BOOTHYORD DEWHURST AND HITACHI AEM DESIGN FOR ASSEMBLY: A COMPARATIVE STUDY

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BOOTHYORD DEWHURST AND HITACHI AEM DESIGN FOR ASSEMBLY: A COMPARATIVE STUDY

MUHAMAD FARKHANIF BIN JAMALUDDIN

Report submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

FACULTY OF MECHANICAL ENGINEERING
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

We certify that the project *entitled Boothyord Dewhurst and Hitachi AEM Design for Assembly: A Comparative Study* is written by *Muhamad Farkhanif Bin Jamaluddin.* We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfilments of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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I Muhamad Farkhanif Bin Jamaluddin declare that this report entitled "Boothyord Dewhurst and Hitachi AEM Design for Assembly: A Comparative Study "is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Dedicated to my beloved family and those involved directly or indirectly for fulfill this project.

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ABSTRACT

Children's tricycles are typically used by children between the ages of two until four before they usually switch to a bicycle. This product is a good design to be commercialized. However, before releasing to the market, the product has to be cheap and good quality. Therefore, to achieve this goal, design for manufacture and assembly methodologies are used to evaluate the design of the product. Specifically, DFMA, which is Boothroyd-Dewhurst and Hitachi AEM, are used to evaluate the product. The strategy of evaluating the existing design is first to choose the available product in the market in order to solve a problem. The products choose were then disassembled into several families or sub-assemblies. This is for understanding how the parts functioning during normal operating mode. After that, each parts been critics and study if there is a chance for redesign. Finally, referring to result from current product based on Boothroyd-Dewhurst and Hitachi AEM method, the new parts designs are generated. Than the results for both analyses for improvement design are compared.

ABSTRAK

Basikal roda tiga biasanya digunakan oleh kanak kanak berusia dua hingga empat tahun sebelum mereka beralih kepada basikal. Produk tersebut adalah sangat berpotensi untuk dipasarkan. Walau bagaimanapun, produk itu haruslah berkualiti dan murah sebelum ianya dijual di pasaran. Oleh yang demikian, untuk mencapai matlamat tersebut, kaedah "*Design for Manufacture and Assembly*" (DFMA) digunakan untuk menilai reka bentuk produk. Dua kaedah yang berbeza digunakan untuk menilai reka bentuk produk iaitu kaedah DFMA yang berdasarkan teknik Boothroyd-Dewhurst dan teknik Hitachi AEM. Strategi dalam menilai potensi rekabentuk sedia ada bermula dengan pemilihan produk yang sesuai dan berpotensi untuk dibangunkan. Kemudian, produk yang dipilih akan di leraikan mengikut kategori yang tertentu bagi memudahkan proses pemahaman cara produk berfungsi. Selepas itu, setiap komponen akan dikaji dan dikritik mengenai cara pemasangan dan pengendaliannya untuk memastikan komponen yang boleh diasingkan atau dicamtum. Akhirnya, merujuk keputusan dari produk semasa berdasarkan teknik Boothroyd-Dewhurst dan teknik Hitachi AEM, reka bentuk komponen baru dibuat. Kemudian keputusan kedua dua analisis untuk rekabentuk yang telah diperbaiki dibandingkan.

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LIST OF SYMBOLS

E_d	Functional efficiency
E_{ma}	Design efficiency
N_{min}	Theoretical minimum number of parts
T_a	Basic assembly time = 3 second
T_h	Handling time
T_{ma}	Estimated time to complete the assembly of the product
T_i	Insertion time

LIST OF ABBREVIATIONS

AEM	Assemblability Evaluation Method
CAD	Computer-aided design
CAE	Computer-aided engineering
CE	Concurrent Engineering
CFE	Candidate for Elimination
DFA	Design for Assembly
DFM	Design for Manufacture
DFMA	Design for Manufacture and Assembly
NPD	New Product Development

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

New Product Development (NPD) is a complex and creative process, which is inherently difficult to manage and improve. Having a great design is one thing, bringing that design effectively to market is another. The ability to deliver innovative products to the market on time, at the right cost and quality is a good indicator of a company's NPD capability. The significance of NPD in the business value chain must not be Underestimated, gone are the days where companies can simply compete on quality and cost.

Developing successful product requires the ability to predict, early in the product development process, the life cycle impact of design decisions. Any misjudges can leads to poor product designs that may cause unforeseen problems and excessive costs. Cost to redesign at this late stage can be prohibitive. Sometimes companies must simply accept higher manufacturing costs and reduced product effectiveness resulting from early design errors.

In this chapter, an overview of the background, objectives and scope of this project are reviewed. Basically, the objective of this study is to redesign a new selected product for a better design and lower production cost. Here, the DFA Method was applied to analyze the original product (children tricycle). Lastly, in this chapter, the overall thesis outlines are reviewed and discussed in general.

1.2 PROJECT BACKGROUND

Design for assembly (DFA) is a way to improve assembly ease and reduce assembly time. It can also reduce product costs by reducing the number of parts, optimizing manufacturing processes, simplifying parts handling and improving product assembly. Furthermore, the implementation of DFA can encourages the design of products to be produced at minimum cost with maximum quality and reliability. Many leading companies such as Ford, Kodak, General Motors, IBM, NCR, Xerox and more have save millions of money when using DFA analysis in their designs.

Three of the better-known quantitative evaluation techniques has been used in industry are Boothroyd-Dewhurst (USA), Lucas (UK) and Hitachi (Japan). However, this project only focuses on design for assembly using Boothroyd Dewhurst method and Hitachi Assembleability Evaluation Method (AEM)

1.3 PROBLEM STATEMENTS

Each new product is a good design to be commercialized. However, before releasing to the market, the product has to be cheap and good quality. Therefore, to achieve this goal, design for manufacture and assembly methodologies are used to evaluate the design of the product. Specifically, DFA, which is Boothroyd- Dewhurst Method and Hitachi method are used to evaluate the product in this project. The results for both analyses are compared to look for any variation in term of parts to be eliminated and combined.

1.4 OBJECTIVE OF STUDIES

The aim of this project are to:

1) To design and improve existing design by using DFA method
2) Comparing 2 method DFA and choice the best evaluation method

1.5 SCOPE OF STUDIES

In order to achieve the objectives the following scope of studies are performed:

1) Information contents gathering
   a. Find out part function for each component.
   b. Dimensioning the current design using manual measured.
   c. Modeling the CAD drawing of current design by using Solid works software.
2) Product select
   a. original design analysis
   b. new design analysis

3) Evaluate the product(children tricycle) based on Hitachi Assembleability Method and Boothroyd Dewhurst.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides a review of the concept of product design and methods of product developments. This chapter also relates how product design affects the cost, cycle time, and overall product quality. Besides that, this chapter also includes the information about advantages and disadvantages of DFA method, various methods of DFA and basic design concept and guidelines.

2.2 DESIGN FOR ASSEMBLY

The manufacturing process of assembly is generally thought of as consisting of two distinct operation: handling followed by insertion. Both handling and insertion can be done either manually or automatically (C. Poli, 2004)

In this project, type of assembly that must be considered is manual assembly. Design for assembly (DFA) may be defined as " a process for improving product design for easy and low-cost assembly, focusing on functionality and on assimilability concurrently .

Design for assembly (DFA) analyzes product designs to improve assembly ease and reduce assembly time. Often this is accomplished through a reduction in part count. The implementation of DFA techniques has played an important role in reducing costs of manufacturing over the last two decades. It is apparent that for both manual and automated assembly, the effective methods to reduce assembly costs were those applied during design; manufacturing and production changes have less impact on product cost.

The majority of commercial DFA methodologies developed in the last 15 years are applicable only during the embodiment design phase. The ability to apply DFA analysis at the conceptual design stage has been neglected. As a result, the DFA methods then force another iteration on the design, thus consuming time, material, and financial resources (R. B. Stone 2004)

2.3 DFA GUIDELINES

Different book described DFA Guidelines in different ways. Some authors list many guidelines and described it with detail while other authors categories it with few list before divided the main principle to another few principle. But surely the main objectives for all guidelines remain same, to reduce the cost of assembly. The principles of DFA are:

1) Reduce the part count. The objective of this guidelines is to minimize the total number of parts. There is two ways how this objectives can be achieved: first, design for minimum number of part and second, minimize number of fasteners and their components. (C. Poli, 2004)
2) Design for minimum number of part. Focussing on the main parts, when number of part is decreasing, the cost the assembly and whole product can decreasing. There is 3 factor that should be considered. First, reduce the number of part. Second, remove non essential component with its function still achieved and third, combine several part into one components and manufactures as integral multifunctional component. (C. Poli, 2004)
3) Minimize number of fasteners and their components. Screw and washers can increase the cost and time to assembly. Other alternatives fasteners can be used to replace the screw and washers, such as snap fits press fits and molded hinges, straps or hook. It seems obvious with this technique (reduce part count), the assembly costs would be less. Butt the question remains whether the overall manufacturing costs have been reduced. (Knut Holt 2002)
4) Standardize on component, materials and fasteners. Generally, small similar shaped component can be difficult to differentiate. Feeders can become jammed because wrong part have been fed in by operators. This also can save the storage, inventory and ordering cost and time. (C. Poli, 2004)

2.4 VARIOUS METHOD OF DFA

There are various methods that were using in Design for Assembly in industry nowadays such as:

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

2.4.1 Boothroyd-Dewhurst DFA Method

Design for assembly (DFA) that formulated by Boothroyd and Dewhurst are one of the most widely DFA methodologies which is used on productivity improvement through product design in term of assembly ease and reduce assembly time. Boothroyd and Dewhurst DFA methodology has been recognized as a very useful tool in increasing competitiveness by reducing the part number of components, simplifying the product design structure and improving product design reliability. The procedure for analyzing product for manual assembly Boothroyd and Dewhurst method is summarized as following below (Stoll W.H, 1999).

1) Obtain the best information about the product or assembly. Useful items include engineering drawing, exploded three-dimensional views, an existing version of the product, or prototype.
2) Take the assembly apart. Assign an identification number to each item as it is removed. Initially, treat subassemblies as parts and then analyze them as assemblies later.
3) Reassemble the product starting with the part having the highest identification number. As each part is added to the assembly, analyze its ease of handling and insertion and use the three questions to decide if it is a candidate for elimination or combination with other parts
4) Redesign the assembly using the insights gained from the analysis. Analyze the new design by repeating step 1 through 4 and gage improvements by comparing design efficiencies between current and modified design. Iterate until satisfied.

The Boothroyd and Dewhurst DFA analysis is basically completed in 6 steps. The flow chart of Boothroyd and Dewhurst DFA analysis is shows in **Figure 2.1** (Boothroyd, *et. al*, 2002)

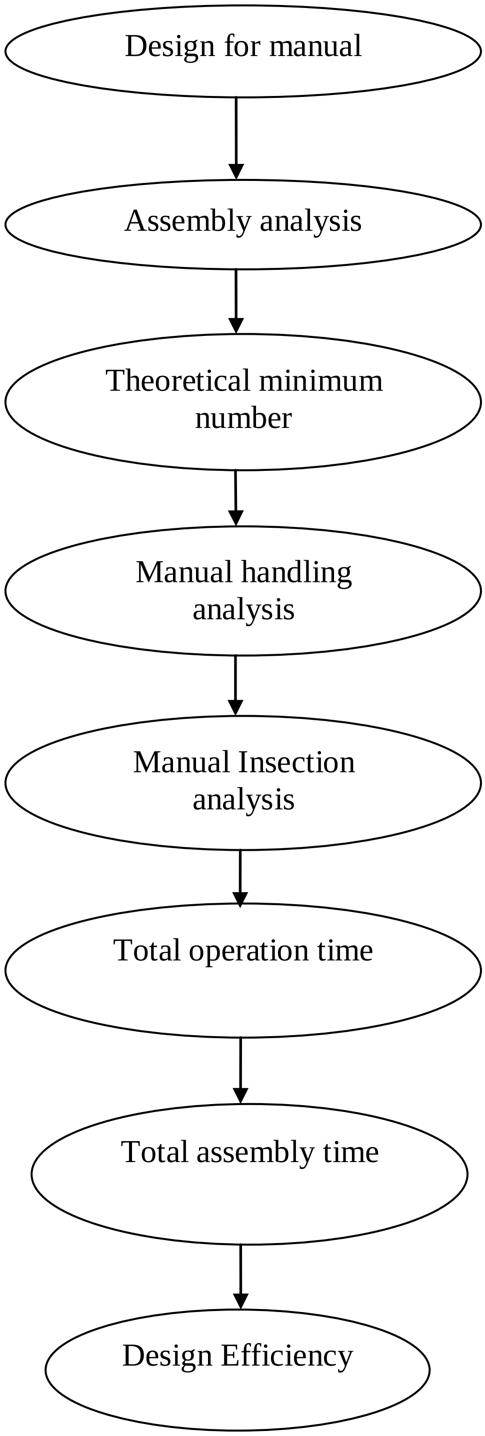


Figure 2.1: Boothroyd Dewhurst DFA analysis.

Source : Muhammad Faizal Bin Alias ,2007.

A DFA analysis is performed by completing a worksheet as shown in **Table 2.1** below:

Table 2.1 : DFA worksheet analysis

		C1	C2	C3	C4	C5	C6	C7	C8	C9	Name of Asembly
α	β	Part ID	No of times the operation is carried consecutively	Manual handling code	Manual handling time per part	Manual insertion code	Manual insertion time per code	Operation time = (C2)(C4+C6)	Operation cost = 1.069x 10^3(C7)	Estimation for theoretical minimum part	WALL SOCKET
								TM	CM	NM	

Source : Boothroyd, *et. al,* 2002

Once the parts have been added to the worksheet the first stage starting with defined the theoretical minimum number. The purpose is to define each part in assembly as a necessary part or candidate to be eliminated or to be combined with other part. Each part in assembly must answer the three following question (Boothroyd, *et. al*, 2002)

1) Does the part move relative to other parts?
2) Must the part, for good reasons, be made of a different material?
3) Does the part need to be separate for assembly or service?

If the answer "yes" to at least one of the following three questions above for a part, the part are the theoretical minimum number. Otherwise if the answer "no", the part are the candidate to eliminate or combine with other part (Boothroyd, *et. al*, 2002).

The second step is manual handling analysis on each part. This analysis is used to define the estimated time for handling the part according the weight, thickness, end-to-end part symmetry and rotational part about the axis. The third step is manual insertion analysis that used to estimate the insertion time for each part according the resistance and alignment during insertion and how the part is secured such as the part secured using snap fit or mechanical tools. Then fourth and fifth step is calculated the total operation time and the total assembly time. The formulated is following below (Boothroyd, *et. al*, 2002).

Total operation time in second = Th + ti

Where;

Th = handling time

Ti = insertion time

Total assembly time (sec) = E x (total operation time of each part)

The last step is calculated the design efficiency. The design efficiency is obtained by using the formula below (Boothroyd, *et. al*, 2002).

$$Design\ efficiency, Ema\ = \frac{Nmin\ xTa}{Tma}$$

Where;

N_{min} = theoretical minimum number of parts

T_a = basic assembly time = 3 second

T_{ma} = estimated time to complete the assembly of the product

2.4.2 Hitachi Assemblability Evaluation Method

This method is developed by Miyakawa and Ohashi in the late 1970 as part Hitachi desire for products, which could be efficiently assembled by automation. The main objective is to facilitate design improvements by identifying 'weaknesses' in the design at the earliest possible stage in the design process, by the use of two indices: (Toshijiro 2002).

i. Assemblability evaluation score ratio (E), used to assess design quality by determining the difficulty of operations
ii. Assembly cost ratio (K) used to project elements of assembly cost

The assembly process is analyzed using 20 AEM elements. The total assemblability evaluation score for the product is defined as the sum of the assemblability scores for the individual tasks, divided by the number of tasks. This may be considered to be a measure of design efficiency where a score of 100 would represent a perfect design. Hitachi consider that an overall score E of 80 is acceptable and overall assembly cost ratio K less than 0.7 is acceptable (Toshijiro 2002).

The Assemblability Evaluation Method (AEM) is an effective tool developed by Hitachi Ltd. to improved design quality for better assembly producibility. The AEM has been widely used by the Hitachi Group as well as by more than 20 other well known companies around the world. Using this method, in the early design stage, product design quality is analyzed quantitatively and weakness in the design's assembly producibility are highlighted. In addition, the effects of design improvement are confirmed with respect to assembly cost(Toshijiro 2002).

The procedure for analyzing product using AEM method is summarized as following below :

1) Construction of the evaluation system

The goal of this work is to develop an assembly producibility evaluation function that visualizes one characteristic of a product and its composing parts, the degree of assembly operation efficiency required for the product and the parts, and that provides information useful for design improvement activities. In order to construct the evaluation scheme, the assembly characteristics and the assembly operation model were considered. The assemblability evaluation uses the most appropriate information related to the behavior or characteristics of the assembled product or part and the related assembly operation in order to output information that indicated the efficiency of the assembly process. To develop the evaluation system, the following three items must be considered: (Toshijiro 2002).

a. What the output should be
b. What the input information should be,
c. How can the input information be converted to output information.

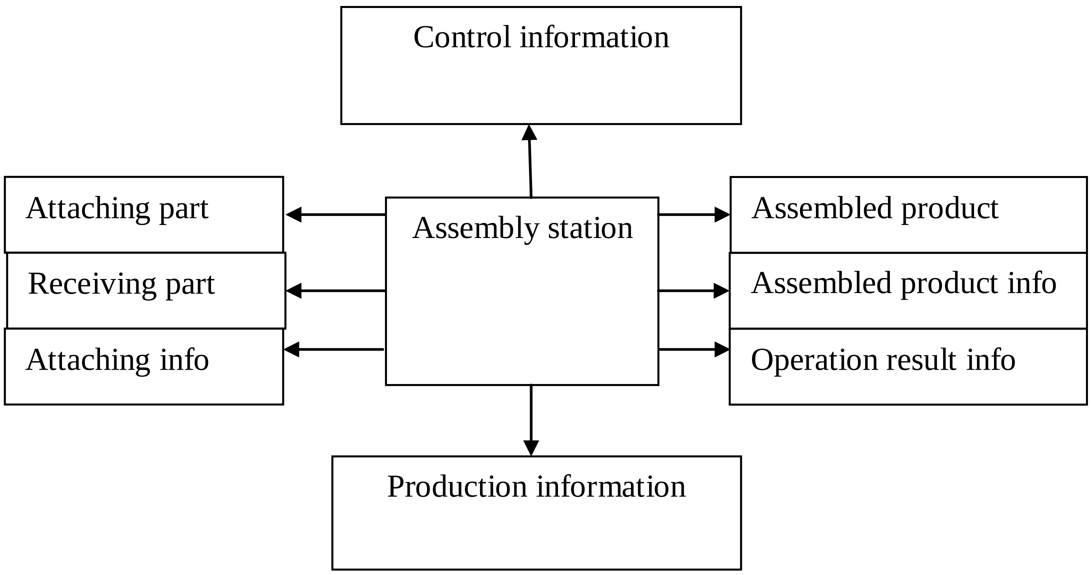


Figure 2.2 The operation model of an assembly station

Source : Toshijiro 2002

2) Define of easy of assembling

In order to determine the target output of the evaluation system. when its assembling expense is small. Reflecting this concept, AEM evaluation indices, in particular its unique index. AEM score, is define as show in table below (Toshijiro 2002).

Table 2.2 : the relationship between AEM score, assemblability, and assembly cost

	Assemblability	
Assembly operation cost (Assembly operation time)	Good	Bad (poor)
AEM Score	High (max : 100)	Low

Source : Toshijiro 2002

3) Input information

The output information should be determine by taking how it is used into account, and the input information should be choose by taking availability into account.

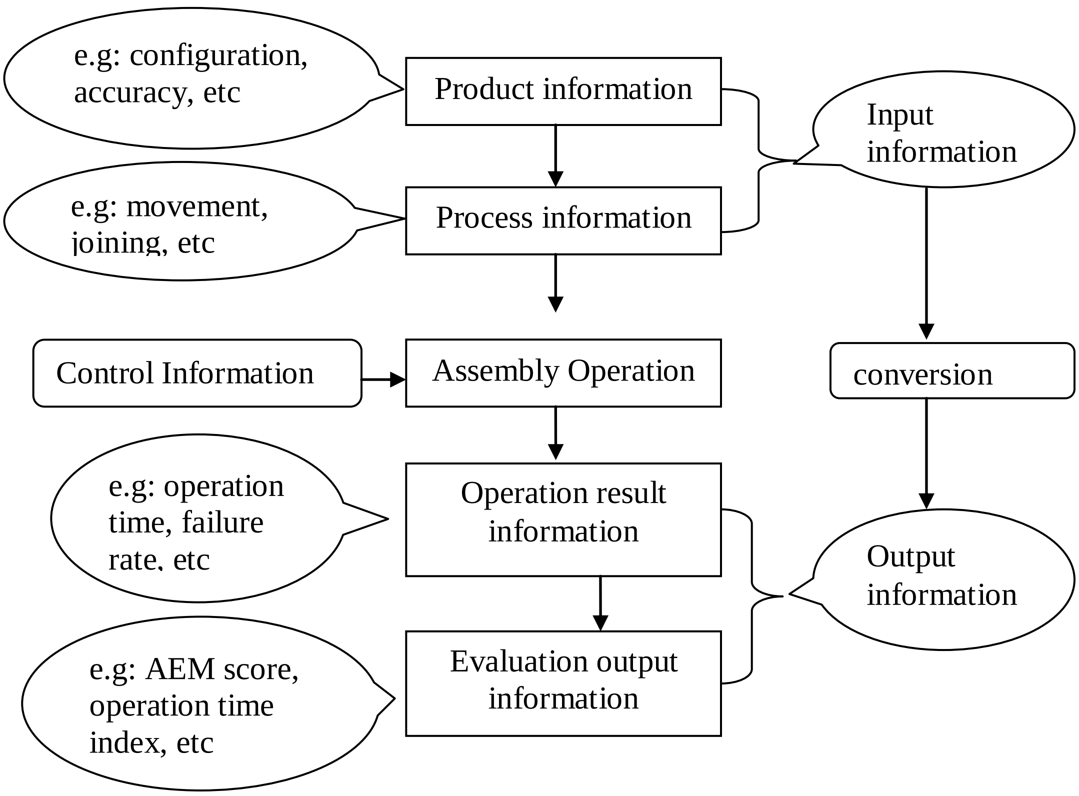


Figure 2.3: production information and evaluation information processing.

