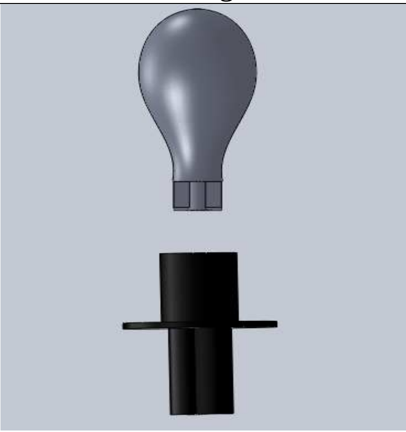
Table 4.9: Assembly sequences for option 2 analysis

Assembly process	Operation
 1. Brake bulb	1. Position a brake bulb socket as a base 2. Bring down a brake bulb and insert the brake bulb to the bulb base



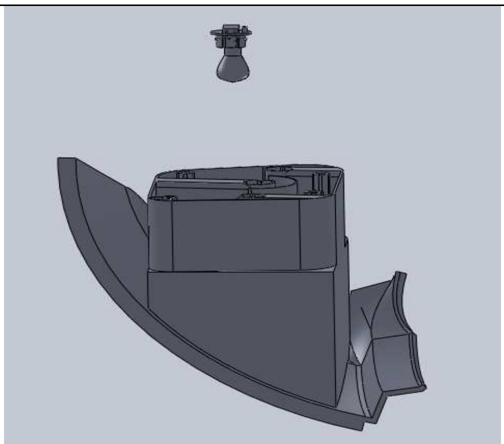
2. Signal bulb

1. Position a signal bulb socket as a base
2. Bring down a signal bulb and insert the signal bulb to the bulb base



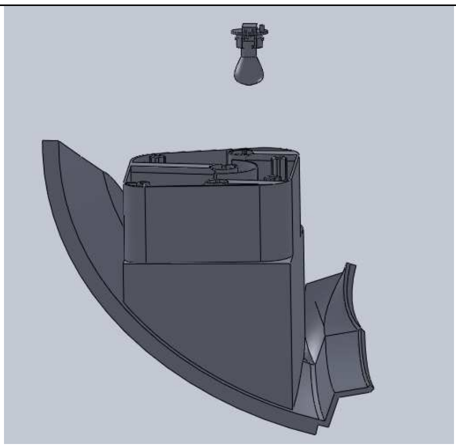
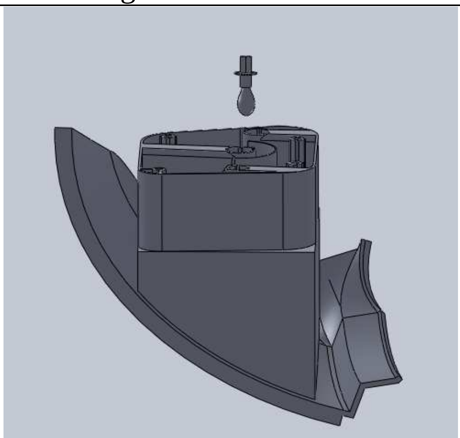
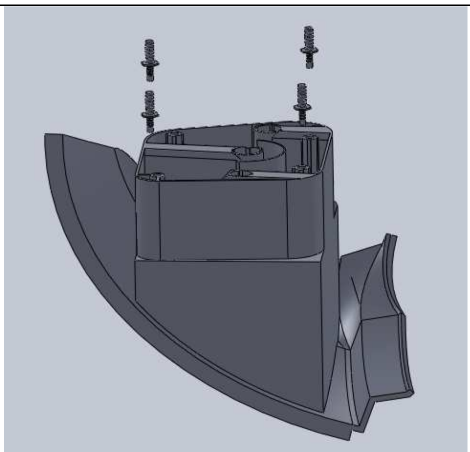
3. Reverse bulb

1. Position the reverse bulb socket as a base
2. Bring down the reverse bulb and insert the bulb to the bulb base



4. brake bulb with socket

1. Position a main casing as a base
2. Bring down and turn the brake bulb with the socket to the main casing

 5. signal bulb with socket	1. Position a main casing as the base 2. Bring down and turn the signal bulb with the socket to the main casing
 6. Reverse bulb with socket	1. Position a main casing as the base 2. Bring down and turn the reverse but with the socket to the main casing
 7. Screws	1. Position the main casing as the base 2. Bring down and turn the screws at the main casing