Source : Toshijiro 2002

The information suitable to be used as input information for evaluation purposes is considered as the followings (Toshijiro 2002).

a) Define basic element

AEM adopts approximately 20 elemental operations as the basic evaluation elements, and each of them is assigned an AEM symbol. The number of these basic elements ware determined by considering both simplicity and evaluation accuracy. If the numbers of basic elements are many, the evaluation accuracy can be better but inconvenient to use. Therefore, approximately 20 is a trade of between accuracy and simplicity.

b) Define supplementary elements

Define supplementary elements that significantly influence assembly operation time. It is necessary that the number of supplementary element is as few as possible, while preserving the evaluation accuracy, in order to allow easier evaluation. Actually, the supplementary elements are part size, dimensional accuracy, configurational and orientational accuracy, and repetition.

4) Calculation formulas for the evaluation.

a) Calculation of part attachment cost and time

Attachment time, $aTi = \sum aTij$

Attachment cost, $aCi = aA \cdot aTi$

Where:

aA : shop rate of the assembly shop ehere part “i” is attached

aTij: attaching time of part “i” . (A part is attached by multiple operations)

The attachment time for the jth operation of part “i” can also be expressed as follows:

$aTij = f1$ (design factor, production environment factor)

Where “design factor “ is a factor that influences attaching operation time, and is determined by design information alone using the basic element and supplementary element. Production environment factor is a factor that determines the operation speed shop, and is influenced by condition such as the capability of workers(Toshijiro 2002).

aTij = $f2$ (basic coefficient, supplementary coefficient, production environment factor)

$f3$· aToi = aDiJ · aToi

Where:

F : structure coefficient

aDiJ : shop basic assembly time, a constant that reflects the average operation speed of the shop.

aToi : structural coefficient that indicates the assembly operation complexity.

The structural coefficient of a product of parts obtained from AEM evaluation and the actual assembly operation AEM evaluation and the actual assembly operation time data for that product or parts are inputted and the aToi for the shop that produced the product is processed is calculated. (Toshijiro 2002).

$$\text{aToi} = \frac{\sum \text{aTij}}{\sum \text{aDij}}$$

Where:

∑aDiJ : sum of the assembly operation time of the product

∑aToi : sum of the structural coefficient of the product

b) Determination of design factors and basic element

The estimated attachment time aTij for the *j*th operation of part "i" and aTi for part "i" are defined as follows[6]:

aTij = aToi · $f3$ (aβij ; aλij , aμij, aΘij , aγij)

aTi = aToi · ∑ $f3$ (aβij ; aλij , aμij, aΘij , aγij)

Where:

aβij : basic coefficient for the jth operation of the part "i" . for (↓), 1 is given.

aλij : size coefficient for the jth operation of the part "i" . for the standard size, 1 is given.

aμij : dimensional accuracy coefficient for the jth operation of part "i". for the standard accurary, 1 is given

aΘij : configurational and orientational accuracy coefficient for the jth operation of part "i" for the standard accuracy condition,1is given

aγij : repetition coefficiency for the jth operation of the part "i". for the standard condition 1 is given.

In order to determine the basic element coefficient aβij, the following equation is used:

$$a\beta ij = \frac{aTx}{aTb}$$

Where:

aTx : the attachment operation time for a part that is attached by only one element “x”.

aTb : the attachment operation time for a part that is attached by only one element “↓”.

c) Calculation of AEM score

The part AEM score aEi is defined so that it decreses when the attaching difficulty of a part, i.e, assembly operation cost aCi or operation time aTi increases, as described in table below(Toshijiro 2002).

Table 2.3: Basic Element Example

Category	Basic element example		AEM symbol	Coefficient
Movement	Downward movement		↓	1.0
Joining	Soldering		**S**	2.2

Source : Toshijiro 2002

More concretely, AEM score aEi for the “i” is defined by following formula

aEi = *f*4 (estimated assembly operation cost)

= *f*5 (design factor)

= *f*6 (element coefficient, supplementary coefficient)

= 100 – (part elimination score)

d) Product AEM score

Product AEM score is define as the average of the AEM scores of all parts in the product.

$$\text{Product AEM score} = \frac{\sum \text{Part AEM score}}{\text{Number of part in the product}}$$

2.4.2 Lucas Hull DFA Method

Although the Boothroyd Dewhurst method is widely used, it is based on timing each of the handling and insertion method. Although tables of data are available, the most accurate numbers are compiled through times studies in particular factories.

Lucas Corporation in the United Kingdom was developed the Lucas DFA method early year of 1980's. The Lucas Method is differ to Boothroyd method, where the Lucas Hull method is based on "point scale" which gives a relative measure of assembly difficulty. Lucas DFA method evaluated the product design process based on three steps: function analysis, handing analysis and fitting analysis. The relations of these three steps are shown in figure. The objectives of Lucas DFA are (Wan Abd. Rahman, 2006).

i. Reducing parts counts.
ii. Ensuring feasible assembly process at minimum cost
iii. Achieving reliable and efficient automatic assembly
iv. Highlights areas for future consideration when business environments permit
v. Standardization of components, assembly sequence and methods across a range of related products.

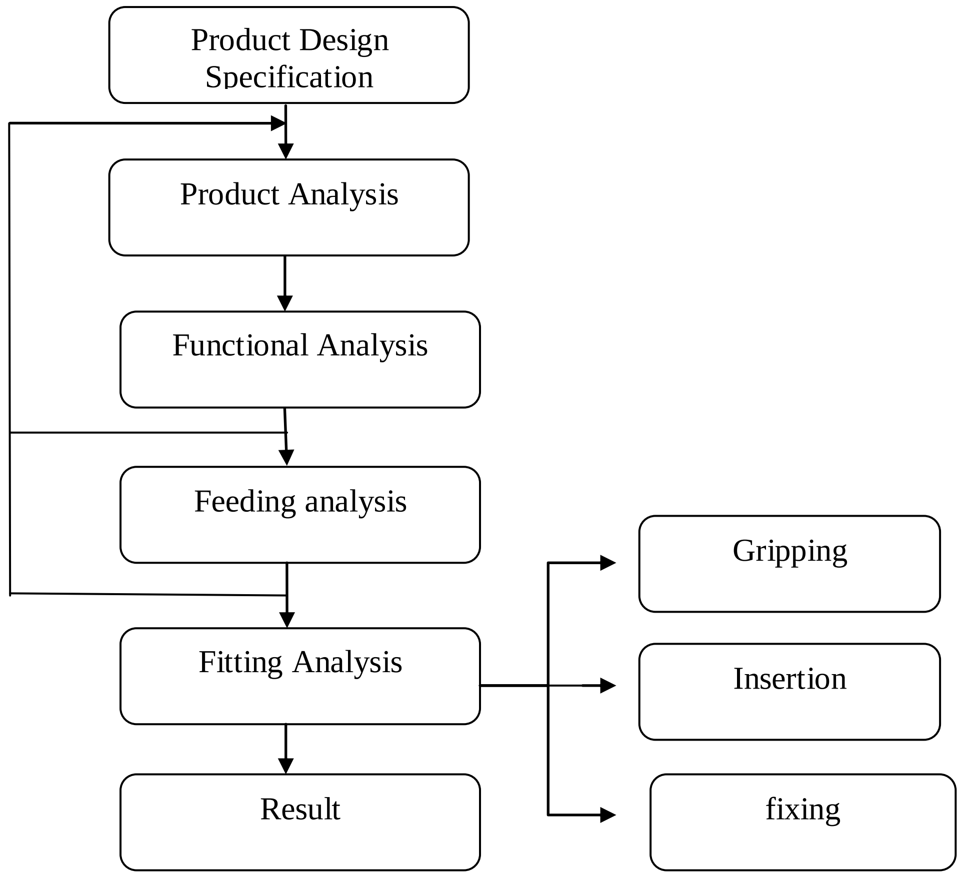


Figure 2.4: Lucas hull DFA analysis.

Source: Mohd Naim Bin Zakaria, 2009.

Manual assembly is considered. The lucas DFA evaluation procedure is shown in **figure 2.4** and every step of procedures can be explaining the following below (Wan Abd. Rahman, 2006).

i. Product Design Specification (PDS)
ii. Product Design
iii. Functional analysis (this is the first Lucas analysis) Possibly loop back to step 2 if the analysis yields problems
iv. Feeding analysis (this is the second Lucas analysis)
v. Fitting analysis (this is the third Lucas analysis)
vi. Assessment
vii. Possibly return to step 2 if the analyses identify problems

1) Product Design Specification (PDS)

Before product design commences (the speciation stage) it is important to decide whether each product is unique and bears no relationship with other products from the factory and opportunities for rationalization and standardization of parts and assembly procedures. Lucas is for high product demand, long lives, and limited variety which the pre-requisites for economically viable assembly automation.

The objectives are to (Wan Abd. Rahman, 2006):

a) Use standard part and common feeders across a range of products.
b) Assemble from the same direction and in the same sequence eliminating the need to duplicate identical feeders.
c) Use common feeding features on the larger component again to minimize the degree of feeder dedication.

2) Product Design

The objective is to maximized tooling utilization and minimize the tooling variation by using common parts within and across the range of the products, to eliminate tooling duplication by assemble in the same direction and to minimize the handling tool by applying the common feeding features on the larger component(Wan Abd. Rahman, 2006).

3) Functional Analysis

In this analysis, the components of the product are reviewed only for their function. The components are divided into two groups. Parts that belong to Group A are those are deemed to be essential to the product's function; Group B parts are those are not essential to the product's function. Group B functions include fastening, locating and etc (Wan Abd. Rahman, 2006).

The functional efficiency of the design can be calculated as:

$$E_d = \frac{A}{(A+B)} \times 100\%$$

Where:

A: the number of essential components

B: the number of non-essential components.

Note that the design efficiency is used to pre-screen a design alternative before more time is spent on it. This is different than the Boothroyd-Dewhurst method (which assumes a design is already available). This analysis is intended to reduce the part count in the product. Typically, a design efficiency of 60% is targeted for initial designs (Wan Abd. Rahman, 2006).

4) Feeding Analysis

It carried out on each part in three stages:

Stage 1:

It is most important to consider whether components are best transported in an orderly manner. Or whether they have to be handled in a disorderly manner from bulk supply and then reorientated at the assembly machine. Therefore, examine the possibility of transporting the component from the point of manufacture to the machine in an orientation maintained manner.

Stage 2:

Assesses the general physical properties for automatic feeding of those components that can not be transported with orientation maintained.

Stage 3:

Examines the suitability of the detailed design of those components proposed for automatic feeding.

Every stage, the problems associated with the handling of the part are score using an appropriate table. relative cost index for feeding is obtained by selecting the most appropriate feeding scenario for each part and assigning the index given. It can see that the components are suitable for orientation maintained or automatic feeding methods score the lowest cost indices. A total relative cost can be computed by summing all the individual feeding indices. Useful measure to assess the overall effectiveness of the product design from a feeding point view is to calculate (Wan Abd. Rahman, 2006).

$$Feeding\ Ratio\ = \frac{Total\ Feeding\ Index}{no.of\ essential\ components}$$

Where:

Total feeding index = sum of all the indices of all the parts

No. of essential = the value A from the functional analysis

The handling index target for a part is 1.5. If the index is greater than 1.5, the part should be considered for redesign. The value of handling ratio should be less than 2.5 is accept and the opposite must be iterated back to the PDS.

5) Fitting Analysis

The analysis is made up of three sections. Which each section is gripping, insertion and fixing (Wan Abd. Rahman, 2006)

a) Gripping

- Which each part can be held for transportation from the point of presentation within the automatic assembly machine to the stage where insertion is complete.
- Each component is examined for its suitability for gripping using appropriate table and is assigned the appropriate gripping index. Each diamond box on the assembly sequence flow chart represents a gripping operation.
- Component where handling is straightforward receive a low gripping index. Individual index values greater than zero are considered inferring the presence of a possible gripping process,

b) Insertion

- The relative ease of difficulty of carrying out each assembly task that is required to assemble the complete product from its constituent parts.
- Each square box on the assembly sequence flow chart represents a fitting process. Placement into a work holder is required the code WH* is added.

- Individual index values of 1.5 or greater are considered to infer the presence of a possible fitting problem.

c) Fixing

A total relative cost can be computed by assuming all the individual fitting indicated. A usefully measure to assess the overall effectiveness of the product design from a fitting point of view is to calculated:

$$\text{Fitting Ratio} = \frac{\text{Gripping Costs} + \text{Insertion Costs} + \text{Fixing Costs}}{\text{No. of essential components}}$$

The value of this ratio for an acceptable design is generally less than 2.5, although the aim must be to minimize this factor

6) Result

The last part of the Lucas method is to calculate the cost of manufacturing each component. This manufacturing cost can influence the choice of material and the process by which the part is made. Although not a true costing of the part, this method helps to guide designers by giving a relative measure of manufacturing cost. Values of each of the following coefficients are derived from detailed tables developed for the purpose. The part manufacturing cost index is (Wan Abd. Rahman, 2006).

$Mi = RcPc + Mc$

Where

$Rc = CcC\text{mp}Cs$ (Ct or Cf) is the relative cost.

Cc = Complexity factor.

$C\text{mp}$ = Material factor.

2.5 COMPARING VARIOUS METHOD OF DFA

The comparison between three DFA methods:

i. Boothroyd and Dewhurst DFA[6]

Advantages

It is very suitable for the redesign product based on design efficiency and the part that required high assembly time to assembly and unnecessary should be redesigned or eliminate.

Disadvantages

Does not show the evaluation of the whole assembly sequence and also has no support on how to redesign the evolution shows a poor results.

ii. Lucas / Hull DFA [6]

Advantages

It is very suitable in develop new product design based on design efficiency and also evaluated the part based on functional, handling and fitting analysis.

Disadvantages

The function analysis does not show the reason why the part should exist and it is also has no support on how to redesign the evolution shows a poor results.

iii. Hitachi Assemblability Evaluation Method (AEM) [6]

Advantages

It is analyzes the assembly operations of each component of the product.

Disadvantages

Only focuses on the insertion and fastening process and neglected the handling process. It is also has no support on how to redesign the evolution shows a poor results.

2.6 Summary

All the methodologies are of the same motive and improvement at the design stage, All the methodologies has same aim for to minimize the total number of part, making the process easier, minimizing the assembly lead time and reduce cost. However all method still remains the functionality of the product. This is important to give the manufacturer good impact after producing and selling the product.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents the review of the methodology that has been suggested in conducting this study for two semesters. Starting with design of study, where the methodology in performing this study has been reviewed. The proposed framework for redesigning, reduce the part of the produce, and improving efficiency of manufacture and assembly. This method seeks to minimize information content by eliminating parts and processes, simplifying the parts and processes that remain, and standardizing where possible.

3.2 DESIGN OF THE STUDY

The first steps that are considerably important are conformation of thesis title. After the conformation, discussions with supervisor have been conduct to arrange the weekly appointment time.

The study is proceeding with identifying the problem statement of the study before the objectives are stated. Then, next steps that has been taken are to identify the scopes of study. This is really important step as these scopes are making the objective of the study clearer. Then the outline of the study was reviewed.

The next steps that has been taken is searching for available journals and references from the internet and library. The common keywords that had been used in searching and browsing the journals are like ‘DFA’, ‘DFMA’, ‘Boothroyd-Dewhurst’, ‘Hitachi AEM’, ‘Lucas’, , ‘Design Guidelines’, and ‘Product Design Improvement’. Basically, there are about five journals mentioned and discuss in previous chapter, are amongst the references that had been used during to this study. Reference and text book other hand are used in understanding the concept and detail methods to evaluating the products.

Then, this study is proceeded with design of the framework and project methodology. In this section, the overview of methods that had been used in completing the study is reviewed in general. Review detail Boothroyd Dewhurst method and Hitachi AEM method

The study progress is proceeded with design evaluation and modeling. In this section the data measured form each parts that have been disassembled are presented. In here, parts dimension and criticism are included. Basically the evaluations of the design consist of two phases. Phase one is evaluation and Solid Works modeling of existing design in order to determine how the system works and function. Evaluation also suggested candidates for elimination in order to perform some modifications to the design. On the other hand, phase two concerns about analysis and selection of new proposed designs. Justifications for each new design is also discussed in this section.

3.3 PROJECT FLOW CHART

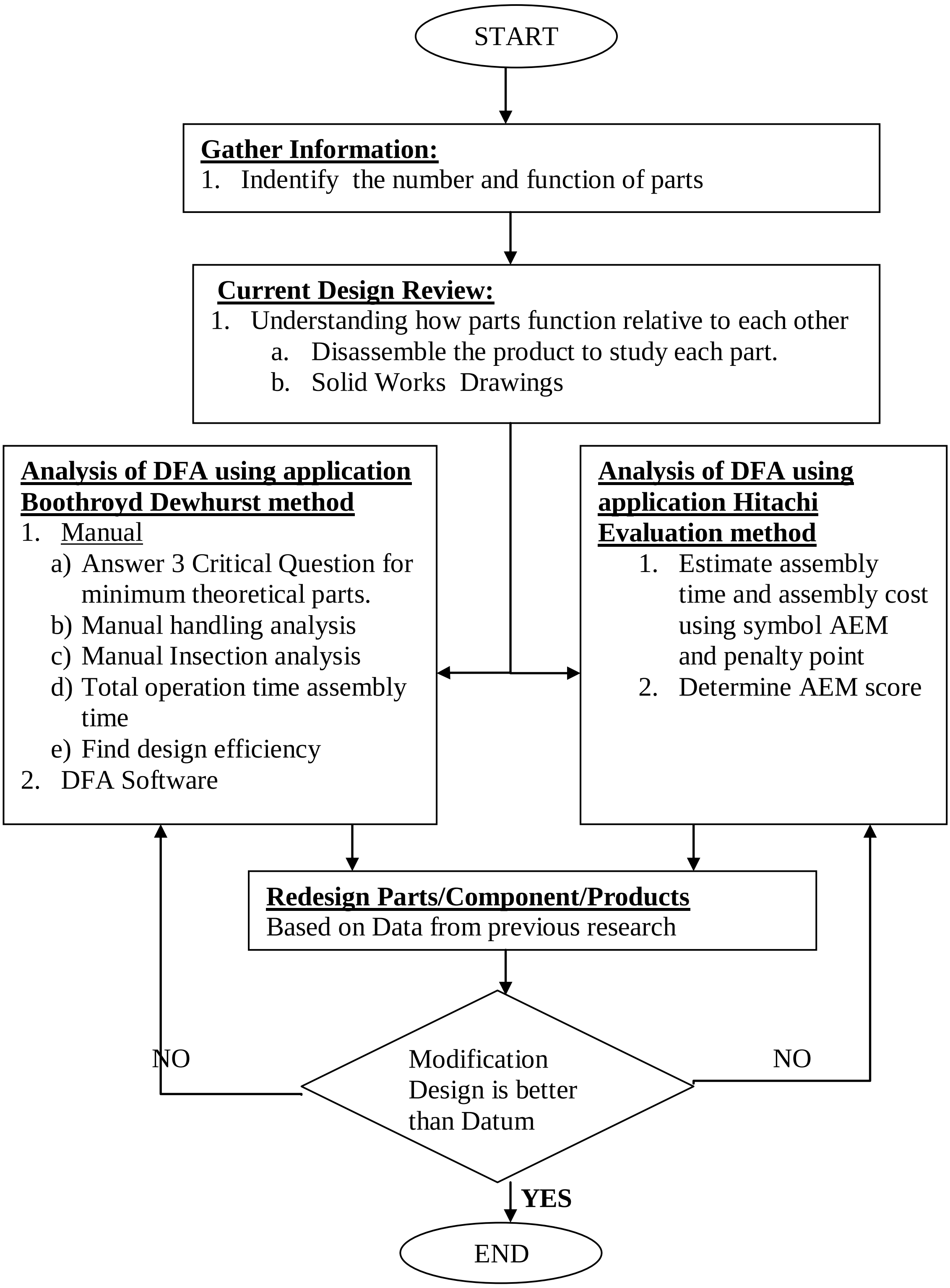


Figure 3.1 Flowchart of the project methodology

3.4 FRAMEWORK OF THE STUDY

The method utilizes an analyze-redesign approach to implement the design guidelines. First, an existing design is analyzed. The insights gained from the analysis are then used to develop and refined redesign alternatives aimed at eliminating parts and making the parts that remain easy to manufacture and assemble. The step-by-step procedure is as follows (Figure 3.1):

1. Gathering the Information of parts/product.
2. Current Design Review
3. Analysis of DFA using application
4. Redesign Parts/Component/Products
5. Modification Design is better than Datum

3.4.1 Gathering the Information of parts/product.

Chosen one product in thus study for determine the optimization of the cost and assembly efficiencies. Find the manufacture of the produce, function of the produce, number part or component to make the complete product and find dimension for each part of the produce. It is absolutely beneficial to reconsider its design for assembly (DFA) features so that overall cost can be reduced.

3.4.2 Current Design Review

The step of analysis the product is begin with gathering information about the current product. The current product must be disassembled part by part to get the detail number of component. Then each parts or component of the product has measured by using manual measuring tool like vernier caliper to get the detail dimension of each part. The next step is to generate 3D modeling using the solidwork software. The 3D modeling of part or component must base on exact dimension.

3.4.3 Analysis of DFA using application Hitachi Evaluation method

a) Calculate assembly time and assembly cost using symbol AEM and penalty point.

Each part is given 100 points.Additional penalty points depending on relative difficulty to insert the part:

1. Direction of motion
2. Needs of fixture and forming
3. Method of joining and processing
4. Multiple operations

b) Determine AEM score

The entire penalty for each process mush be considered and calculate the AEM score for each part of modification

$$\text{Product AEM score} = \frac{\sum \text{Part AEM score}}{\text{Number of part in the product}}$$

3.4.4 Analysis of DFA using application Boothroyd Dewhurst Evaluation method

3.4.4.1 Manual

a) Answer 3 Critical Question for minimum theoretical parts.