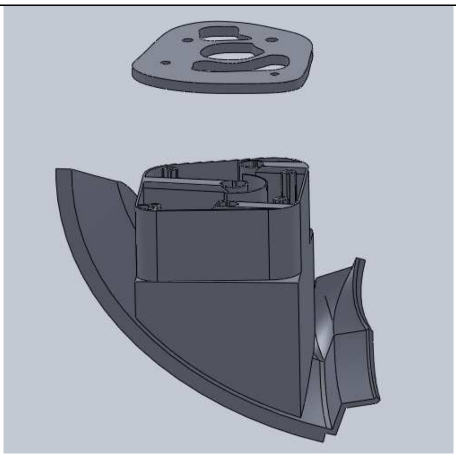
 8. Cover	1. Position the main casing as the base 2. Bring down and insert the cover to the main casing

Table 4.10: Hitachi AEM DFA method for option 2 analysis

Part			Number of Operations	Summation Method			
Name	Count (n)	Operation Symbols	(m)	Total Penalty (S Penalty)	M = 100 + S Penalty	T = M * a (+15% add op)	T * n
main casing	1	base	1	0	100	100	100
cover	1	down	1	0	100	100	100
main casing	1	base	1	0	100	100	100
screws	4	down, rotational	2	65	165	189.75	759
main casing	1	base	1	0	100	100	100
brake bulb with socket	1	down, clinching	2	30	130	149.5	149.5
Main casing	1	base	1	0	100	100	100
Signal bulb with socket	1	down, clinching	2	30	130	149.5	149.5
Main casing	1	base	1	0	100	100	100
Reverse bulb with socket	1	down, clinching	2	30	130	149.5	149.5
brake bulb socket	1	base	1	0	100	100	100
brake bulb	1	down,	2	0	100	100	100
Signal bulb socket	1	base	1	0	100	100	100
Signal bulb	1	down,	2	0	100	100	100
Reverse bulb socket	1	base	1	0	100	100	100
Reverse bulb	1	down	2	0	100	100	100
	19					S T*n =	2407.5
						Assembly Time	= 24.07Tdown

From the redesign 2 of the rear lamp, the total assembly time for the design is 24.07 Tdown after the improvements of the brake bulb with socket and the signal bulb with socket and the assembly time is reduced to 1.0 Tdown.

4.4.5 Option 2 Calculations

Below are the costing assumptions that have been made to find the design efficiency for the option 2 design.

(i) Labor cost per month for one labor to produce the product is assumed RM 800.
(ii) Working day per week for one labor is assumed 5 days.
(iii) Working hour per day for one labor is assumed 8 hours.
(iv) Working hour per month for one labor is:
(4 weeks x 5 days x 8 hours) = 160 hours
(v) Labor cost per hour per month for one labor is:
RM 800 /160 hours = RM 5.00
Labor cost per second for one labor is RM 0.001389

From Eq (2.2):

$$\text{Design efficiency} = \frac{\sum part\ count}{\sum(assembly\ time\ in\ T\ down)} \text{ x } 100\%$$

$$= \frac{\sum n}{\sum T} \text{ x}100\%$$

$$= \frac{19}{24.07} \text{ x } 100\%$$

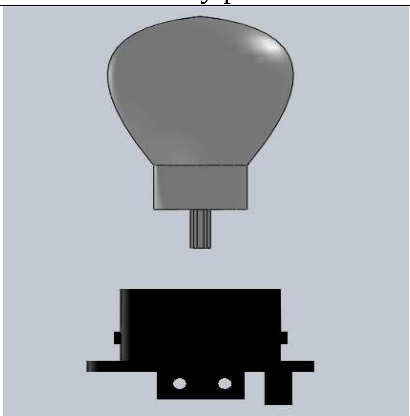
$$= 78.936\%$$

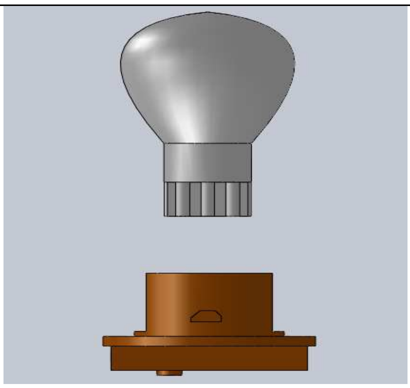
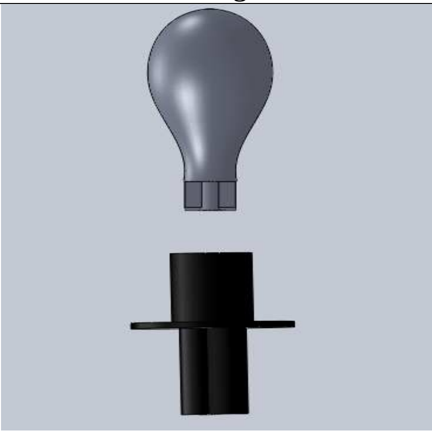
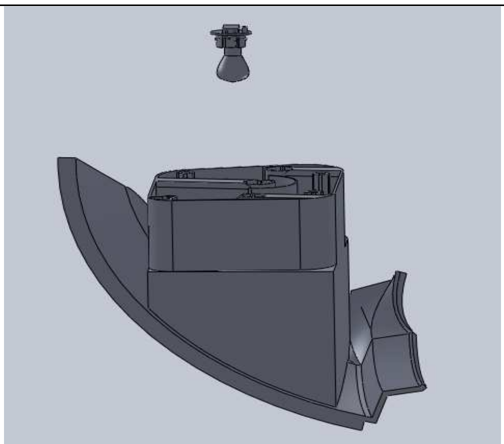
From the calculation, the result of design efficiency for the option 2 of the rear lamp design has been obtained. The value of design efficiency for the option 2 of the rear lamp is 78.936%

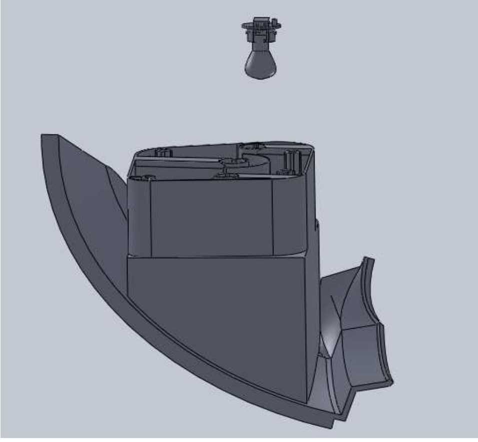
4.4.6 Option 3 Analysis

From the option 1 and the option 2, the improvement that have made is to reduce the amount of the screws and redesign back the signal bulb, brake bulb and the sockets according to the original reverse bulb with the socket. All improvements that have made are the option 3 which is the combination of the improvement from the option 1 and option 2. From the improvements that have been made, the option 3 will have the most efficient design efficiency due to the combination of the option 1 and option 2. Table 4.11 shown the assembly sequences for the option 3 analysis

Table 4.11: Assembly sequences for option 3 analysis

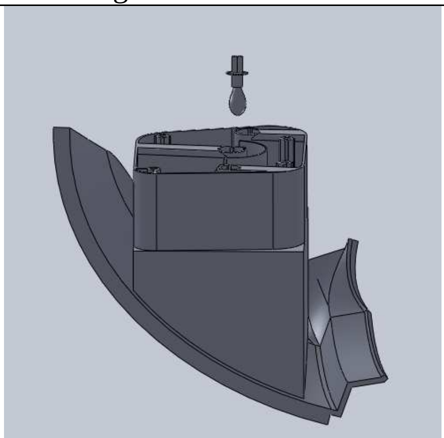
Assembly process	Operation
 1. Brake bulb	1. Position a brake bulb socket as a base 2. Bring down a brake bulb and insert the brake bulb to the bulb base

 2. Signal bulb	1. Position a signal bulb socket as a base 2. Bring down a signal bulb and insert the signal bulb to the bulb base
 3. Reverse bulb	1. Position the reverse bulb socket as a base 2. Bring down the reverse bulb and insert the bulb to the bulb base
 4. brake bulb with socket	1. Position a main casing as a base 2. Bring down and turn the brake bulb with the socket to the main casing