The purpose is to define each part in assembly as a necessary part or candidate to be eliminated or to be combined with other part. Each part in assembly must answer this three following questions;

i. Does the part move relative to other parts?

ii. Must the part, for good reasons, be made of a different material?

iii. Does the part need to be separate for assembly or service?

b) Manual handling analysis

This analysis is used to define the estimated time for handling the part according the weight, thickness, end-to-end part symmetry and rotational part about the axis.

c) Manual Insection analysis

estimate the insertion time for each part according to the resistance and alignment during insertion and how the parts are secured whether by using snap fit or mechanical tools

d) Total operation time assembly time

The formulated is following below:

Total operation time in second = Th + ti

where;

Th = handling time

Ti = insertion time

Total assembly time (sec) = E x (total operation time of each part)

e) Find design efficiency

The design efficiency is obtained by using the formula below

$$Design\ efficiency, Ema\ = \frac{Nmin\ xTa}{Tma}$$

where;

N_{min} = theoretical minimum number of parts

T_a = basic assembly time = 3 second

T_{ma} = estimated time to complete the assembly of the product

3.4.4.2 DFA Software

DFA software that evaluates product design based on Boothroyd- Dewhurst DfMA methodology, Using DFMA, designers are able to evaluate the product for improvement much faster and more convenience that the manual method.

3.4.5 Modification Design is better than Datum

For DFA using Hitachi Evaluation Method, the result evaluated based on AEM score of the product. If the score of AEM for modification design is over than current design so that the design is acceptable and If the score of AEM for modification design is below than current design. So, that the design is need to redesign and do some modification

For DFA using Boothroyd Dewhurst evaluation method, the result evaluated based on design efficiency. if the design efficiency current design is better that the design efficiency modification design it should iterated back to the gather information . Otherwise, if the modification design is better than datum, the process evaluate is done.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter provides a discussion of the. The design for assembly result for selected product was analyzed by using Hitachi Assimilability Evaluation Method (AEM) and Boothroyd Dewhurst DFA Method

4.2 PRODUCT DESCRIPTION

Children tricycle is chosen in this study because this product is a good design to be commercialized. Nowadays, the tricycle is being widely used. While tricycles are often associated with the small three-wheeled vehicles used by pre-school age children, they are also used by adults for a variety of purposes. In the United States and Canada, adult-sized tricycles are used primarily by older persons for recreation, shopping, and exercise. In Asia and Africa, tricycles are used primarily for commercial transportation, either of passengers in pedicabs, or of freight and deliveries.

Human-powered tricycles are usually powered by pedals, although some models have hand cranks. Motorized tricycle can be powered with a variety of methods, including motorcycle engines, smaller automatic transmission scooter motors, and electric motors.

Children's tricycles are made for a recreational market are usually of a direct-drive type and have no brakes, Tricycles are typically used by children between the ages of two and four, after which point they usually switch to a bicycle, often with training wheels. Parents choosing a tricycle for their child should ensure that the tricycles is not too tall and that the seat is too high, and that the wheelbase is wide enough, because if this is not the case, the child may tip over easily. The seat should be stable, which is not always the case with the most inexpensive models. Some tricycles have back rests which provide support and a push bar for parents so that the parents can push the child up hills or hold the child back when descending, or in case of the sudden approach of other traffic. For safety many parents make children wear a helmet when riding a tricycle. Some parents also attach a safety flag to the tricycle so that the child can be more visible to drivers.

Children's tricycles are made of steel frames or plastic. One disadvantage of plastic frames is that they be more likely to tip over than a steel frame if a heavier child is riding. On the plus side, plastic frames cannot rust like steel frames if the tricycles is left out in the rain. A good quality tricycles wheels can have treads, which provide better traction.

4.3 SPECIFICATION OF CHILDREN TRICYCLE

For more detail of specification please refer to Table 4.1. The children tricycle current product is shown in Figure 4.1.

Table 4.1: Children Tricycle Specification.

Product Characteristic	Product Specification
Product Name	Children Tricycle
Features	Lightweight, easy to bring anywhere,
	Different Colour Choice,
Applications	Train children before switch to a bicycle
No. of Part	71
Price	RM 59.90

Figure 4.1: Children tricycle current product

4.4 PART CRITIQUE

The Table 4.2 below shows the critique point of each part for the Children Tricycle and also material of the part made of.

Table 4.2: Part Critique and Material

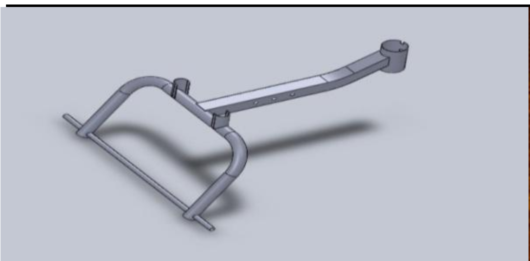
No	Part Name	Critique	Material
1	Chassis	as a support and most crucial element that give strength and stability	steel
2	Cap Fork	Hold pin and cover the fork	Plastic
3	Fork Truss	as a support front part for make handle tricycle	steel
2	Tricycle Dashboard	Holder for horn and side mirror	Plastic
3	Front Cover	Cover the fork truss	Plastic
5	Pin	To join frame and fork truss	Steel
6	Pin Clip	To tie the pin	Plastic
7	Front Wheel	For lateral movement and support load	Plastic
8	Paddle Shaft	To move the front wheel	Steel
9	Holder	Connect together with paddle shaft and front	Rubber

		wheel	
10	Pin Holder	Use to lock wheel holder to prevent wheel holder to move side word	Steel
11	Hand Gripped	As a handle	Rubber
12	Side Mirror	Use to see rear view	Plastic
13	Horn	Used to alert someone	Rubber
14	Wheel Clip	To prevent wheel loose out	Steel
15	Washer	used to support a fastener like a screw or to function as a spacer	Steel
16	Rim	As a cap for wheel	Plastic
15	Bracket	To lock pedal shaft with fork truss	Plastic
16	Paddle	To move the paddle shaft	Plastic
17	Seat	A place a children to sit	Plastic
18	Seat cover	For comfort while sitting	Plastic
19	Bolt	To fasten more than one component	Steel
20	Screw	To attach more than one component	Steel
21	Nut	as a fasten of connecting with the screw or bolt	Steel
22	Bush	As a space between frame and wheel	Plastic
23	Rear wheel	For lateral movement and support load	Plastic
24	Basket	the storage of goods	Plastic
25	Lifter	facilitate the lifting tricycle	Plastic
26	U Tube	dependent children for comfort when sitting down	Steel

4.5 FIGURES AND DIMENSION OF THE PART

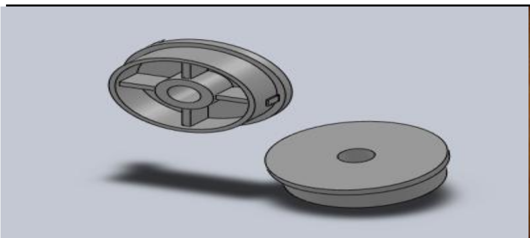
Table 4.3 until table 4.39 show a children tricycle parts that has been dismantled for measured dimensions of the current part, orientation and also quantity of the part.

Table 4.3: Chassis (base).



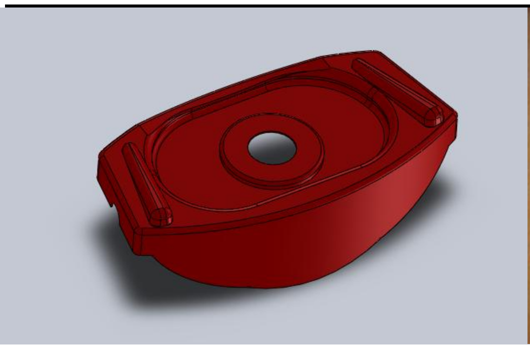

Part Name	Chassis (base)
Dimension	Thickness = 25mm
	Size = 499mm
Quantity	1
Orientation	$\alpha = 0$
	$\beta = 0$

Table 4.4: Cap Fork.



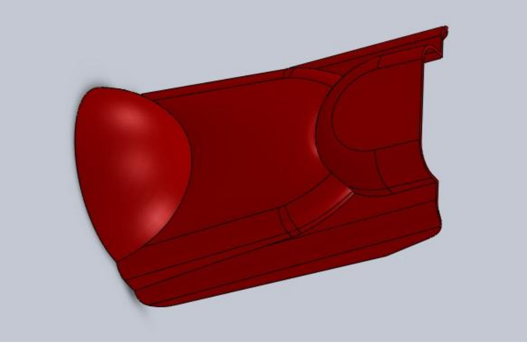

Part Name	Cap Fork
Dimension	Thickness = 12.5mm
	Size = 39mm
Quantity	2
Orientation	$\alpha = 0$
	$\beta = 360$

Table 4.5: Tricycle Dashboard



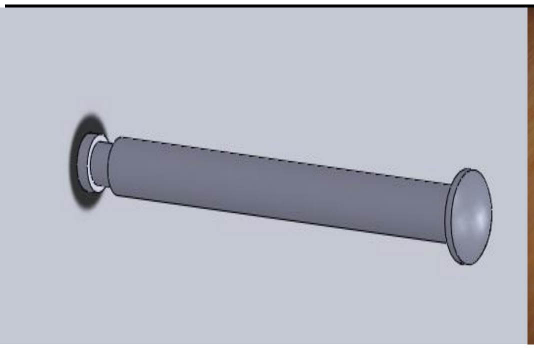
Part Name	Tricycle Dashboard
Dimension	Thickness = 2mm
	Size = 230mm
Quantity	1
Orientation	$\alpha = 360$
	$\beta = 360$

Table 4.6: Front Cover.



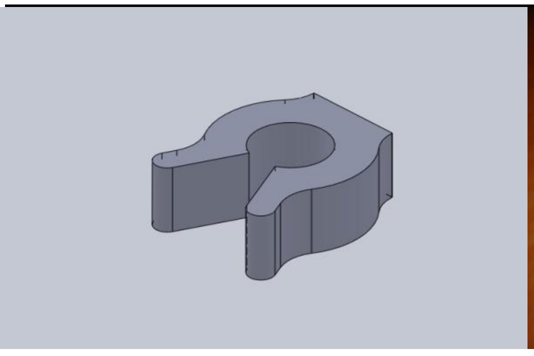
Part Name	Front Cover
Dimension	Thickness = 1.5mm
	Size = 175mm
Quantity	1
Orientation	$\alpha = 360$
	$\beta = 360$

Table 4.7: Pin.



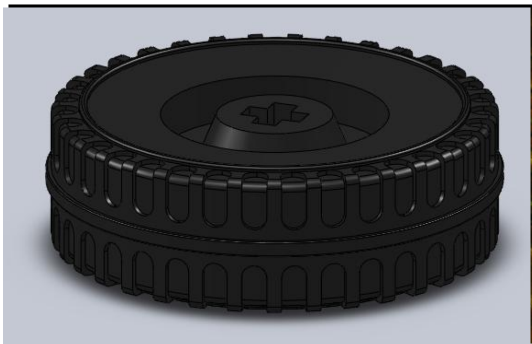

Part Name	Pin
Dimension	Thickness = 13mm Size = 96mm
Quantity	1
Orientation	α = 360 β = 360

Table 4.8: Pin Clip.



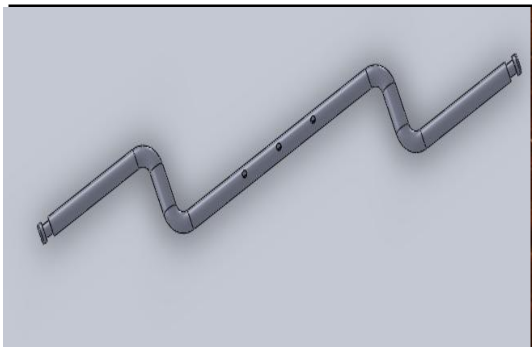

Part Name	Pin Clip
Dimension	Thickness = 4mm Size = 16mm
Quantity	1
Orientation	α = 180 β = 360

Table 4.9: Front Wheel.



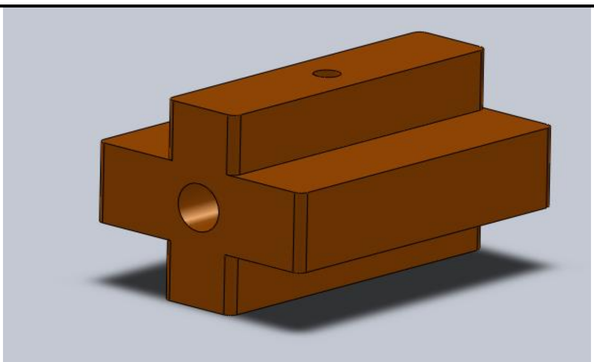
Part Name	Front Wheel
Dimension	Thickness = 58mm
	Size = 180mm
Quantity	1
Orientation	$\alpha = 0$
	$\beta = 180$

Table 4.10: Paddle Shaft.



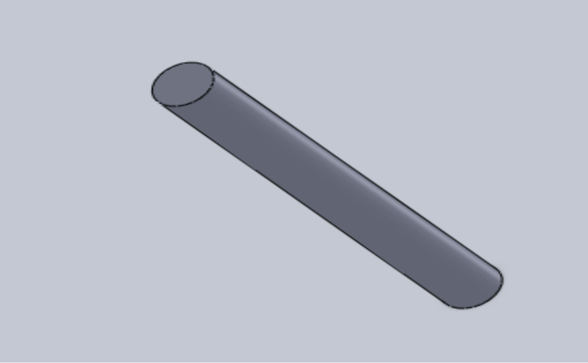
Part Name	Paddle Shaft
Dimension	Thickness = 8mm
	Size = 310mm
Quantity	1
Orientation	$\alpha = 0$
	$\beta = 0$

Table 4.11: Wheel Holder.



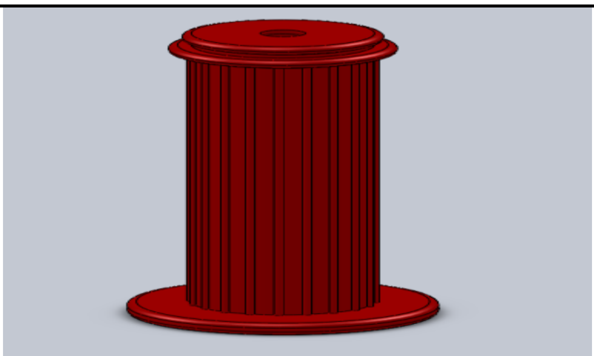
Part Name	Wheel holder
Dimension	Thickness = 10mm Size = 40mm
Quantity	1
Orientation	$\alpha = 90$ $\beta = 180$

Table 4.12: Pin Holder.



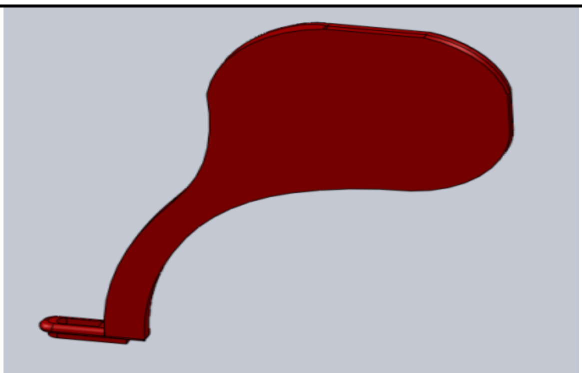
Part Name	Pin Holder
Dimension	Thickness = 3mm Size = 15mm
Quantity	1
Orientation	$\alpha = 180$ $\beta = 0$

Table 4.13: Hand Grip.



Part Name	Hand Grip
Dimension	Thickness = 20mm Size = 68mm
Quantity	2
Orientation	α = 0 β = 360

Table 4.14: Side Mirror.

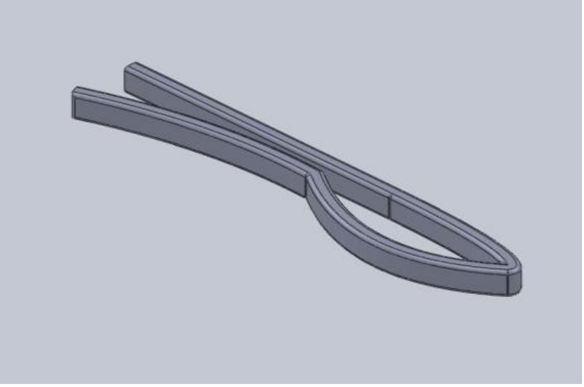


Part Name	Side Mirror
Dimension	Thickness = 8mm Size = 155mm
Quantity	2
Orientation	α = 360 β = 360

Table 4.15: Horn.

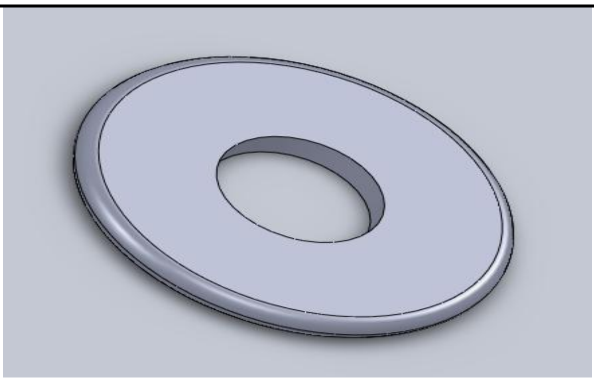
Part Name	Horn
Dimension	Thickness = 38mm Size = 78mm
Quantity	1
Orientation	$\alpha = 360$ $\beta = 0$

Table 4.16: Wheel Clip.



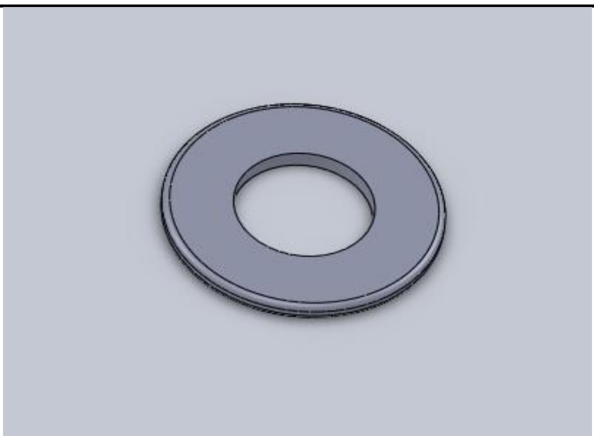
Part Name	Wheel Clip
Dimension	Thickness = 2 mm Size = 12mm
Quantity	4
Orientation	$\alpha = 360$ $\beta = 180$

Table 4.17: Big Washer.

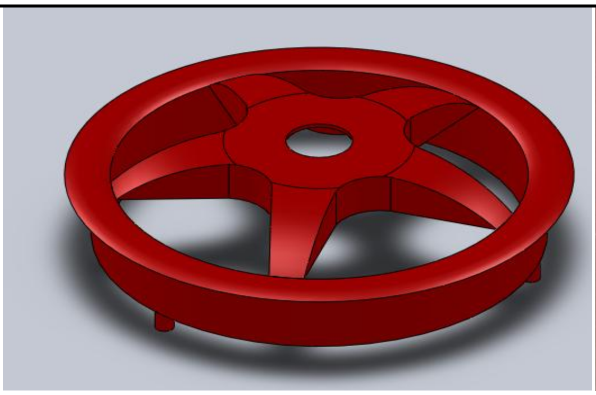
Part Name	Big Washer
Dimension	Thickness = 1.5 mm Size = 27mm
Quantity	2
Orientation	α = 0 β = 180

Table 4.18: Medium Washer

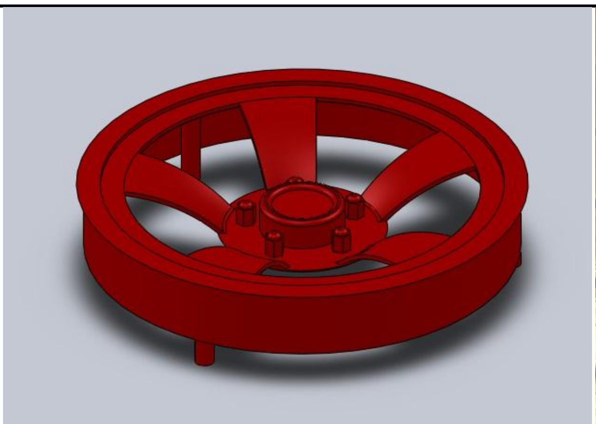
Part Name	Medium Washer
Dimension	Thickness = 1 mm Size = 17mm
Quantity	4
Orientation	α = 0 β = 180

Table 4.19: Front Rim.



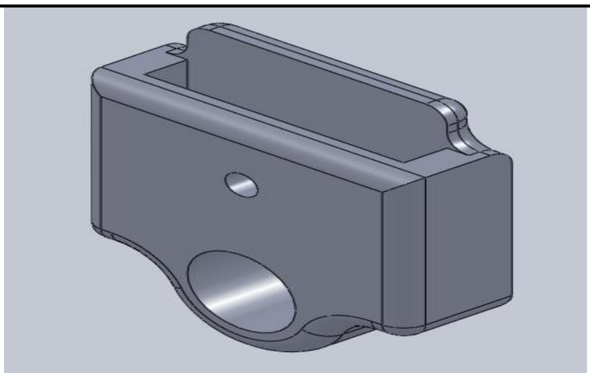

Part Name	Front Rim
Dimension	Thickness = 2 mm Size = 106mm
Quantity	2
Orientation	α =90 β = 360

Table 4.20: Rear Rim.



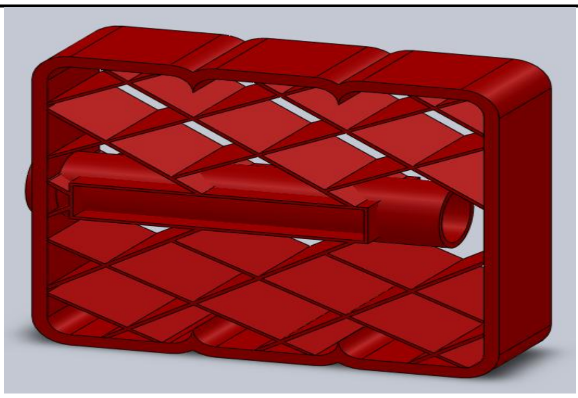
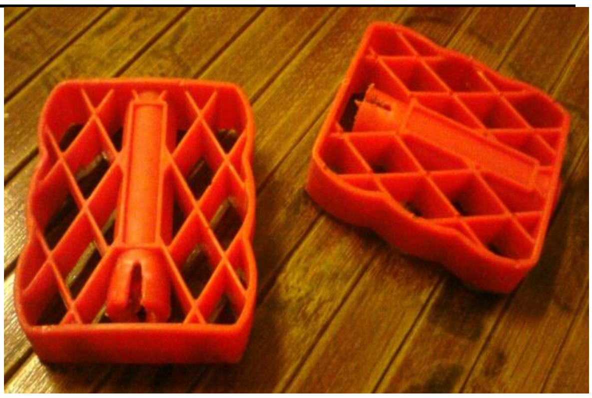

Part Name	Rear Rim
Dimension	Thickness = 2 mm Size = 106mm
Quantity	2
Orientation	α = 90 β = 360

Table 4.21: Bracket.



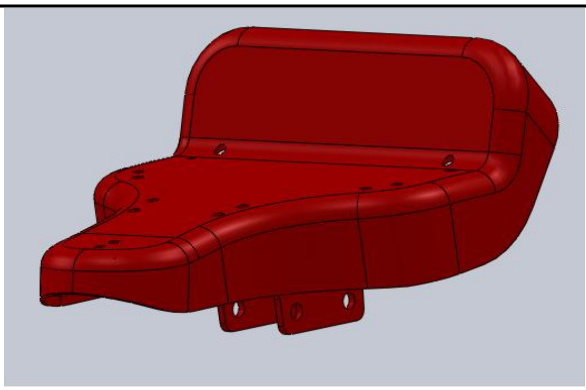

Part Name	Bracket
Dimension	Thickness = 10 mm Size = 30mm
Quantity	2
Orientation	α =360 β = 360

Table 4.22: Paddle

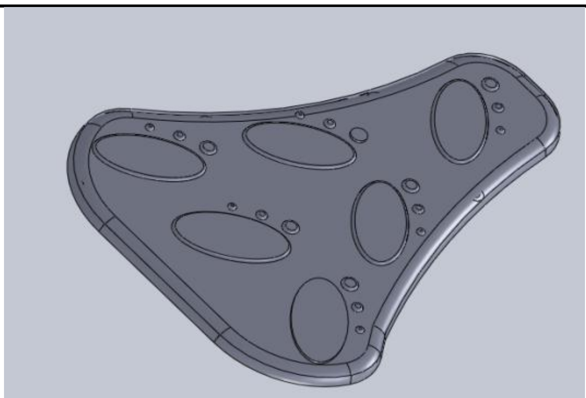
Part Name	Paddle
Dimension	Thickness = 15mm Size = 61mm
Quantity	2
Orientation	α =0 β = 360

Table 4.23: Seat



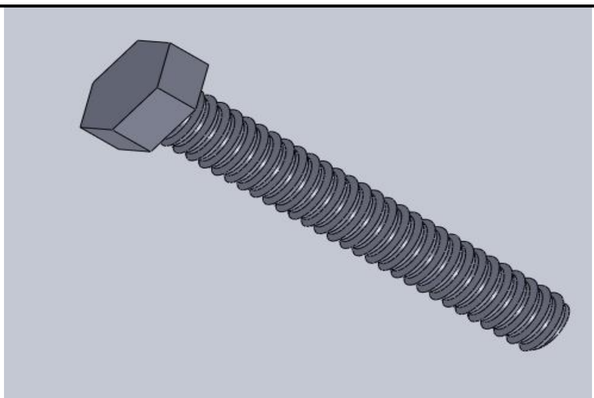
Part Name	Seat
Dimension	Thickness = 4mm
	Size = 250mm
Quantity	1
Orientation	α =360
	β = 360

Table 4.24: Seat Cover.



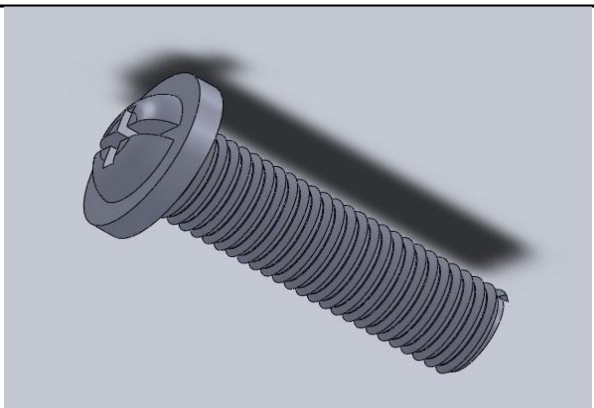
Part Name	Seat cover
Dimension	Thickness = 1.4mm
	Size = 180mm
Quantity	1
Orientation	α =360
	β = 360

Table 4.25: Bolt Seat

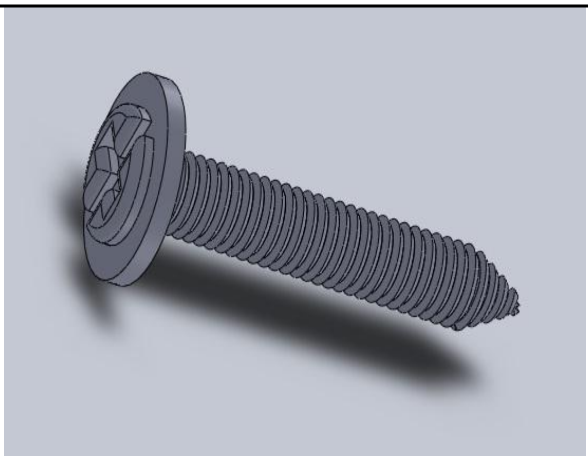
Part Name	Bolt Seat
Dimension	Thickness = 6mm
	Size = 44mm
Quantity	2
Orientation	α = 0
	β = 360

Table 4.26: Screw U Tube.

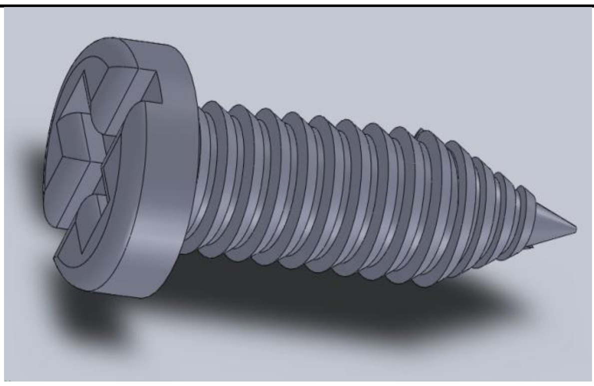
Part Name	Screw U Tube
Dimension	Thickness = 5mm
	Size = 28mm
Quantity	2
Orientation	α = 0
	β = 360

Table 4.27: Screw Cover Seat.



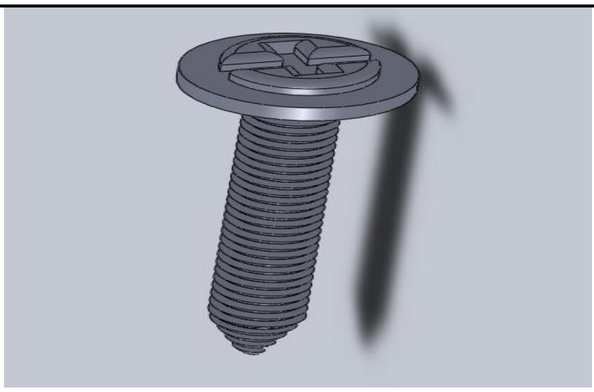
Part Name	Screw cover seat
Dimension	Thickness = 3mm Size = 8mm
Quantity	6
Orientation	$\alpha = 360$ $\beta = 0$

Table 4.28: Screw Front Cover



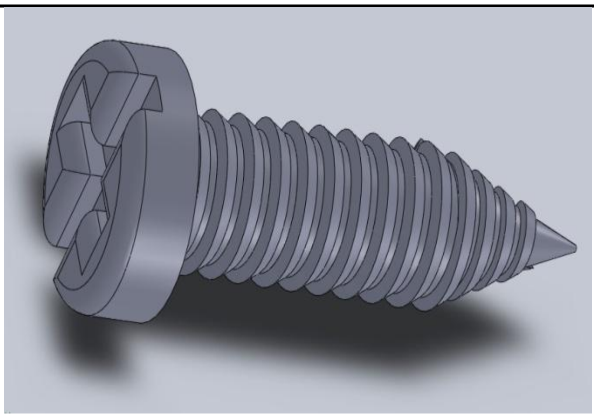
Part Name	Screw front cover
Dimension	Thickness = 4mm Size = 13mm
Quantity	2
Orientation	$\alpha = 0$ $\beta = 360$

Table 4.29: Screw Dashboard.



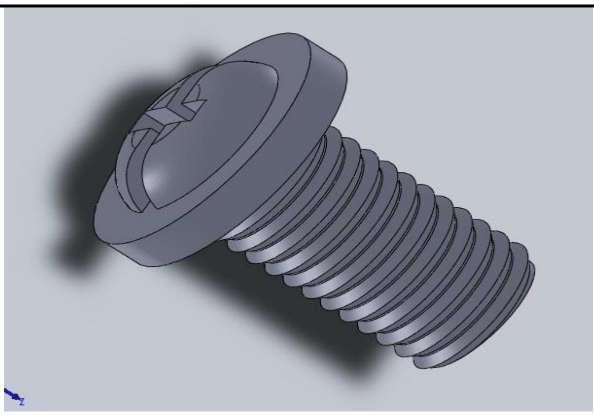

Part Name	Screw Dashboard
Dimension	Thickness = 4mm Size = 22mm
Quantity	2
Orientation	α =360 β = 0

Table 4.30: Screw Bracket.



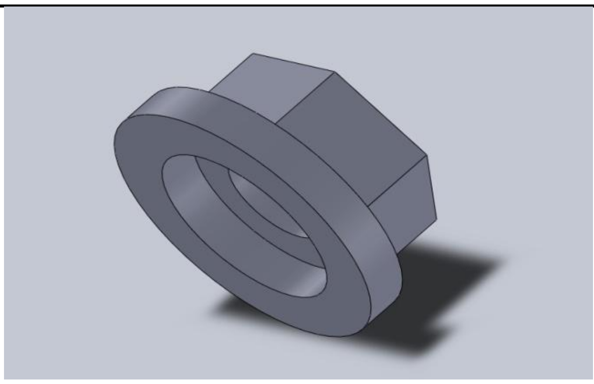

Part Name	Screw bracket
Dimension	Thickness = 4mm Size = 13mm
Quantity	2
Orientation	α = 0 β = 360

Table 4.31: Screw Basket.

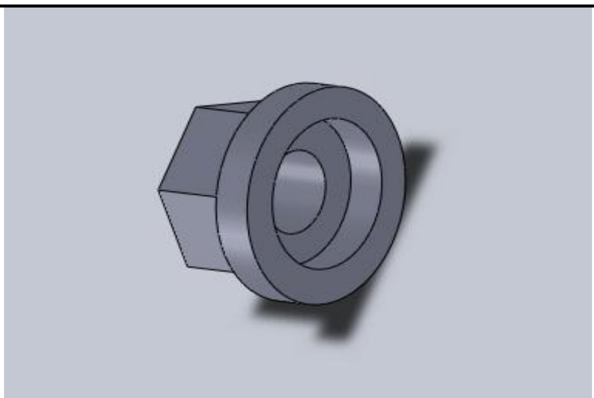
Part Name	Screw Basket
Dimension	Thickness = 5mm
	Size = 28mm
Quantity	3
Orientation	α =360
	β = 0

Table 4.32: Big Nut.

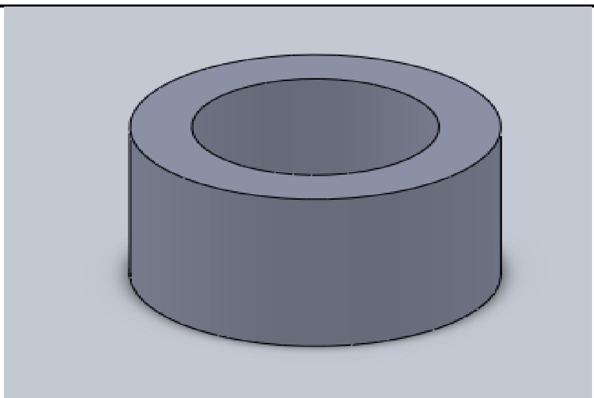
Part Name	Big Nut
Dimension	Thickness = 5mm
	Size = 10mm
Quantity	2
Orientation	α = 0
	β = 360

Table 4.33: Medium Nut.



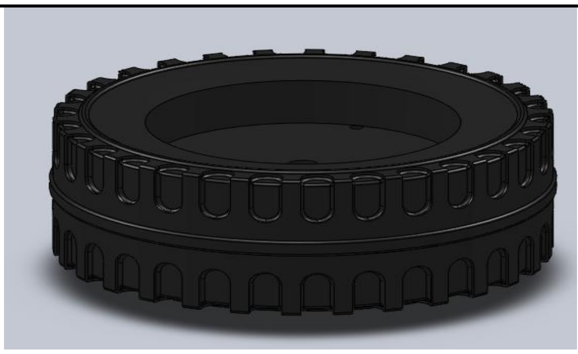
Part Name	Medium Nut
Dimension	Thickness = 5mm Size = 8mm
Quantity	5
Orientation	α =360 β = 0

Table 4.34: Bush.



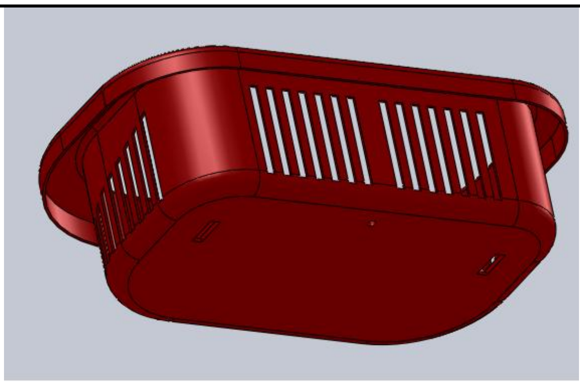
Part Name	Bush
Dimension	Thickness = 11mm Size = 18mm
Quantity	2
Orientation	α =0 β = 180

Table 4.35: Rear Wheel.



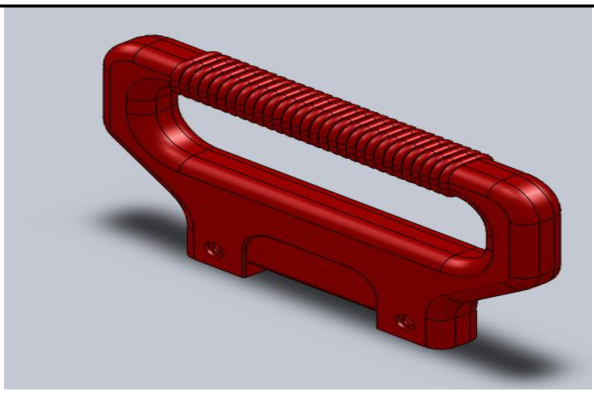
Part Name	Rear wheel
Dimension	Thickness = 55mm Size = 152mm
Quantity	2
Orientation	α =0 β = 360

Table 4.36: Basket.



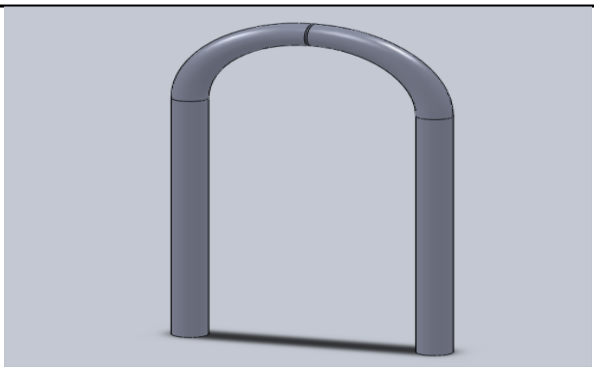
Part Name	Basket
Dimension	Thickness = 3mm Size = 290mm
Quantity	1
Orientation	α =360 β = 360

Table 4.37: Lifter.



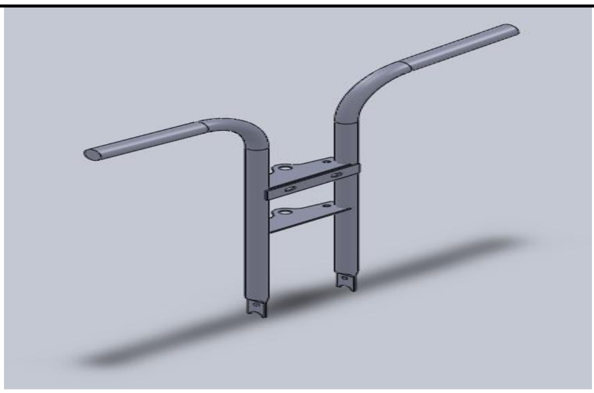

Part Name	Lifter
Dimension	Thickness = 28mm Size = 230mm
Quantity	1
Orientation	α =360 β = 360

Table 4.38: U Tube




Part Name	U Tube
Dimension	Thickness = 16mm Size = 230mm
Quantity	1
Orientation	α =360 β = 180

Table 4.39: Fork Truss.




Part Name	Fork Truss
Dimension	Thickness = 18mm Size = 335mm
Quantity	1
Orientation	α =360 β = 360

4.6 PRODUCT TREE FOR CURRENT DESIGN

Figure 4.2 shows the children tricycle product tree. The product tree is divided into 4 major sub-assemblies, which are Front Assembly, Middle Assembly, Rear Assembly, and Front Wheel Assembly and combine all subassembly into Main Assembly.

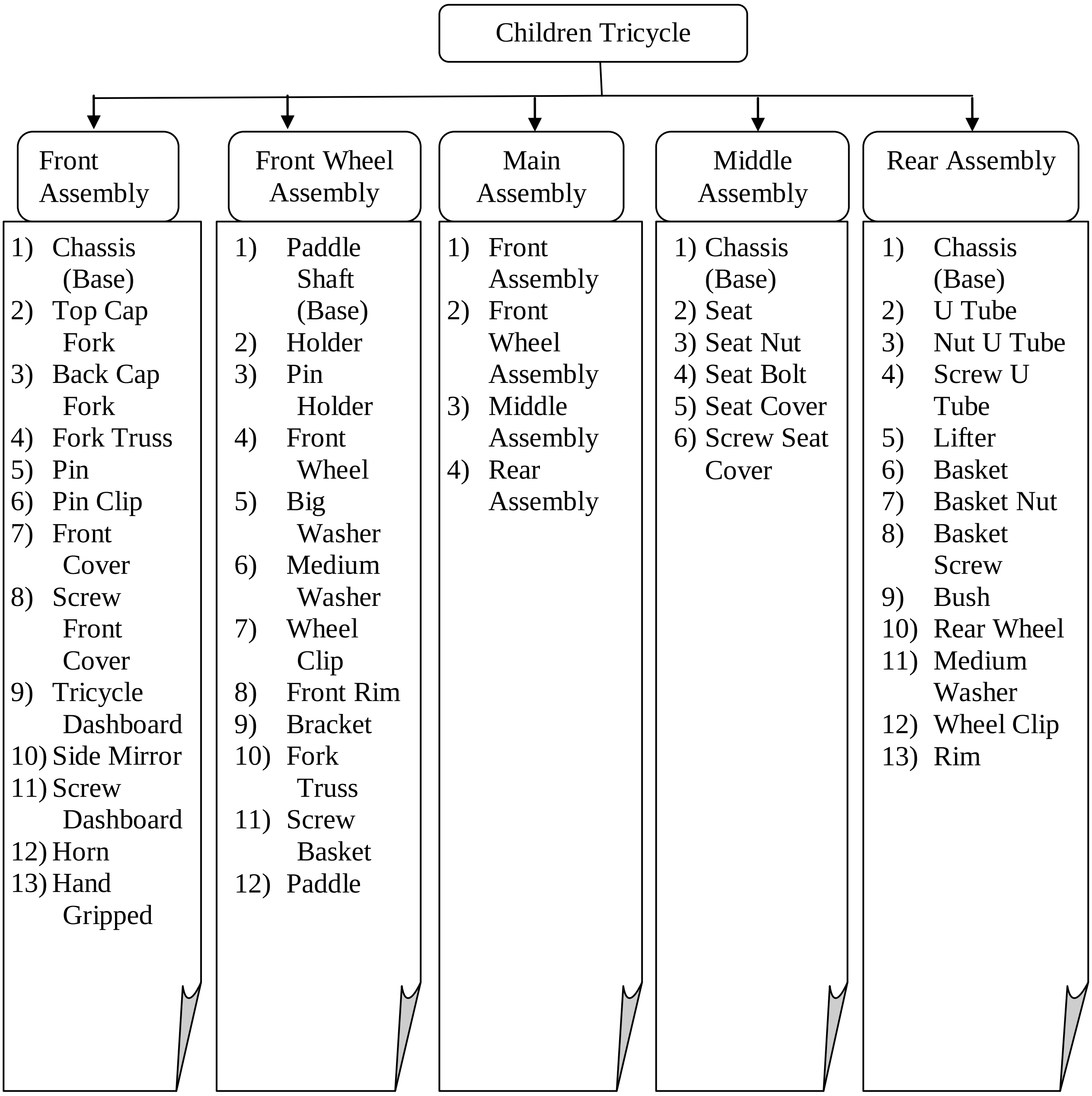


Figure 4.2: Children Tricycle Product Tree

4.7 PRODUCT ASSEMBLY OPERATION SEQUENCE FOR CURRENT DESIGN

Assembly operation sequence is needed in order to determine the step to produce the complete children tricycle. Therefore every subassembly needs to analyze the assembly sequence. Figure 4.3 until figure 4.7 representing assembly operation sequence for every subassembly.