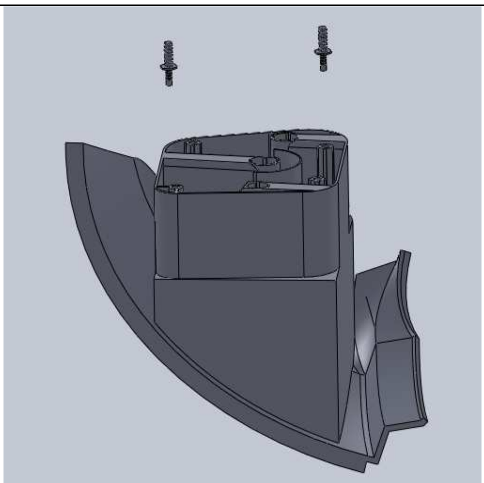
5. signal bulb with socket

1. Position a main casing as the base
2. Bring down and turn the signal bulb with the socket to the main casing



6. Reverse bulb with socket

1. Position a main casing as the base
2. Bring down and turn the reverse but with the socket to the main casing



7. Screws

1. Position the main casing as the base
2. Bring down and turn the screws at the main casing

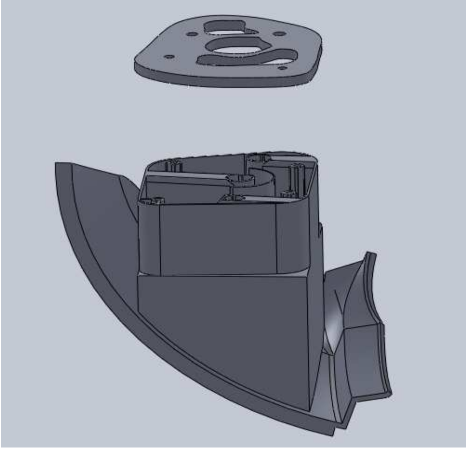
 8. Cover	1. Position the main casing as the base 2. Bring down and insert the cover to the main casing

Table 4.12: Hitachi AEM method for option 3 analysis

Name	Count (n)	Operation Symbols	Operations (m)	Total Penalty (S Penalty)	M = 100 + S Penalty	T = M * a (+15% add op)	T * n
main casing	1	base	1	0	100	100	100
cover	1	down	1	0	100	100	100
main casing	1	base	1	0	100	100	100
screws	2	down, rotational	2	65	165	189.75	379.5
main casing	1	base	1	0	100	100	100
brake bulb with socket	1	down, clinching	2	30	130	149.5	149.5
Main casing	1	base	1	0	100	100	100
Signal bulb with socket	1	down, clinching	2	30	130	149.5	149.5
Main casing	1	base	1	0	100	100	100
Reverse bulb with socket	1	down, clinching	2	30	130	149.5	149.5
brake bulb socket	1	base	1	0	100	100	100
brake bulb	1	down	1	0	100	100	100
Signal bulb socket	1	base	1	0	100	100	100
Signal bulb	1	down	1	0	100	100	100
Reverse bulb socket	1	base	1	0	100	100	100
Reverse bulb	1	down	2	0	100	100	100
	17					S T*n =	2028
						Assembly Time	= 20.28Tdown

Option 3 is the combination of redesign 1 and redesign 2 of the rear lamp to get the best result of the design efficiency and to improve the assembly time of the rear lamp. The assembly time is improved to 20.28 Tdown and the design efficiency is 83.826%.

4.4.7 Option 3 Calculations

Below are the costing assumptions that have been made to find the design efficiency for the option 3 design.

i. Labor cost per month for one labor to produce the product is assumed RM 800.
ii. Working day per week for one labor is assumed 5 days.
iii. Working hour per day for one labor is assumed 8 hours.
iv. Working hour per month for one labor is:
(4 weeks x 5 days x 8 hours) = 160 hours
v. Labor cost per hour per month for one labor is:
RM 800 /160 hours = RM 5.00
Labor cost per second for one labor is RM 0.001389

From the Eq (2.2):

$$\text{Design efficiency} = \frac{\sum part\ count}{\sum(assembly\ time\ in\ T\ down)} \times 100\%$$

$$= \frac{\sum n}{\sum T} \times 100\%$$

$$= \frac{17}{20.28} \times 100\%$$

$$= 83.826\%$$

From the calculation, the result of design efficiency for the option 3 of the rear lamp design has been obtained. The value of design efficiency for the option 3 of the rear lamp is 83.826%

4.5 SUMMARY

4.5.1 Results of Boothroyd DFA method

Table 4.13: Results of Boothroyd DFA method

Design	Total Assembly time (second)	Total Assembly cost (RM)	Design efficiency (%)
Original design	73.61	0.1022	48.9
Option 1	55.75	0.0774	64.5
Option 2	72.61	0.1008	49.5
Option 3	54.75	0.0760	65.7