4.7.1 Middle Assembly

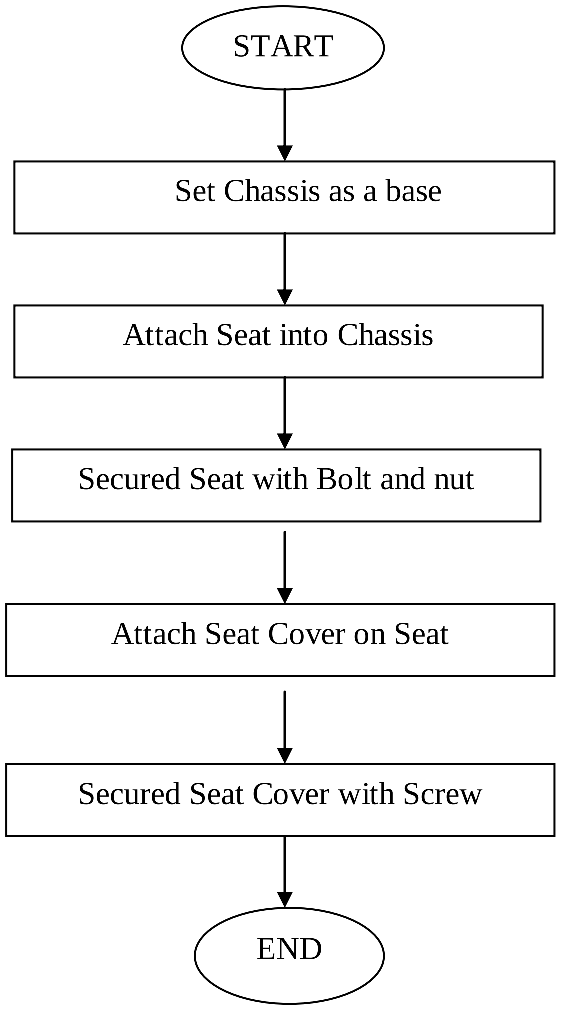


Figure 4.3: Middle Assembly operaton sequence for current design

4.7.2 Front Assembly

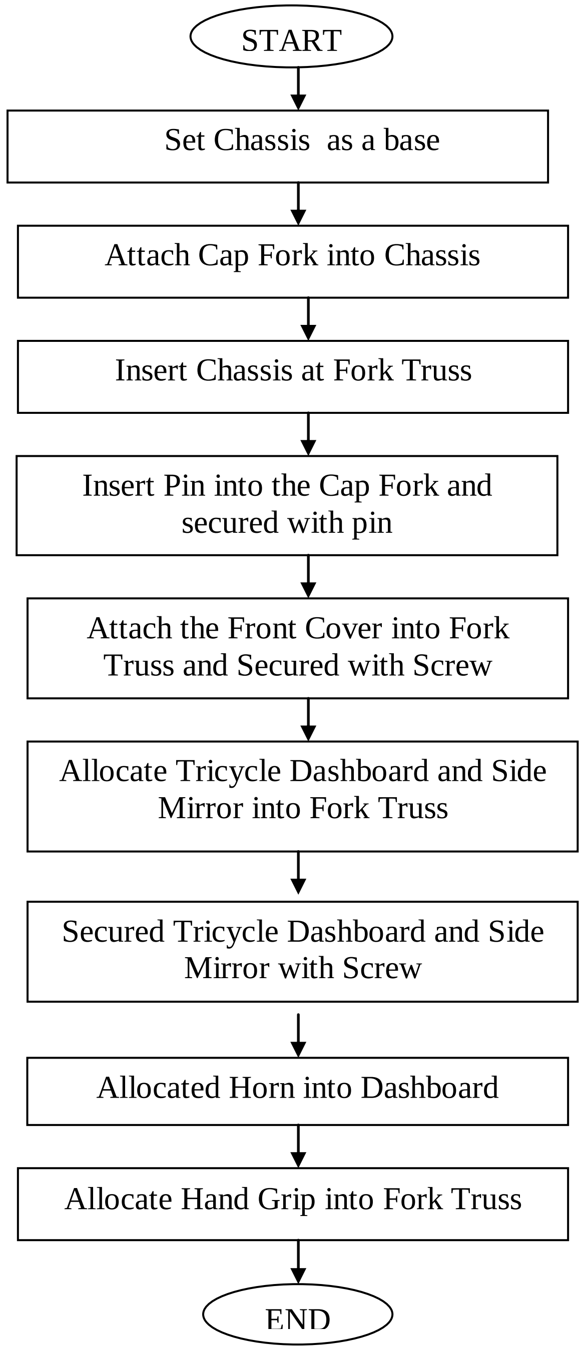


Figure 4.4: Front Assembly operaton sequence for current design

4.7.3 Front Wheel Assembly

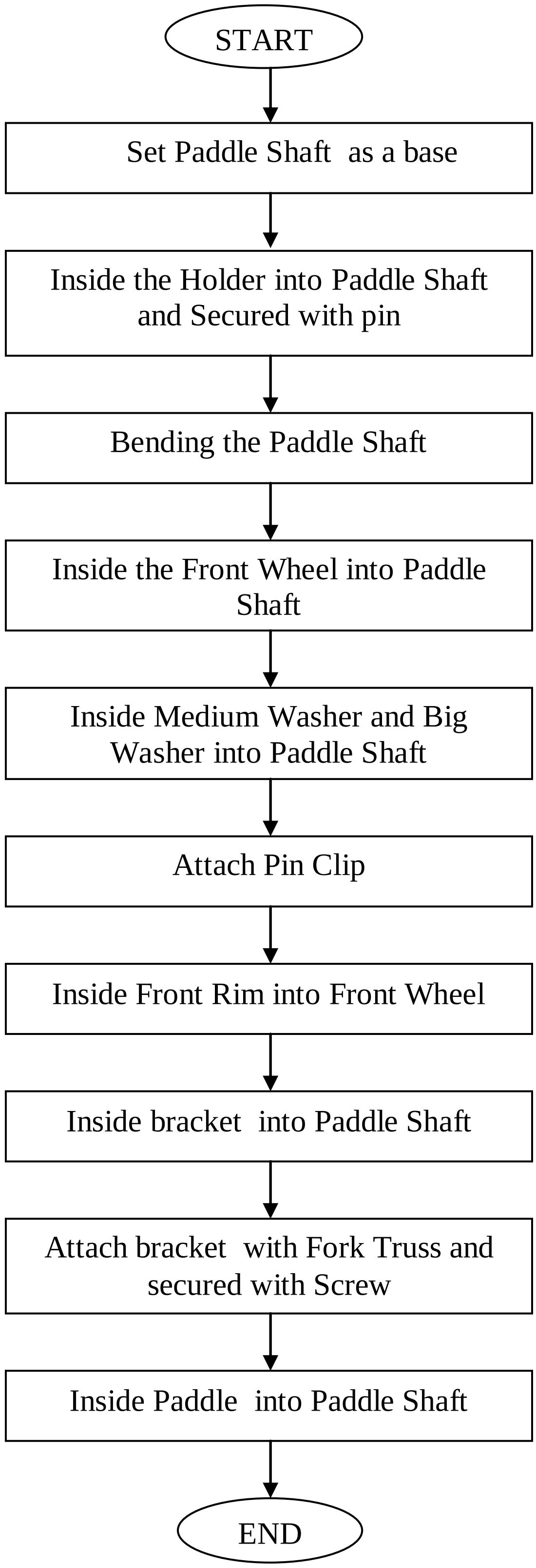


Figure 4.5: Front Wheel Assembly operation sequence for current design

4.7.4 Rear Assembly

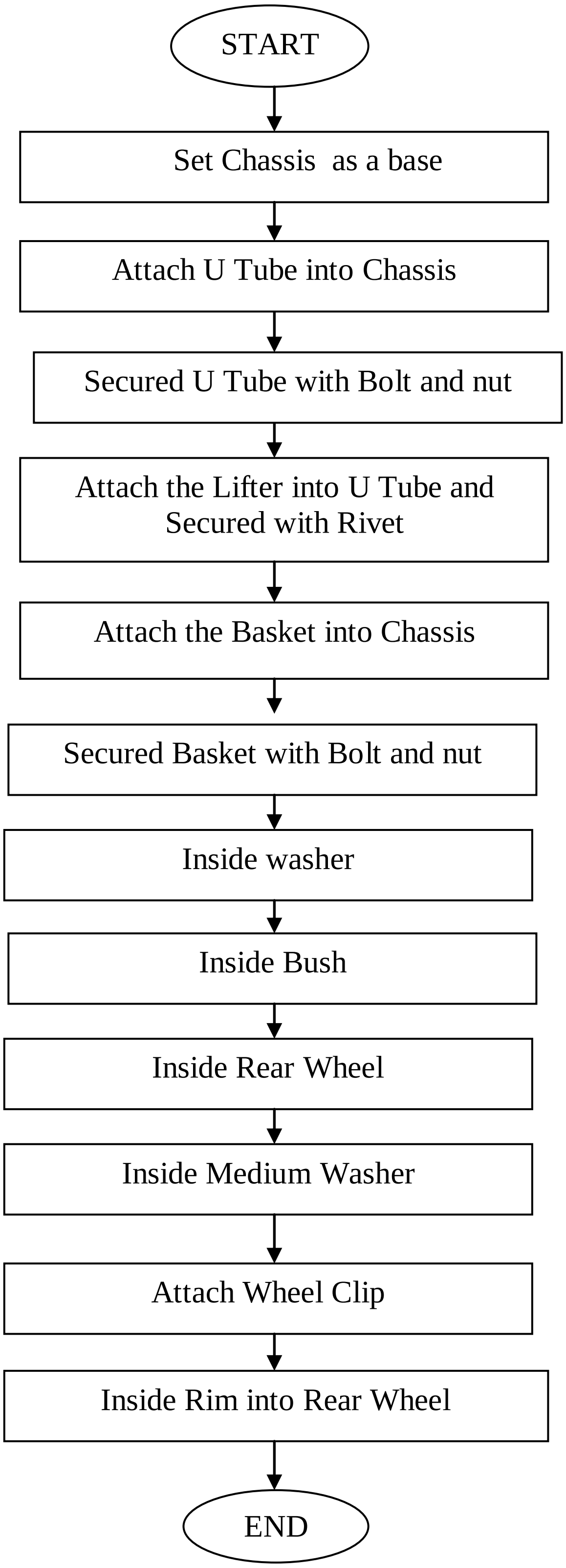


Figure 4.6: Rear Assembly operation sequence for current design

4.7.5 Main Assembly

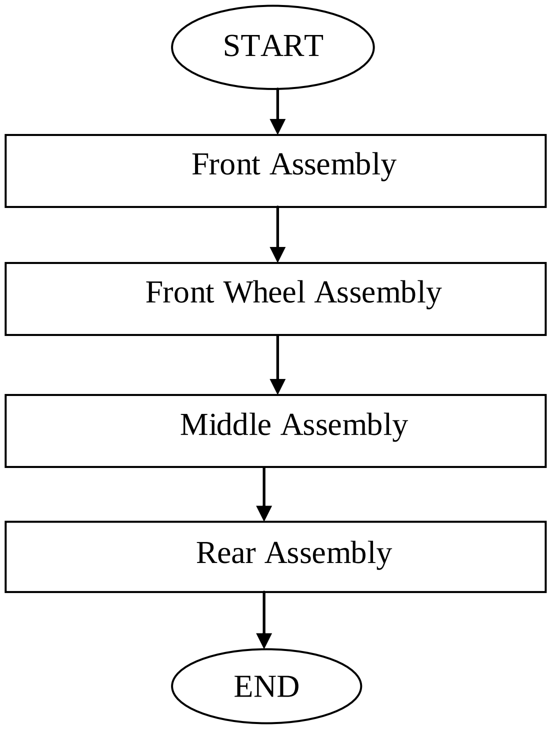


Figure 4.7: Main Assembly operation sequence for current design

4.8 APPLICATION OF HITACHI ASSEMBLABILITY EVALUATION METHOD (AEM) ON CURRENT PRODUCT

In order to perform Hitachi Assemblability Evaluation Method of the product, the product mush be disassembled and the part of the product are counted. The Operation, AEM evaluation score and penalty score for each subassembly are show in table 4.40 until table 4.48.

4.8.1 Middle Assembly

Table 4.40: Current Middle Assembly Hitachi Worksheet A

Part			Number of Operation (m)	Summations Method			
Name	**Count (n)**	**Operation**		**Total Pen (∑Penalty**	**M= 100 + ∑Penalty**	**T=M*n (+15% add op)**	**T*n**
Chassis	1	Base	1	0	100	100	100
Seat	1	Down , F	2	40	140	161	161
Seat Nut	2	Horizontal, f	2	40	140	161	322
Seat Bolt	2	Horizontal, Turn	2	50	150	172.5	345
Seat Cover	1	Down. F	2	40	140	161	161
Screw Seat Cover	6	Up , Turn	2	60	160	184	1104
					∑ T*n = 2193		
					Assembly Time = 21.93Tdown		
					Assembly Efficiency =59.27%		

$$\text{Assembly Time } = \frac{\sum \mathbf{T} * \mathbf{n}}{100}$$

= 2193/100

= 21.93 Tdown

$$\text{Assembly Efficiency } = \frac{1300}{2193} x\ 100 = 59.27\%$$

Table 4.41: Current Middle Assembly Hitachi Worksheet B

No.	Part Name	Part Evaluation Score, E	Assembly Cost, C (RM)	Assembly Time (s)
1	Chassis	100	0.0500	6.00
2	Seat	60	0.1167	14.00
3	Seat Nut	88	0.0700	8.40
4	Seat Bolt	30	0.1667	20.00
5	Seat Cover	60	0.1167	14.00
6	Screw Seat Cover	20	0.1833	22.00
		∑E= 358	∑C= 0.7034	∑Assy.time=181.2

$$\text{Middle Assemble AEM Score, E } = \frac{\sum \text{Part AEM score E}}{\sum \text{No of part}}$$

= 358/6

= 59.66

4.8.2 Front Assembly

Table 4.42: Current Front Assembly Hitachi Worksheet A

Part			No of Operation (m)	Summations Method			
Name	**Count (n)**	**Operation**		**Total Penalty (∑Penalty)**	**M= 100 + ∑Penalty**	**T=M*n (+15% add op)**	**T*n**
Chassis	1	Base	1	0	100	100	100
Top Cap Fork	1	Down	1	0	100	100	100
Back Cap Fork	1	Up	1	30	130	149.5	149.5
Fork Truss	1	Horizontal,	1	20	120	138	138
Pin	1	Down, f	2	20	120	138	138
Click	1	Horizontal	1	20	120	138	138
Front Cover	1	Horizontal, F	2	60	160	184	184
Screw Front Cover	2	Horizontal, Turn	2	50	150	172.5	345
Tricycle Dashboard	1	Down, F	2	60	160	184	184
Side Mirror	2	Down, f	2	20	120	138	276
Screw Dashboard	2	Down, Turn	2	30	130	149.5	299
Horn	1	Down	1	0	100	100	100
Hand Gripped	2	Horizontal	1	20	120	138	276
					∑ T*n = 2427.5		
					Assembly Time = 24.28Tdown		
					Assembly Efficiency =70%		

$$\text{Assembly Time} = \frac{\sum \mathbf{T} * \mathbf{n}}{100}$$

= 2427.5/100

= 24.28 Tdown

$$\text{Assembly Efficiency} = \frac{1700}{2428.5} x\ 100 = 70.00\%$$

Table 4.43: Current Front Assembly Hitachi Worksheet B

No.	Part Name	Part Evaluation Score, E	Assembly Cost, C (RM)	Assembly Time (s)
1	Chassis	100	0.0500	6.00
2	Top Cap Fork	100	0.0500	6.00
3	Back Cap Fork	60	0.1167	14.00
4	Fork Trus	80	0.0833	10.00
5	Pin	98	0.0533	6.40
6	Click	80	0.0833	10.00
7	Front Cover	50	0.1333	16.00
8	Screw Front Cover	30	0.1667	20.00
9	Tricycle Dashboard	60	0.1167	14.00
10	Side Mirror	98	0.0533	6.40
11	Screw Dashboard	40	0.1500	18.00
12	Horn	100	0.0500	6.00
13	Hand Gripped	80	0.0833	10.00
		∑E= 976	∑C= 1.1899	∑Assy.time=142.8

$$\text{Front Assemble AEM Score, E} = \frac{\sum \text{Part AEM score E}}{\sum \text{No of part}}$$

= 976/13

= 75.08

4.8.3 Rear Assembly

Table 4.44: Current Rear Assembly Hitachi Worksheet A

Name	Part Count (n)	Operation	No of Operation (m)	Summations Method Total Penalty (∑Penalty)	M= 100 + ∑Penalty	T=M*n (+15% add op)	T*n
Chassis	1	Base	1	0	100	100	100
U Tube	1	Down, F	2	40	140	161	161
Nut U Tube	2	Horizontal, f	2	40	140	161	322
Screw U Tube	2	Horizontal, Turn	2	50	150	172.5	345
Lifter	1	C	1	40	140	161	161
Basket	1	Down, F	2	40	140	161	161
Basket Nut	3	Up, f	2	50	150	172.5	517.5
Basket Screw	3	Down, Turn	2	30	130	149.5	448.5
Big Washer	2	Horizontal	1	20	120	138	276
Bush	2	Horizontal	1	20	120	138	276
Rear Wheel	2	Horizontal	1	20	120	138	276
Medium Washer	2	Horizontal	1	20	120	138	276
Wheel Clip	2	Down	1	0	100	100	200
Rim	2	Horizontal	1	20	120	138	276
					∑ T*n = 3796		
					Assembly Time= 37.96Tdown		
					Assembly Efficiency =68.49%		

$$\text{Assembly Time } = \frac{\sum \mathbf{T} * \mathbf{n}}{100}$$

= 3796/100

= 37.96 Tdown

$$\text{Assembly Efficiency } = \frac{2600}{3796} x\ 100 = 68.49\%$$

Table 4.45: Current Rear Assembly Hitachi Worksheet B

No.	Part Name	Part Evaluation Score, E	Assembly Cost, C (RM)	Assembly Time (s)
1	Chassis	100	0.0500	6.00
2	U Tube	60	0.1167	14.00
3	Nut U Tube	88	0.0700	8.00
4	Screw U Tube	30	0.1667	20.00
5	Lifter	30	0.1667	20.00
6	Basket	60	0.1167	14.00
7	Basket Nut	78	0.0867	10.00
8	Basket Screw	40	0.1500	18.00
9	Bush	80	0.0833	10.00
10	Rear Wheel	80	0.0833	10.00
11	Medium Washer	80	0.0833	10.00
12	Wheel Clip	100	0.0500	6.00
13	Rim	80	0.0833	10.00
		∑E= 906	∑C= 1.14	∑Assy.time=156

$$\text{Rear Assemble AEM Score, E } = \frac{\sum \text{Part AEM score E}}{\sum \text{No of part}}$$

=906/13

= 69.69

4.8.4 Front Wheel Assembly

Table 4.46: Current Front Wheel Assembly Hitachi Worksheet A

Part			No of Operation (m)	Summations Method			
Name	**Count (n)**	**Operation**		**Total Penalty (∑Penalty)**	**M= 100 - ∑Penalty**	**T=M*n (+15% add op)**	**T*n**
Paddle Shaft	1	Base, P	2	20	120	138	138
Holder	1	Horizontal, f	2	40	140	161	161
Pin Holder	1	Down	1	0	100	100	100
Front Wheel	1	Horizontal	1	20	120	138	138
Big Washer	2	Horizontal	1	20	120	138	276
Medium Washer	2	Horizontal	1	20	120	138	276
Wheel Clip	2	Down,	1	0	100	100	200
Front Rim	2	Horizontal,	1	20	120	138	276
Bracket	2	Horizontal, f	2	40	140	161	322
Fork Truss	1	Down. F	2	40	140	161	161
Screw Bracket	2	Horizontal, Turn	2	50	150	172.5	345
Paddle	2	Horizontal.	1	20	120	138	276
					∑ **T*n** = 2669		
					Assembly Time = 26.69Tdown		
					Assembly Efficiency =71.18%		

$$\text{Assembly Time} = \frac{\sum \mathbf{T} * \mathbf{n}}{100}$$

= 2669/100

= 26.69 Tdown

$$\text{Assembly Efficiency} = \frac{1900}{2669} x\ 100 = 71.18\%$$

Table 4.47: Current Front Wheel Assembly Hitachi Worksheet B

No.	Part Name	Part Evaluation Score, E	Assembly Cost, C (RM)	Assembly Time (s)
1	Paddle Shaft	-10	0.2333	28.00
2	Holder	88	0.0700	8.40
3	Pin Holder	100	0.0500	6.00
4	Front Wheel	80	0.0833	10.00
5	Big Washer	80	0.0833	10.00
6	Medium Washer	80	0.0833	10.00
7	Wheel Clip	100	0.0500	6.00
8	Front Rim	80	0.0833	10.00
9	Bracket	88	0.0700	8.40
10	Fork Truss	60	0.1167	14.00
11	Screw Bracket	30	0.1667	20.00
12	Paddle	80	0.0833	10.00
		∑E= 856	∑C= 1.1732	∑Assy.time=140.8

$$\text{Front Wheel Assemble AEM Score, E} = \frac{\sum \text{Part AEM score E}}{\sum \text{No of part}}$$

= 856/12

= 71.33

4.8.5 Main Assembly

Table 4.48: Current main Assembly Hitachi Worksheet

No	Name Subassembly	Subassembly Evaluation Score, E	Subassembly Cost, C (RM)	Subassembly Assembly Time (s)	Assembly Efficiency
1	Middle	59.66	0.7036	181.2	59.27%
2	Front	75.08	1.1899	142.8	70%
3	Rear	69.69	1.1400	156	68.49%
4	Front Wheel	71.33	1.1732	140.8	71.18%
		∑E= 275.76	∑C= 4.21	∑Assy.time=620.8	67,24%

$$\text{Product AEM Score, E} = \frac{\sum \text{Part AEM score E}}{\sum \text{No of part}}$$

= 275.76/4

= 68.94

So, the estimation of total product assembled in one hour for designs are calculated below

1 Hour = 60 min,

Total Assembly Time = 620.8 Sec

= 10.35min

So one hour produced =60/10.35 min

= 5.8 product/hr

= 5 product/hr

4.9 APPLICATION OF BOOTHROYD DEWHURST ON CURRENT PRODUCT

In order to perform Boothroyd Dewhurst of the product, the product mush be disassembled and the part of the product are counted. This current design analysis is very important to obtain the DFA suggestion on part elimination and improved design. The analysis data are calculated and arranged in a table or DFA Worksheet

Estimation of Assembly Cost for the current design

Costing Assumption:

Labor Cost per Month	= RM 700
Working Day per Week	= 5 days
Working Hour per Day	= 8 hours
Working Hour per Month	= 160 hours
Labor Cost per Hour	= RM 4.375
Labor Cost per Second	= RM 0.001215

Table 4.49 until table 4.58 shows a complete worksheets manual analysis and software analysis for every subassembly