Source: Result of Boothroyd DFA method

4.5.2 Results of Hitachi AEM DFA method

Table 4.14: Results of Hitachi AEM DFA method

Design	Total Assembly time in T down (second)	Total Assembly cost in T down (RM)	Design efficiency (%)
Original design	25.07	0.0348	75.78
Option 1	21.27	0.0295	79.92
Option 2	24.07	0.0334	78.93
Option 3	20.28	0.0282	83.83

Source: Result of Hitachi AEM DFA method

4.6 CONCLUSION

From Boothroyd Dewhurst DFA analysis, original design and each option of redesign of the rear lamp is evaluated in term of assembly efficiency. All related data to the Boothroyd Dewhurst DFA analysis of the original design and redesign are stated in the Boothroyd Dewhurst DFA worksheet. All total result for all design is shown in Table 4.13. After the full analysis of Boothroyd Dewhurst is completed, option of 3 of redesign is the best design compare to option of redesign 1 and 2 of the rear lamp.

Meanwhile, for Hitachi AEM DFA analysis, original design and each option of the redesign of the rear lamp is evaluated in term of assembly efficiency. All related data to the Hitachi AEM DFA analysis of the original design and redesign are stated in the Hitachi AEM DFA worksheet. All total result for all design is shown in Table 4.14. After the full analysis of Hitachi AEM DFA is completed, the option 3 of redesign of is the best design compare to option of redesign 1 and option of redesign 2 of the rear lamp.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

This chapter summarized the conclusions and recommendations for the overall objective of the project based on Boothroyd Dewhurst DFA analysis and Hitachi AEM DFA analysis. Firstly, the conclusion is the design efficiency of the original and option of redesign the rear lamp of Proton Saga BLM is evaluated by using Boothroyd-Dewhurst DFA method and Hitachi AEM DFA method. For Boothroyd-Dewhurst DFA method, the original design efficiency of the rear lamp is 48.9%, option of redesign 1 is 64.5%, option of redesign 2 is 49.5% and option of redesign 3 is65.7%. For Hitachi AEM DFA method, the design efficiency of the original rear lamp is 75.78%, option of redesign 1 is 79.93%, option of redesign 2 is 78.93% and option of redesign 3 is 83.83%.

Secondly, the suggestions to reduce the assembly cost of the rear lamp are performed by eliminated two of the screws and redesign the brake bulb, signal bulb and the sockets according to the original reverse bulb with the socket to reduce the assembly time of the rear lamp. Thirdly, by using the Boothroyd-Dewhurst DFA method, the assembly cost of the original design is RM 0.1022 and after improvements, the assembly cost is RM 0.0760 while for Hitachi AEM DFA method, the assembly cost of the original design is RM 0.0348 T down and the cost after improvements is RM 0.0282 T down. The final conclusion is the best option of redesign which is option 3 is chosen to redesign the rear lamp with higher design efficiency than original design.

5.3 RECOMMENDATIONS FOR FUTURE WORKS

For further research, the Boothroyd Dewhurts DFM analysis can be conducted on the rear lamp of the proton Saga BLM. By combination of the DFM and DFA analysis in the further research, it will result to the DFMA analysis. The DFMA analysis can give result based on assembly efficiency and manufacturing efficiency. By DFMA analysis, a fully analysis of the rear lamp from design stage into to the manufacturing stage can be performed effectively. Besides that, software analysis also can be used to analyze the design efficiency for the rear lamp in order to get an accurate result for the future research.

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APPENDIX A1

GANTTCHART OF FYP 1

No	Activities	week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Project progress																
1	Chapter : Introduction	Planning															
		Actual															
2	Chapter 2: Literature review	Planning															
		Actual															
3	Chapter 3: Methodology	Planning															
		Actual															
4	Finalizing thesis writing as draft 1	Planning															
		Actual															
5	Presentation	Planning															
		Actual															

Planning to complete work

Actual complete work

APPENDIX A1

GANTTCHART OF FYP 2

No	Activities	week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Project progress																
1	Redesign rear lamp using solidworks software	Planning															
		Actual															
2	Fill up Boothroyd- Dewhurst DFA worksheet for all design	Planning															
		Actual															
3	Fill up Hitachi AEM DFA worksheet for all design	Planning															
		Actual															
4	Obtained full results	Planning															
		Actual															
5	Finishing of final draft with logbook	Planning															
		Actual															
6	Submission of final draft with logbook	Planning															
		Actual															

Planning to complete work   Actual complete work