4.9.1 Middle Assembly

4.9.1.1 Manual Analysis

Table 4.49: Current Middle Assembly Boothroyd Dewhurst Worksheet

		C1	C2	C3	C4	C5	C6	C7	C8	C9	Name of Asembly
A	**B**	**Part ID**	**No of operation**	**Handling code**	**Handling time**	**Insertion code**	**Insertion time**	**Operation time = (C2)(C4+C6)**	**Operation cost = RM0.001215 (C7)**	**theoretical minimum part**	**Children Tricycle**
0	0	1	1	00	1.13	00	1.5	2.63	0.003	1	**Chassis**
360	360	2	1	30	1.95	06	5.5	7.45	0.009	1	**Seat**
0	360	3	2	11	1.80	06	5.5	14.6	0.018	1	**Seat Nut**
0	360	4	2	10	1.50	49	10.5	24.0	0.029	1	**Seat Bolt**
360	360	5	1	33	2.51	30	2	4.51	0.005	0	**Seat Cover**
360	0	6	6	11	1.80	38	6	46.8	0.057	0	**Screw Seat Cover**
								99.99	0.12	4	**Design efficiency**
								TM	CM	NM	**= 12%**

$$\text{Design Efficiency} = \frac{3 \times NM}{TM} \times 100\ \%$$

$$= \frac{3 \times 4}{99.99} \times 100\ \%$$

$$= 12.00\ \%$$

4.9.1.2 Software DFM Concurrent Costing

The following is the result of the Design for Assembly analysis. The details result can be referred to the Table Appendix B1:

Table 4.50: Current Middle Assembly Software DFA

Number of parts:	**13**
Number of different entries	6
Theoretical minimum number of items:	4
DFA index:	11.1
Total assembly cost	0.13
Total assembly labor time, s	105.21

4.9.2 Front Assembly

4.9.2.1 Manual

Table 4.51: Current Front Assembly Boothroyd Dewhurst Worksheet

		C1	C2	C3	C4	C5	C6	C7	C8	C9	Name of Assembly
α	**B**	**Part ID**	**No of operation**	**Manual handling code**	**Manual handling time**	**Manual insertion code**	**Manual insertion time**	**Operation time = (C2)(C4+C6)**	**Operation cost = RM0.001215 (C7)**	**Estimation for theoretical minimum**	**Children Tricycle**
0	0	1	1	00	1.13	00	1.5	2.63	0.003	1	Chassis
0	360	2	1	10	1.50	30	2	3.5	0.004	1	Top Cap Fork
0	360	3	1	10	1.50	30	2	3.5	0.004	1	Back Cap Fork
360	360	4	1	30	1.95	06	5.5	7.45	0.009	1	Fork Truss
360	0	5	1	10	1.50	30	2	3.5	0.004	1	Pin
180	360	6	1	20	1.80	30	2	3.8	0.005	1	Click
360	360	7	1	33	2.51	06	5.5	8.01	0.010	1	Front Cover
0	360	8	2	11	1.80	38	6	15.6	0.019	0	Screw Front Cover
360	360	9	1	33	2.51	06	5.5	8.01	0.010	1	Tricycle Dashboard
360	360	10	2	30	1.95	06	5.5	14.9	0.018	1	Side Mirror
360	0	11	2	10	1.50	38	6	15.0	0.018	1	Screw Dashboard
360	0	12	1	10	1.5	31	5	6.5	0.008	1	Horn
0	360	13	2	10	1.5	31	5	13.0	0.016	1	Hand Gripped
								105.4	0.128	11	Design efficiency =
								TM	CM	NM	31.3%

Design Efficiency

$$= \frac{3 \times NM}{TM} \times 100\ \%$$

$$= \frac{3 \times 11}{105.4} \times 100\ \%$$

$$= 31.3\ \%$$

4.9.2.2 Software DFM Concurrent Costing

The following is the result of the Design for Assembly analysis. The details result can be referred to the Table Appendix B2:

Table 4.52: Current Front Assembly Software DFA

Number of parts:	**17**
Number of different entries	13
Theoretical minimum number of items:	11
DFA index:	24
Total assembly cost	0.16
Total assembly labor time, s	134.41

4.9.3 Rear Assembly

4.9.3.1 Manual

Table 4.53: Current Rear Assembly Boothroyd Dewhurst Worksheet

		C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**Name of Asembly**
A	**B**	**Part ID**	**No of operation**	**Manual handling code**	**Manual handling time**	**Manual insertion code**	**Manual insertion time**	**Operation time = (C2)(C4+C6)**	**Operation cost = RM0.001215 (C7)**	**Estimation for theoretical minimum**	**Children Tricycle**
0	0	1	1	00	1.13	00	1.5	2.63	0.003	1	Chassis
360	180	2	1	20	1.80	06	5.5	7.3	0.009	0	U Tube
360	0	3	2	11	1.80	06	5.5	14.6	0.018	0	Nut U Tube
0	360	4	2	10	1.50	38	8	19	0.023	0	Screw U Tube
360	360	5	1	30	1.95	35	7	8.95	0.011	1	Lifter
360	360	6	1	30	1.95	06	5.5	10.725	0.013	1	Basket
360	0	7	3	11	1.80	06	5.5	21.9	0.027	0	Basket Nut
360	0	8	3	10	1.50	08	6	22.5	0.027	0	Basket Screw
0	180	9	2	00	1.13	06	5.5	13.26	0.016	1	Bush
0	360	10	2	10	1.50	06	5.5	14	0.017	1	Rear Wheel
0	180	11	2	03	1.69	06	5.5	14.38	0.017	1	Medium Washer
360	180	12	2	23	2.36	30	2	8.72	0.011	1	Wheel Clip
90	360	13	2	13	2.06	30	3.02	8.72	0.011	1	Rim
								166.085	0.225	8	Design efficiency = 14.5%
								TM	CM	NM	

Design Efficiency

$$= \frac{3 \times NM}{TM} \times 100\ \%$$

$$= \frac{3 \times 8}{166.085} \times 100\ \%$$

$$= 14.5\ \%$$

4.9.3.2 Software DFM Concurrent Costing

The following is the result of the Design for Assembly analysis. The details result can be referred to the Table Appendix B3:

Table 4.54: Current Rear Assembly Software DFA

Number of parts:	**24**
Number of different entries	13
Theoretical minimum number of items:	8
DFA index:	14
Total assembly cost	0.21
Total assembly labor time, s	169.91

4.9.4 Front Wheel Assembly

4.9.4.1 Manual

Table 4.55: Current Front Wheel Assembly Boothroyd Dewhurst Worksheet

		C1	C2	C3	C4	C5	C6	C7	C8	C9	Name of Asembly
α	**B**	**Part ID**	**No of operation**	**Manual handling**	**Manual handling**	**Manual insertion**	**Manual insertion**	**Operation time = (C2)(C4+C6)**	**Operation cost = RM0.001215 (C7)**	**Estimation for theoretical minimum**	**Children Tricycle**
0	0	1	1	00	1.13	00	1.5	2.630	0.003	1	Paddle Shaft
90	180	2	1	00	1.13	06	5.5	6.630	0.008	1	Holder
180	0	3	1	01	1.43	31	5	6.430	0.008	1	Pin Holder
-	-	-	-	-	-	90	4	4.000	0.005	-	Paddle Shaft (Dummy)
0	180	4	1	00	1.13	07	6.5	7.630	0.009	1	Front Wheel
0	180	5	2	03	1,69	06	5.5	14.380	0.017	0	Big Washer
0	180	6	2	03	1.69	06	5.5	14.380	0.017	1	Medium Washer
360	180	7	2	23	2.36	30	2	8.720	0.011	1	Wheel Clip
90	360	8	2	13	2.06	30	2	8.120	0.010	1	Front Rim
360	360	9	2	30	1.95	06	5.5	14.900	0.018	1	Bracket
360	360	10	1	30	1.95	06	5.5	7.450	0.009	1	Fork Truss
0	360	11	2	11	1.80	38	6	15.600	0.019	1	Screw Bracket
0	360	12	2	10	1.50	31	5	13.000	0.016	1	Paddle
								123.87	0.15	11	Design efficiency
								TM	CM	NM	= 26.6

Design Efficiency

$$= \frac{3 \times NM}{TM} \times 100\ \%$$

$$= \frac{3 \times 11}{123.87} \times 100\ \%$$

$$= 26.6\ \%$$

4.9.4.2 Software DFM Concurrent Costing

The following is the result of the Design for Assembly analysis. The details result can be referred to the Table Appendix B4 :

Table 4.56: Current Front Wheel Assembly Software DFA

Number of parts:	**19**
Number of different entries	12
Theoretical minimum number of items:	11
DFA index:	28.4
Total assembly cost	0.16
Total assembly labor time, s	113.29

4.9.5 Main Assembly

4.9.5.1 Manual

Table 4.57: Current Main Assembly Boothroyd Dewhurst Worksheet

No	Name Subassembly	Subassembly Cost, C (RM)	Subassembly Assembly Time (s)	Assembly Efficiency (%)
1	Middle	0.120	99.990	12
2	Front	0.128	105.400	31.3
3	Rear	0.225	166.085	14.45
4	Front Wheel	0.150	123.870	26.6
		∑C= 0.623	∑Assy.time=495.345	21.08

So, the estimation of total product assembled in one hour for designs are calculated below

1 Hour = 60 min,

Total Assembly Time = 495.345 Sec

= 8.257 min

So one hour produced =60/8.257 min

= 7.266 product/hr

= 7 product/hr

4.9.5.2 Software DFM Concurrent Costing

Table 4.58: Current Main Assembly Software DFM

No	Name Subassembly	Subassembly Cost, C (RM)	Subassembly Assembly Time (s)	Assembly Efficiency (%)
1	Middle	0.13	105.21	11.1
2	Front	0.16	134.41	24
3	Rear	0.21	169.91	14
4	Front Wheel	0.14	113.29	28.4
		∑C= 0.64	∑Assy.time=522.82	19.375

So, the estimation of total product assembled in one hour for designs are calculated below

1 Hour = 60 min,

Total Assembly Time = 522.82 Sec

= 8.714 min

So one hour produced =60/8.714 min

= 6.885 product/hr

= 6 product/hr

4.10 SUGGESTION OF IMPROVEMENT ON CURRENT CHILDREN TRICYCLE

Based on Boothroyd Dewhurst and Hitachi AEM evaluation that has been done, the improvement suggestions of design changes of children tricycle are proposed. Table 4.59 show a description weak point and the suggestion of improvement.

Table 4.59: Suggestion Improvement

Assembly	**Part Name**	**AEM Score**	**Description weak point**	**Suggestion of improvement design**
middle	Seat Cover	60	The part related with screw seat cover and need to fasten	This part not essential part and can be eliminated or combine with seat
middle	Screw Seat Cover	20	This part has a low AEM score due the too many sequence of assembly operation. Where 6 screw are needed to fasten seat cover	This part can be eliminated by combining the seat cover with seat
Front	Screw Front Cover	30	This part has low AEM score. Where 2 screw are needed to fasten Front Cover	Eliminated two screw and change the screw with the snap fit
Rear	U Tube	60	This part related with screw and nut U Tube	This part can be combining with Chassis because no need to separated for assembly or service follow theory minimum number.

Rear	Nut U Tube	88	This part related with U Tube and Screw U tube where 2 nut needed to fasten the U tube	This part can be eliminated after U Tube combine with Chassis
Rear	Screw U Tube	30	This part related with U Tube and Nut U tube where 2 Screw needed to fasten the U tube	This part can be eliminated after U Tube combine with Chassis
Rear	Basket Nut	78	This part related with Basket and Basket Screw where 3 nut needed to fasten the Basket	Eliminate three nut and change the fasten with the snap fit or press fit
Rear	Basket Screw	40	This part related with Basket and Basket Nut where 3 Screw needed to fasten the Basket	Eliminate three Screw and change the fasten with the snap fit or press fit
Rear	Rear Rim	80	This part design easy to collide with wheel clip	This part can be change follow front rim design for standardize part designs.
Front Wheel	Big Washer	80	This part has high AEM score but same function with medium washer	This part can be changed with medium washer to standardize part designs to reduce theory minimum number

4.11. PRODUCT TREE FOR IMPROVEMENT DESIGN

Figure 4.8 shows the children tricycle product tree for improvement design. The product tree is divided into 4 major sub-assemblies, which are Front Assembly, Middle Assembly, Rear Assembly, Front Wheel Assembly and combine all subassembly into Main Assembly

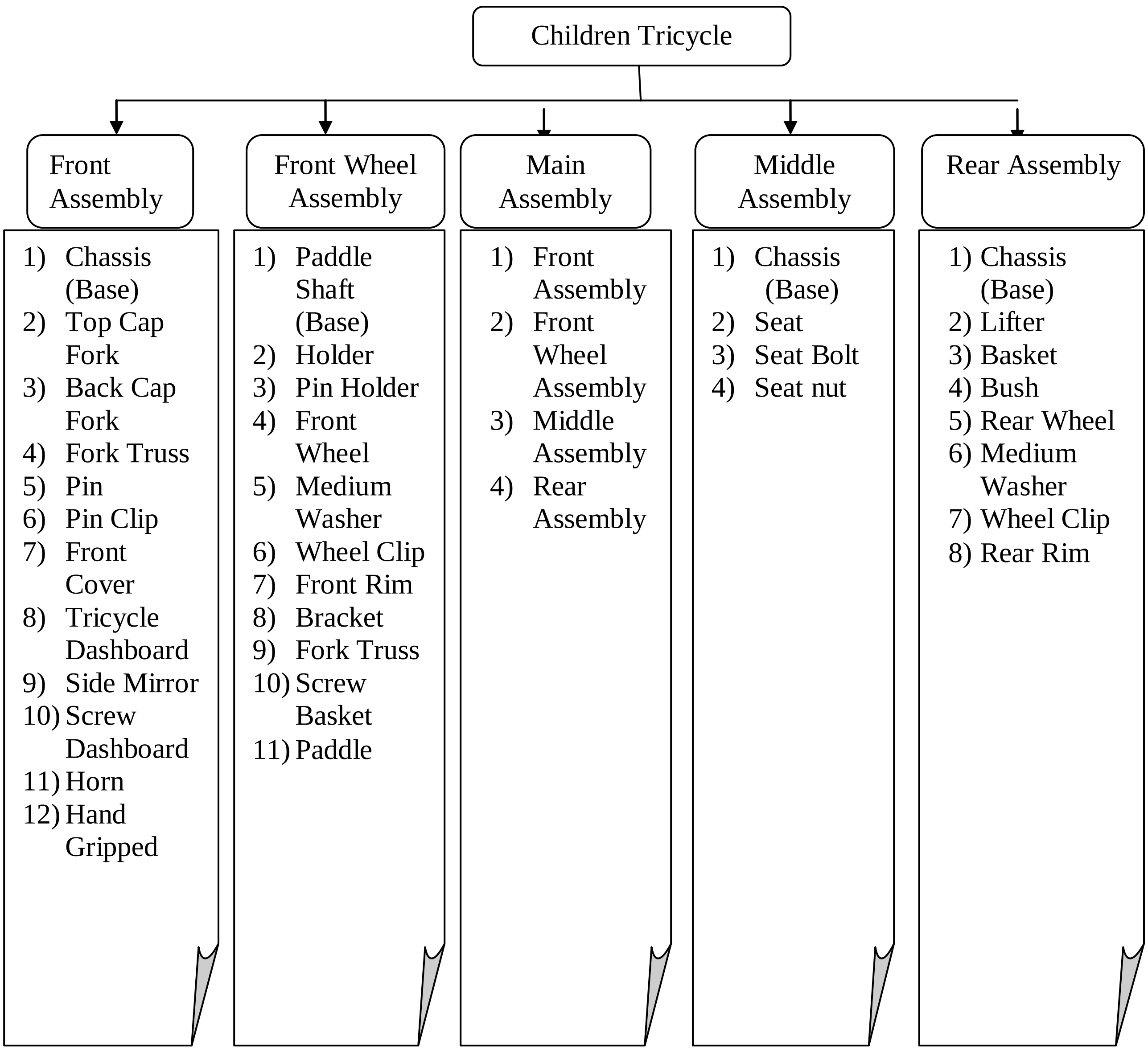


Figure 4.8: Children tricycle product tree for improvement design

4.12. PRODUCT ASSEMBLY OPERATION SEQUENCE FOR IMPROVEMENT DESIGN

The product assembly operation sequence for improvement design must be identified by using application Hitachi Assemnblability Evaluation Method and Boothroyd Dewhurst DFA Method in order to perform a new analysis to get the data. Figure 4.9 until figure 4.13 representing assembly operation sequence for every subassembly for improvement design.

4.12.1. Middle Assembly

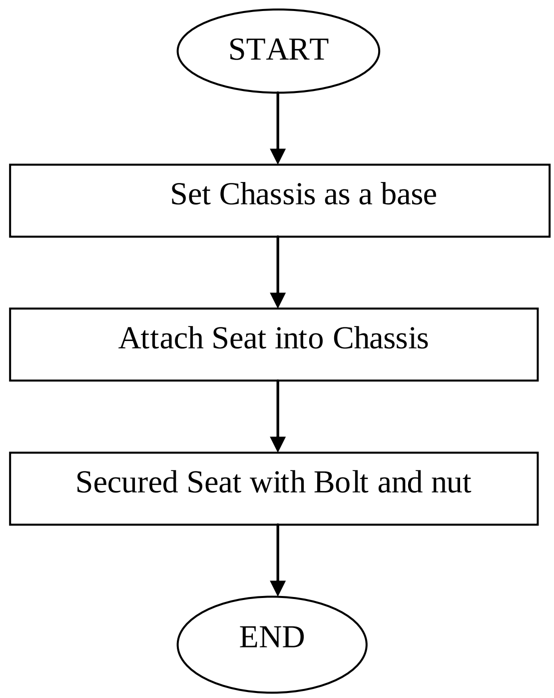


Figure 4.9: Middle redesign assembly operation sequence for improvement design

4.12.2. Front Assembly

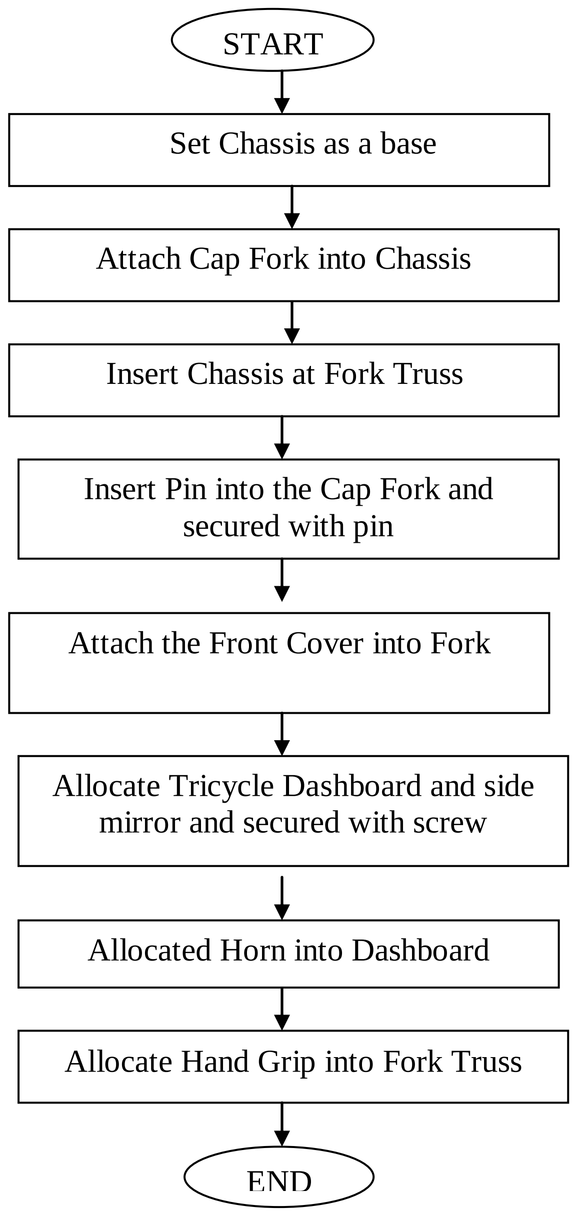


Figure 410: Front redesign assembly operation sequence for improvement design

4.12.3. Front wheel Assembly

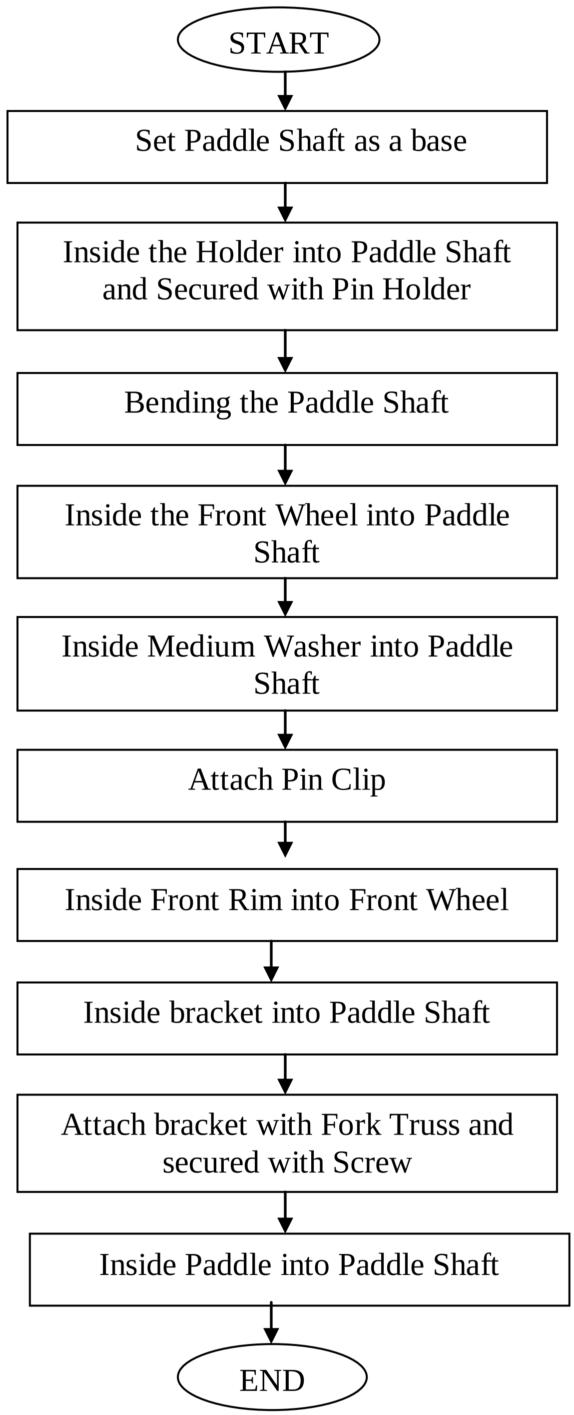


Figure 4.11: Front Wheel redesign assembly operation sequence for improvement design

4.12.4. Rear Assembly

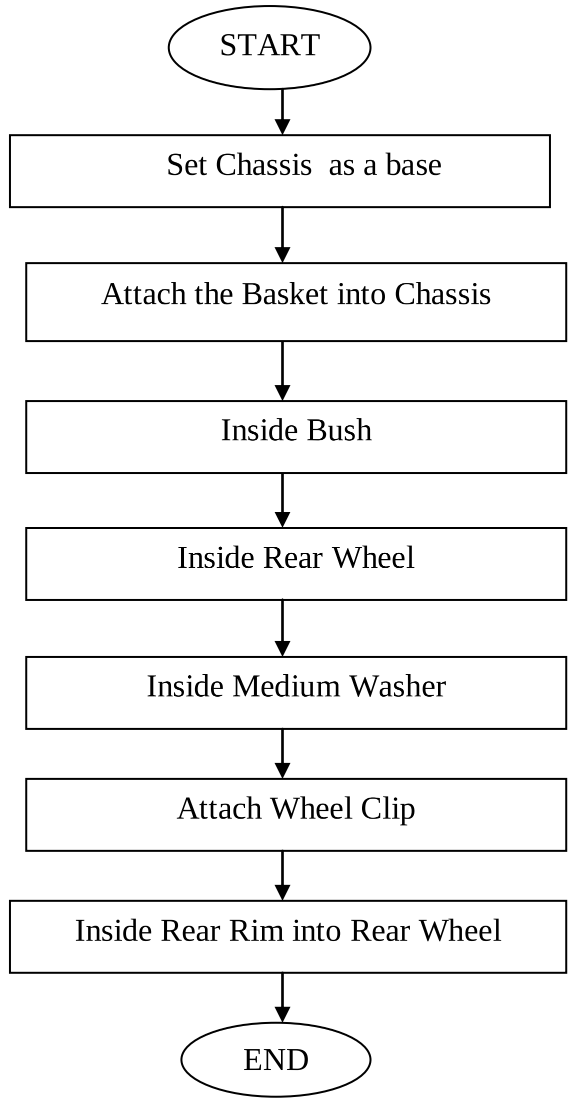


Figure 4.12: Rear redesign assembly operation sequence for improvement design

4.12.5. Main Assembly

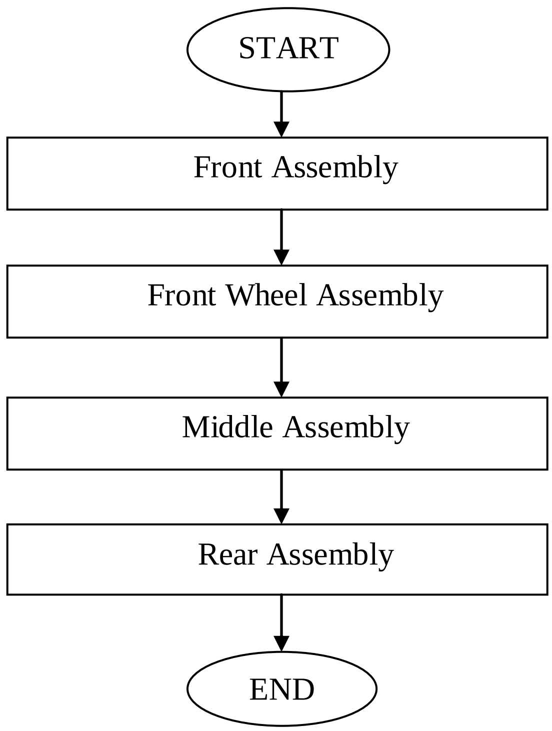


Figure 4.13: Main redesign assembly operation sequence for improvement design

APPLICATION OF HITACHI ASSEMBLABILITY EVALUATION METHOD (AEM) ON IMPROVEMENT PRODUCT

Based on suggestion of improvement, evaluate once again so that comparison score can be made between current design and improvement design. The results of penalty score for improvement design are shows in the table 4.60 until table 4.68

4.13.1 Middle Assembly

Table 4.60: Improvement Design Middle Assembly Hitachi Worksheet A

Part			No of	Summations Method			
Name	**Count (n)**	**Operation**	**Operation (m)**	**Total Penalty (∑Penalty)**	**M= 100 + ∑Penalty**	**T=M*n (+15% add op)**	**T*n**
Chassis	1	Base	1	0	100	100	100
Seat	1	Down , F	2	40	140	161	161
Seat Nut	2	Horizontal, f	2	40	140	161	322
Seat Bolt	2	Horizontal , Turn	2	50	150	172.5	345
					∑ T*n = 928		
					Assembly Time = 9.28Tdown		
					Assembly Efficiency =64.66%		

$$\text{Assembly Time } = \frac{\sum \mathbf{T} * \mathbf{n}}{100}$$

= 928/100

= 9.28 Tdown

$$\text{Assembly Efficiency } = \frac{600}{928} x\ 100 = 64.65\%$$

Table 4.61: Improvement Design Middle Assembly Hitachi Worksheet B

No.	Part Name	Part Evaluation Score, E	Assembly Cost, C (RM)	Assembly Time (s)
1	Chassis	100	0.0500	6.00
2	Seat	60	0.1167	14.00
3	Seat Nut	88	0.0700	8.40
4	Seat Bolt	30	0.1667	20.00
		∑E= 278	∑C= 0.4034	∑Assy.time=48.4

$$\text{Middle Assemble AEM Score, E } = \frac{\sum \text{Part AEM score E}}{\sum \text{No of part}}$$

= 278/4

= 69.5

4.13.2 Front Assembly

Table 4.62: Improvement Design Front Assembly Hitachi Worksheet A

Part			No of Operation (m)	Summations Method			
Name	**Count (n)**	**Operation**		**Total Penalty (∑Penalty)**	**M= 100 + ∑Penalty**	**T=M*n (+15% add op)**	**T*n**
Chassis	1	Base	1	0	100	100	100
Top Cap Fork	1	down	1	0	100	100	100
Back cap Fork	1	up	1	30	130	149.5	149.5
Fork Truss	1	Horizontal	1	20	120	138	138
Pin	1	Down, f	2	20	120	138	138
Click	1	Horizontal	1	20	120	138	138
Front Cover	1	Horizontal	2	20	120	138	138
Tricycle Dashboard	1	Down, F	2	60	160	184	184
Side Mirror	2	Down, f	2	20	120	138	276
Screw Dashboard	2	Down, Turn	2	30	130	149.5	299
Horn	1	Down	1	0	100	100	100
Hand Gripped	2	Horizontal	1	20	120	138	276
					∑ T*n = 2036.5		
					Assembly Time = 20.37Tdown		
					Assembly Efficiency =73.66%		

$$\text{Assembly Time } = \frac{\sum \mathbf{T} * \mathbf{n}}{100}$$

= 2036.5/100

= 20.37 Tdown

$$\text{Assembly Efficiency } = \frac{1500}{2036.5} x\ 100 = 73.66\%$$

Table 4.63: Improvement Design Front Assembly Hitachi Worksheet B

No.	Part Name	Part Evaluation Score, E	Assembly Cost, C (RM)	Assembly Time (s)
1	Chassis	100	0.0500	6.00
2	Top Cap Fork	100	0.0500	10.00
3	Back Cap Fork	60	0.1167	14.00
4	Fork Truss	80	0.0833	10.00
5	Pin	98	0.0533	6.40
6	Click	80	0.0833	10.00
7	Front Cover	80	0.0833	10.00
8	Tricycle Dashboard	60	0.1167	14.00
9	Side Mirror	98	0.0533	6.40
10	Screw Dashboard	40	0.1500	18.00
11	Horn	100	0.0500	6.00
12	Hand Gripped	80	0.0833	10.00
		∑E= 976	∑C= 0.9726	∑Assy.time=120.8

$$\text{Front Assemble AEM Score, E } = \frac{\sum \text{Part AEM score E}}{\sum \text{No of part}}$$

= 976/12

= 81.33

4.13.3 Rear Assembly

Table 4.64: Improvement Design Rear Assembly Hitachi Worksheet A

Part			No of Operation (m)	Summations Method			
Name	**Count (n)**	**Operation**		**Total Penalty (∑Penalty)**	**M= 100 + ∑Penalty**	**T=M*n (+15% add op)**	**T*n**
Chassis	1	Base	1	0	100	100	100
Lifter	1	C	1	40	140	161	161
Basket	1	Down,	2	0	100	100	100
Bush	2	Horizontal	1	20	120	138	276
Rear Wheel	2	Horizontal	1	20	120	138	276
Medium Washer	2	Horizontal	1	20	120	138	276
Wheel Clip	2	down	1	0	100	100	200
Rear Rim	2	Horizontal	1	20	120	138	276
					∑ T*n = 1665		
					Assembly Time= 16.65Tdown		
					Assembly Efficiency =72.20%		

$$\text{Assembly Time} = \frac{\sum \mathbf{T} * \mathbf{n}}{100}$$

= 1665/100

= 16.65Tdown

$$\text{Assembly Efficiency} = \frac{1300}{1665} x\ 100 = 78\%$$

Table 4.65: Improvement Design Rear Assembly Hitachi Worksheet B

No.	Part Name	Part Evaluation Score, E	Assembly Cost, C (RM)	Assembly Time (s)
1	Chassis	100	0.0500	6.00
2	Lifter	30	0.1667	20.00
3	Basket	100	0.0500	6.00
4	Bush	80	0.0833	10.00
5	Rear Wheel	80	0.0833	10.00
6	Medium Washer	80	0.0833	10.00
7	Wheel Clip	100	0.0500	6.00
8	Rim	80	0.0833	10.00
		∑E= 650	∑C=0.6499	∑Assy.time=78

$$\text{Rear Assemble AEM Score, E} = \frac{\sum \text{Part AEM score E}}{\sum \text{No of part}}$$

= 650/8

= 81.25

4.13.4 Front Wheel Assembly

Table 4.66: Improvement Design Front Wheel Assembly Hitachi Worksheet A

Part			No of Operation (m)	Summations Method			
Name	**Count (n)**	**Operation**		**Total Penalty (∑Penalty)**	**M= 100 + ∑Penalty**	**T=M*n (+15% add op)**	**T*n**
Paddle Shaft	1	Base, P	2	20	120	138	138
Holder	1	Horizontal, f	2	40	140	161	161
Pin Holder	1	Down	1	0	100	100	100
Front Wheel	1	Horizontal	1	20	120	138	138
Medium Washer	4	Horizontal	1	20	120	138	552
Wheel Clip	2	Down,	1	0	100	100	200
Front Rim	2	Horizontal,	1	20	120	138	276
Bracket	2	Horizontal, f	2	40	140	161	322
Fork Truss	1	Down. F	2	40	140	161	161
Screw Bracket	2	Horizontal, Turn	2	50	150	172.5	345
Paddle	2	Horizontal.	1	20	120	138	276
					∑ **T*n =** 2669		
					Assembly Time = 26.69Tdown		
					Assembly Efficiency =69.22%		

$$\text{Assembly Time} = \frac{\sum \mathbf{T} * \mathbf{n}}{100}$$

= 2669/100

= 26.69 Tdown

$$\text{Assembly Efficiency} = \frac{1900}{2669} x\, 100 = 71.18\%$$

Table 4.67: Improvement Design Front Wheel Assembly Hitachi Worksheet B

No.	**Part Name**	**Part Evaluation Score, E**	**Assembly Cost, C (RM)**	**Assembly Time (s)**
1	Paddle Shaft	-10	0.2333	28.00
2	Holder	88	0.0700	8.40
3	Pin Holder	100	0.0500	6.00
4	Front Wheel	80	0.0833	10.00
5	Medium Washer	80	0.0833	10.00
6	Wheel Clip	100	0.0500	6.00
7	Front Rim	80	0.0833	10.00
8	Bracket	88	0.0700	8.40
9	Fork Truss	60	0.1167	14.00
10	Screw Bracket	30	0.1667	20.00
11	Paddle	80	0.0833	10.00
		∑E= 776	∑C= 1.0899	∑Assy.time=130.8

$$\text{Front Wheel Subassemble AEM Score, E} = \frac{\sum \text{Part AEM score E}}{\sum \text{No of part}}$$

= 776/11

= 70.55

4.13.5 Main Assembly

Table 4.68: Improvement Design Main Assembly Hitachi Worksheet A

No	Name Subassembly	Subassembly Evaluation Score, E	Assembly Cost, C (RM)	Assembly Time (s)	Assembly Efficiency
1	Middle	69.5	0.4034	48.4	64.66%
2	Front	81.33	0.9726	120.8	73.66%
3	Rear	81.25	0.6499	78	78%
4	Front Wheel	70.55	1.0899	130.8	71.18%
		∑E= 302.63	∑C= 2.9931	∑Assy.time=378	71.875

$$\text{Product AEM Score, E} = \frac{\sum \text{Part AEM score E}}{\sum \text{No of part}}$$

= 302.63/4

= 75.66

So, the estimation of total product assembled in one hour for designs are calculated below

1 Hour = 60 min,

Total Assembly Time = 378 Sec

= 6.30 min

So one hour produced =60/6.30 min

= 9.52 product/hr

= 9 product/hr

4.13. APPLICATION OF BOOTHROYD DEWHURST ON IMPROVEMENT PRODUCT

Based on suggestion of improvement, evaluate once again so that comparison score can be made between current design and improvement design. The results of DFA index are show in table below

Estimation of Assembly Cost for the current design

Costing Assumption:

Labor Cost per Month	= RM 700
Working Day per Week	= 5 days
Working Hour per Day	= 8 hours
Working Hour per Month	= 160 hours
Labor Cost per Hour	= RM 4.375
Labor Cost per Second	= RM 0.001215

Table 4.69 until table 4.78 shows a complete worksheets manual analysis and software analysis for every subassembly improvement design.

4.14.1 Middle Assembly

4.14.1.1 Manual

Table 4.69: Improvement Middle Design Assembly Boothroyd Dewhurst Worksheet

		C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**Name of Asembly**
α	**B**	**Part ID**	**No operation**	**Handling code**	**Handling time**	**Insertion code**	**Insertion time**	**Operation time = (C2)(C4+C6)**	**Operation cost = RM0.001215**	**theoretical minimum part**	**Children Tricycle**
0	0	1	1	00	1.13	00	1.5	2.63	0.003	1	**Chassis**
360	360	2	1	30	1.95	06	5.5	7.45	0.009	1	**Seat**
0	360	3	2	11	1.80	06	5.5	14.6	0.018	1	**Seat Nut**
0	360	3	2	10	1.50	49	10	24.0	0.029	1	**Seat Bolt**
								48.69	0.140	4	**Design efficiency = 24.64%**
								TM	CM	NM	

Design Efficiency

$$= \frac{3 \times NM}{TM} \times 100\ \%$$

$$= \frac{4 \times 3}{48.69} \times 100\ \%$$

$$= 24.6\%.$$

4.14.1.2 Software DFM Concurrent Costing

The following is the result of the Design for Assembly analysis. The details result can be referred to the Table Appendix C1 :

Table 4.70: Improvement Middle Assembly Software DFA

Number of parts:	**4**
Number of different entries	3
Theoretical minimum number of items:	3
DFA index:	42.3
Total assembly cost	0.03
Total assembly labor time, s	20.78

4.14.2 Front Assembly

4.14.2.1 Manual

Table 4.71: Improvement Front Design Assembly Boothroyd Dewhurst Worksheet

		C1	C2	C3	C4	C5	C6	C7	C8	C9	Name of Asembly
α	B	Part ID	No operation	Manual handling code	Manual handling time	Manual insertion code	Manual insertion time	Operation time = (C2)(C4+C6)	Operation cost = RM0.001215 (C7)	Estimation for theoretical minimum	Children Tricycle
0	0	1	1	00	1.13	00	1.5	2.63	0.003	1	Chassis
0	360	2	1	10	1.50	30	2	3.5	0.004	1	Top Cap Fork
0	360	3	1	10	1.50	30	2	3.5	0.004	1	Back Cap Fork
360	360	4	1	30	1.95	06	5.5	7.45	0.009	1	Fork Trus
360	0	5	1	10	1.50	30	2	3.5	0.004	1	Pin
180	360	6	1	20	1.80	30	2	3.8	0.005	1	Click
360	360	7	1	33	2.51	31	5	7.51	0.009	1	Front Cover
360	360	9	1	33	2.51	06	5.5	8.01	0.010	1	Tricycle Dashboard
360	360	10	2	30	1.95	06	5.5	14.9	0.018	1	Side Mirror
360	0	11	2	10	1.50	38	6	15.0	0.018	1	Screw Dashboard
360	0	12	1	10	1.5	31	5	6.5	0.008	1	Horn
0	360	13	2	10	1.5	31	5	13.0	0.016	1	Hand Gripped
								89.3	0.108	12	Design
								TM	CM	NM	efficiency = 44.4%

Design Efficiency

$$= \frac{3 \times NM}{TM} \times 100\ \%$$

$$= \frac{3 \times 12}{74.4} \times 100\ \%$$

$$= 48.38\%.$$

4.14.2.2 Software DFM Concurrent Costing

The following is the result of the Design for Assembly analysis. The details result can be referred to the Table Appendix C2 :

Table 4.72: Improvement Front Assembly Software DFA

Number of parts:	**13**
Number of different entries	11
Theoretical minimum number of items:	11
DFA index:	48.2
Total assembly cost	0.08
Total assembly labor time, s	66.83

4.14.3 Rear Assembly

4.14.3.1 Manual

Table 4.73: Improvement Rear Design Assembly Boothroyd Dewhurst Worksheet

		C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**Name of Asembly**
α	B	Part ID	No of times the	Manual handling	Manual handling	Manual insertion	Manual insertion	Operation time = (C2)(C4+C6)	Operation cost = RM0.001215 (C7)	Estimation for	Children Tricycle
0	0	1	1	00	1.13	00	1.5	2.63	0.003	1	Chassis
360	360	5	2	30	1.95	35	7	8.95	0.011	1	Lifter
360	360	6	1	30	1.95	31	5	6.95	0.008	1	Basket
0	180	9	2	00	1.13	06	5.5	13.26	0.016	1	Bush
0	360	10	2	10	1.50	06	5.5	14	0.017	1	Rear Wheel
0	180	11	2	03	1.69	06	5.5	14.38	0.017	1	Medium Washer
360	180	12	2	23	2.36	30	2	8.72	0.011	1	Wheel Clip
90	360	13	2	13	2.06	30	3.02	8.72	0.011	1	Rear Rim
								77.61	0.094	8	Design
								TM	CM	NM	efficiency = 30.9%

Design Efficiency

$$= \frac{3 \times NM}{TM} \times 100\ \%$$

$$= \frac{3 \times 8}{77.61} \times 100\ \%$$

$$= 30.9\%$$

4.14.3.2 Software DFM Concurrent Costing

The following is the result of the Design for Assembly analysis. The details result can be referred to Table Appendix C3:

Table 4.74: Improvement Rear Assembly Software DFA

Number of parts:	**13**
Number of different entries	8
Theoretical minimum number of items:	8
DFA index:	30.8
Total assembly cost	0.09
Total assembly labor time, s	76.11

4.14.4 Front Wheel Assembly

4.14.4.1 Manual

Table 4.75: Improvement Middle Design Assembly Boothroyd Dewhurst Worksheet

		C1	C2	C3	C4	C5	C6	C7	C8	C9	Name of Asembly
α	B	Part ID	No of times the	Manual handling	Manual handling	Manual insertion	Manual insertion	Operation time = (C2)(C4+C6)	Operation cost = RM0.001215 (C7)	Estimation for	Children Tricycle
0	0	1	1	00	1.13	00	1.5	2.630	0.003	1	Paddle Shaft
90	180	2	1	00	1.13	06	5.5	6.630	0.008	1	Holder
180	0	3	1	01	1.43	31	5	6.430	0.008	1	Pin Holder
-	-	-	-	-	-	90	4	4.000	0.005	-	Paddle Shaft (Datum)
0	180	4	1	00	1.13	07	6.5	7.630	0.009	1	Front Wheel
0	180	6	4	03	1.69	06	5.5	28.76	0.034	1	Medium Washer
360	180	7	2	23	2.36	30	2	8.720	0.011	1	Wheel Clip
90	360	8	2	13	2.06	30	2	8.120	0.010	1	Front Rim
360	360	9	2	30	1.95	06	5.5	14.900	0.018	1	Bracket
360	360	10	1	30	1.95	06	5.5	7.450	0.009	1	Fork Truss
0	360	11	2	11	1.80	38	6	15.600	0.019	1	Screw Bracket
0	360	12	2	10	1.50	31	5	13.000	0.016	1	Paddle
								123.87	0.133		Design efficiency =26.69%
								TM	CM	NM	

Design Efficiency

$$= \frac{3 \times NM}{TM} \times 100\ \%$$

$$= \frac{3 \times 11}{123.87} \times 100\ \%$$

$$= 26.64\ \%$$

4.14.4.2 Software DFM Concurrent Costing

The following is the result of the Design for Assembly analysis. The details result can be referred to the Table Appendix C4 :

Table 4.76: Improvement Front Wheel Assembly Software DFA

Number of parts:	**17**
Number of different entries	11
Theoretical minimum number of items:	11
DFA index:	32.4
Total assembly cost	0.12
Total assembly labor time, s	99.51

4.14.5 Main Assembly

4.14.5.1 Manual

Table 4.77: Improvement Main Design Assembly Boothroyd Dewhurst Worksheet

No	Name Subassembly	Assembly Cost, C (RM)	Assembly Assembly Time (s)	Assembly Efficiency (%)
1	Middle	0.041	34.08	34.08
2	Front	0.108	89.3	48.4
3	Rear	0.094	30.9	30.9
4	Front Wheel	0.133	26.69	26.67
		∑C= 0.376	∑Assy.time=180.97	34.01

So, the estimation of total product assembled in one hour for designs are calculated below

1 Hour = 60 min,

Total Assembly Time = 180.97 Sec

= 3.016 min

So one hour produced =60/3.016 min

= 19.89 product/hr

= 19. product/hr

4.14.5.2 Software DFM Concurrent Costing

The following is the result of the Design for Assembly analysis. The details result can be referred to the Table Appendix:

Table 4.78: Improvement Main Assembly Software DFA

No	Name Subassembly	Assembly Cost, C (RM)	Subassembly Assembly Time (s)	Assembly Efficiency (%)
1	Middle	0.03	20.78	42.3
2	Front	0.08	66.83	48.2
3	Rear	0.09	76.11	30.8
4	Front Wheel	0.12	99.51	32.4
		∑C= 0.32	∑Assy.time=263.23	38.43

So, the estimation of total product assembled in one hour for designs are calculated below

1 Hour = 60 min,

Total Assembly Time = 263.23 Sec

= 4.387 min

So one hour produced =60/4.387 min

= 13.67 product/hr

= 13 product/hr

4.15 COMPARISON CURENT DESIGN AND IMPROVEMENT DESIGN

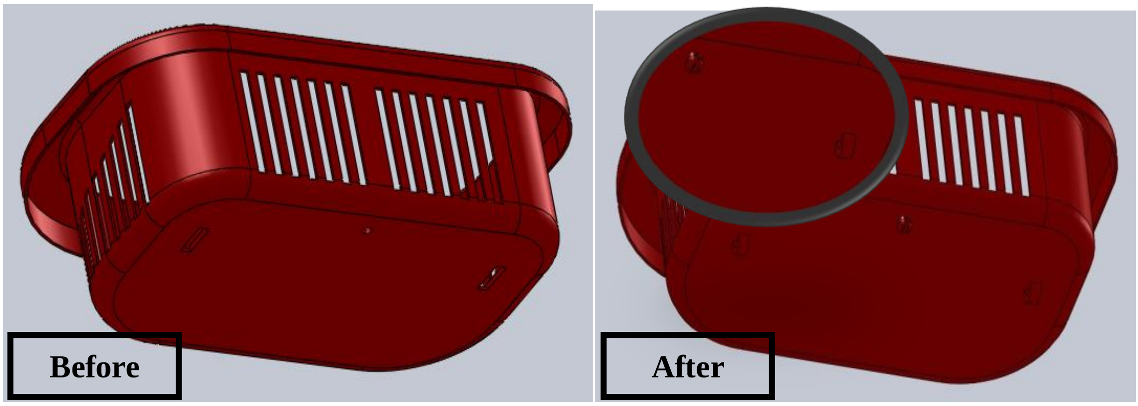


Figure 4.14 Comparison basket design,

Figure 4.14 shows a comparison between two basket designs. Before redesign the basket needed to use 3 screws and 3 nut to fasten basket into the chassis. After redesign the basket is secured with 2 hook and 1 snap fit. The basket also easier to assembly and the assembly time is reduced. The basket for after redesign no need to make hole, it can reduce manufacturing time. The disadvantages the redesign basket cannot to disassemble after assemble into chassis but the basket no need to disassemble to service and maintenance. The max estimated load can be support for the basket was 25kg

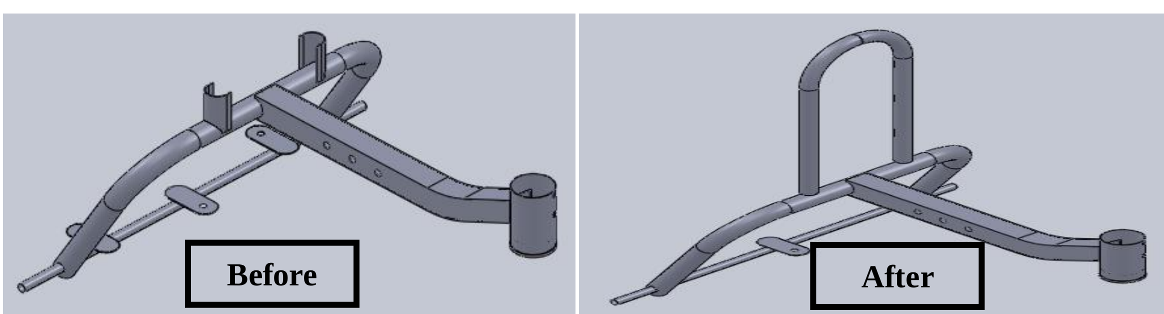


Figure 4.15 Comparison chassis design,

Figure 4.15 shows a comparison between two chassis designs. Before redesign the chassis is separated from u tube and needs to use 2 screws and 2 nuts for fasten the u tube onto chassis. U tube can be combined with the chassis because the parts are same which are made by steel and no need to be separated for service or maintenance. The redesign chassis no needed 2 supported baskets because the redesign basket have 2 hook and only needed 1 supported basket for fasten redesign basket with redesign chassis using snap fit. The advantages of redesign chassis can be help reduce assembly part and also reduce assembly time. After redesign the basket and chassis, 2 screws and 2 nuts for fasten the basket onto chassis can be eliminate because need to use. The manufacturing time also can be reduced because the welding part for complete chassis was reduced.

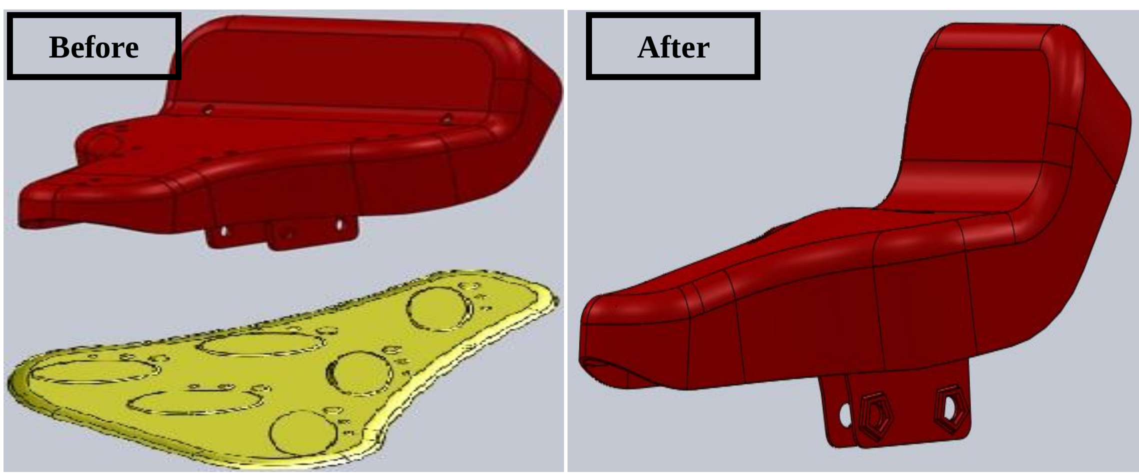


Figure 4.16 Comparison Seat design,

Figure 4.16 shows a comparison between two seat designs. Before redesign the seat separated with the seat cover and needed to use 6 screws fasten seat cover into seat. The seat cover can be combine with seat for minimize assembly part and reduce assembly time. The redesign seat also has located nut for secured the nut immediately.

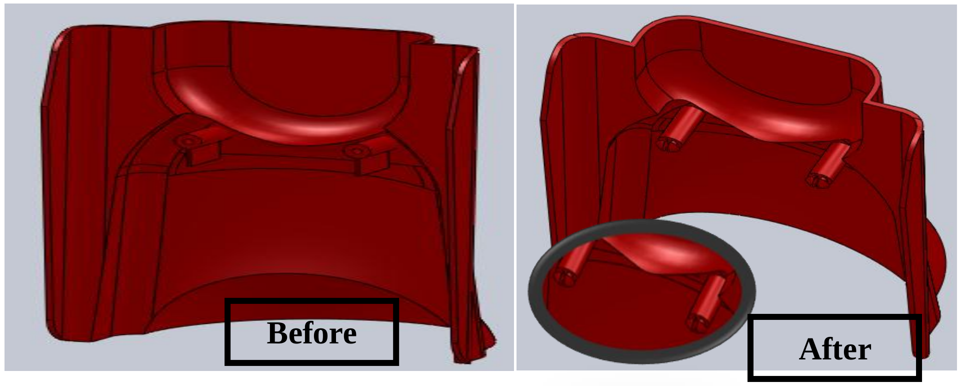


Figure 4.17 Comparison front cover design,

Figure 4.17 shows a comparison between two front cover designs. Before redesign the front cover needs to use 2 screws for fasten front cover into fork truss. 2 screws can be eliminated and change screws with the snap fit to reduce assembly time because easy to assemble. The disadvantages the redesign front cover cannot to disassemble after assemble into fork truss but the front cover no need to disassemble to service and maintenance.

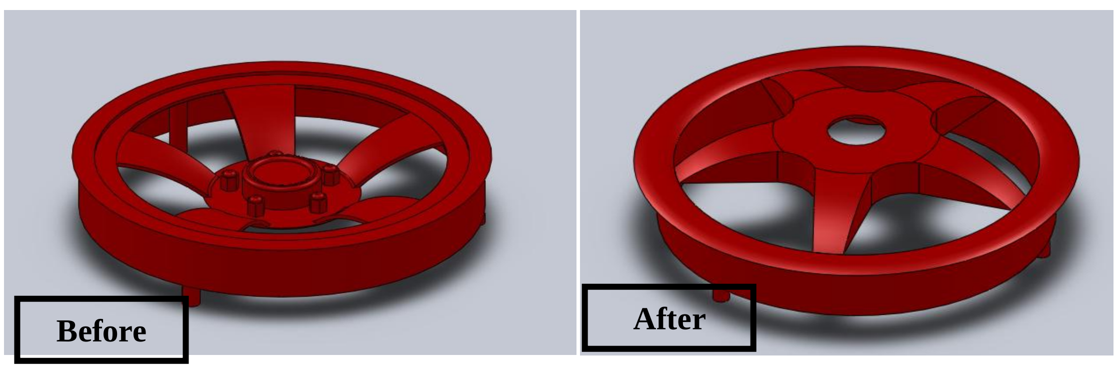


Figure 4.18 Comparison rear rim design

Figure 4.18 shows a comparison between two rear rims. Before redesign the rims easy to collide wheel clip. Rear rim design can be change follow front rim design for standardize part designs. The advantage of redesign can help reduce mold pattern and can use front rim mold.

4.16 COMPARISON HITACHI AEM AND BOOTHROYD DEWHURST DFA METHOD

Table 4.79 shows the comparison between the previous and modification design in terms of number of components, labor time, cost estimation, and design efficiency.

Table 4.79: Totals comparison between current and improvement design.

	Method Analysis	Current Design	Improve Design	Percent Change(%)
Product Part	Hitachi AEM Boothroyd Dewhurst DFM Software	71	50	35.21
Product in 1 hour	Hitachi AEM	5	9	44.44
	Boothroyd Dewhurst	7	19	66
	DFM Software	6	13	53
Total Assembly Cost (RM)	Hitachi AEM	4.21	2.9931	28.90
	Boothroyd Dewhurst	0.623	0.376	42.54
	DFM Software	0.64	0.32	50
Total Assembly Time	Hitachi AEM	620.8	378	41.49
	Boothroyd Dewhurst	493.345	180.97	66.33
	DFM Software	522.82	263.23	49.65
Total Efficiency	Hitachi AEM	67.24	71.875	9.94
	Boothroyd Dewhurst	21.08	34.01	38.01
	DFM Software	19.373	38.43	49.58

From table 4.79, it can be concluded that by applying the Hitachi AEM and Boothroyd Dewhurst analysis, the total number of components reduced from 71 components to 50 components. The objective of the project was achieved by reducing number of component and also integrating between parts.

The total time per product in both analyses ware also decreased. This reduction in assembly time also affected the assembly cost for one product. The cost in both analyses ware also decreased. After redesign, the efficiency in both analyses ware also increased.

From project, the productivity of manufactured is increased after redesign the children tricycle. The objective of this project is achieve.

Boothroyd Dewhurst method and Hitachi AEM use different methodologies in evaluating the design of product. Hitachi AEM evaluate based on penalty score and AEM score but Boothroyd-Dewhurst DFA evaluate based on securing method, part symmetry, handling difficulties and insertion difficulties. The scores that reflect each condition is different between the both method. In term of user-friendliness, Boothroyd-Dewhurst DFA is better than Hitachi AEM.

Using Boothroyd-Dewhurst DFMA and Hitachi AEM to evaluate the original and improved design of Children Tricycle, results indicate that there is no similar result between these two methodologies. However, the two methodologies shows same result, the improvement design is better than current design in terms of total labor time, design of efficiency and DFA index, and cost per product. Compared from both result, Boothroyd Dewhurst DFMA is more user-friendly and accurate than Hitachi because of the details assembly process parameters available compared to Hitachi AEM. However, Hitachi AEM is the ideal method to user who is not very familiar with the assembly processes parameters.

These result can also be seen in figure 4.19 and figure 4.20 where there the comparison are shown graphically in figures

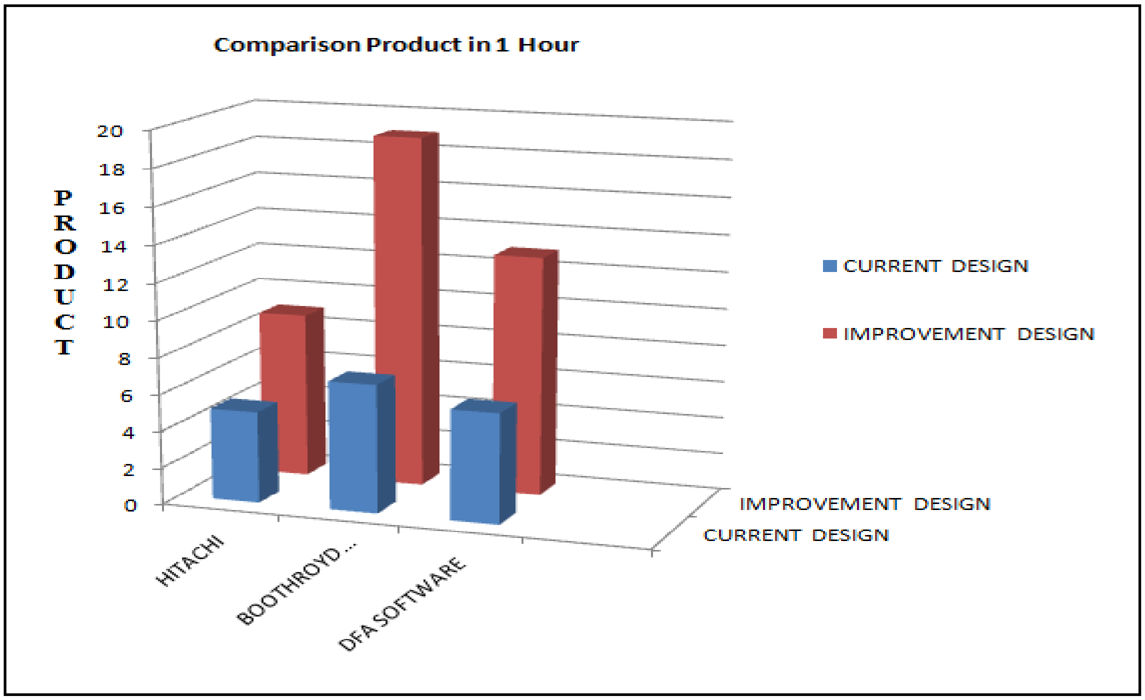


Figure 4.19: Comparison product in 1 hour

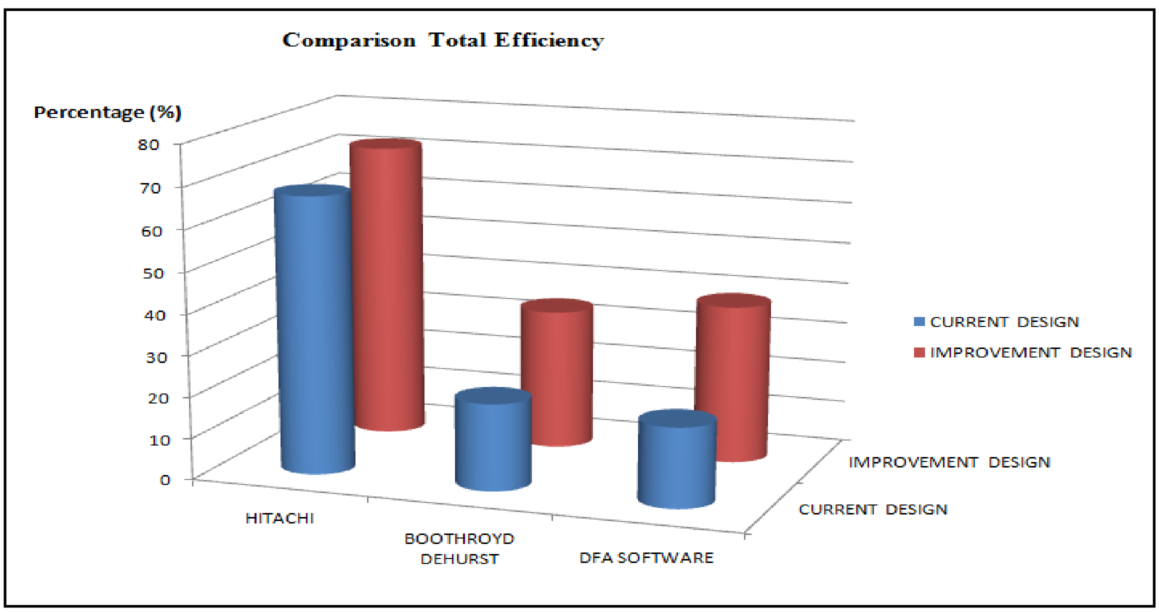


Figure 4.20: Comparison total effiency

4.17 SUMMARY

This chapter discuss the results of the project which based on applying Hitachi AEM and Boothroyd Dewhurst method in optimizing children tricycle design. The evaluation results showed the total efficiency for Hitachi AEM increased 71.875% from 67.24% and the total efficiency Boothroyd Dewhurst method also is increased 34.01% from 21.08% .The number of assembly component ware reduce from 71 component to 50 component after combination or component elimination..

CHAPTER 5

CONCLUSION & RECOMENDATION

5.1 INTRODUCTION

After completing all the tasks required to fulfill the scope of project, some important concluding remarks and future recommendations are discussed in this last chapter.

5.2 CONCLUSION

The use of DFA methodology for assembly analyses is to provide the best product design in terms of reducing the part in a product. This can shorter the assembly time, lower the manufacturing and assembly cost, besides increasing the quality of the product. The main purpose of this project related to DFA method where the product design is improved by using Boothroyd Dewhurst method and Hitachi AEM method. Children tricycle is chosen in this project because this product is a good design to be commercialized. For achieving this purpose it requires four stages which must be accomplished included:

First stage: The literature review is done on advantages and disadvantages of DFA method, various methods of DFA and basic design concept and guidelines of DFA For DFA methods, the well known ones such as Boothroyd-Dewhurst DFA Method, Lucas-Hull DFA Method, and Hitachi Assemblability Evaluation Method (AEM) were discussed.

Second stage: Identifying the mechanical product for the project and which included the product detail, structure, sequence and the evaluation at product level and part level.

Third stage: Redesigning the product and proposed the new improvement which can give a good impact to automatic assembly. The new design is done with its details which included the product detail, structure, sequence and the evaluation at product level and part level.

Fourth stage: Comparison between the old and new design done to see if there is any improvement on the product for achieved the purpose of this project. The children tricycle is analyze by using Boothroyd Dewhurst DFA method and Hitachi AEM method.

5.3 FUTURE RECOMMENDATION

Possibly, there are some drawbacks existed in the current DFA, and most of them may be subjected for future research and improvement. For future recommendations, there is a number of possibilities to be developed further on as stated as below:

First, introduces software that can simplify the process of DFA where the designer only required to key in the necessary value to get the overall result. It can simplify method and standardize method.

Second, A proper way towards material selection of the new design product could be performed. This should be more accurate if one to know the exact cost needed in redesigning a new product.

Third, Should also consider the manufacturing process required to produce the new design parts. This is by considering include research in Design for Manufacturing (DFM).

REFERENCES

Boothroyd, et. al, (2002). *Product Design for Manufacturing and Assembly,* New York: Marcel Dekker, Inc

Boothroyd Dewhurst, Inc (2005). *Design for Assembly 9 User Guide, Version 9.2,* March 2005

Boothroyd Dewhurst, Inc (2006). *DFM Concurrent Costing User Guide, Version 2.2,* May 2006

Corrado Poli, C. Poli. (2004) *Design for Manufacturing: A Structured Approach*. *for Manufacturing: A Structured Approach*

knut holt (2002), kluwer academic publishers. *market orinted product innovation akey to survival in third millennium*

Muhammad Faizal Bin Alias (2007). Optimization of kitchen scale scale design by using boothroyd-dewhurst dfa method, Bachelor Thesis, Universiti Malaysia Pahang

Mohd Naim Bin Zakaria (2009). Design for assembly and application using Hitachi assemblability evaluation method, Bachelor Thesis, Universiti Malaysia Pahang

Masood H.S, et. al. (2003). An investigation into design and manufacturing of mechanical conveyors systems for food processing, International Journal of Advance Manufacturing Technology **25**: 551–559

Redford, A and Chal, J. (1994), Design for Assembly – Principles and Practice. England: McGraw-Hill.

R. B. Stone, D. A. McAdams, V. J. Kayyalethekkel (2004). *A product architecture-based conceptual DFA technique, Design Studies*, 25, 301-325.

Stoll W.H (1999). *Product Design Methods and Practices*, New York: Marcel Dekker, Inc.

Toshijiro OHASHI, Minoru IWATA, Shoji ARIMOTO and Seii MIYAKAWA, "*Extended Assemblability Evaluation Method (AEM)*", JSME International Journal Series C, Vol. 45, No. 2 (2002), pp.567-574

Ulrich, K.L et. al, (2004). *Product Design and Development*. New York: McGraw-Hill/Irwin.

Wan Abd . Rahman Assyahid Bin Wan Ibrahim. *"Incorporating design for manufacture and assembly methodologies into the design of a modified spark plug"* UTM :master thesis. 2006

APPENDIX A1 : GANTT CHART FYP 1

Project Progress		**W 1**	**W 2**	**W 3**	**W 4**	**W 5**	**W 6**	**W 7**	**W 8**	**W 9**	**W 10**	**W 11**	**W 12**	**W 13**	**W 14**
1) Meeting with supervisor.	Planning														
	Actual														
2) Gather the basic knowledge about project.	Planning														
	Actual														
3) Do research and collect the information from researching resources.	Planning														
	Actual														
4) State the objective, scope and importance of the study (Chapter I)	Planning														
	Actual														
5) Study of Hitachi AEM method (Chapter II)	Planning														
	Actual														
6) Study of Lucas Hull method (Chapter II)	Planning														
	Actual														
7) Study of Boothroyd Dewhurst method (Chapter II)	Planning														
	Actual														
10) Study flow chat and plan of study	Planning														
	Actual														
11) Submit draft thesis and log book for final year project 1	Planning														
	Actual														
12) Final year project 1 presentation	Planning														
	Actual														

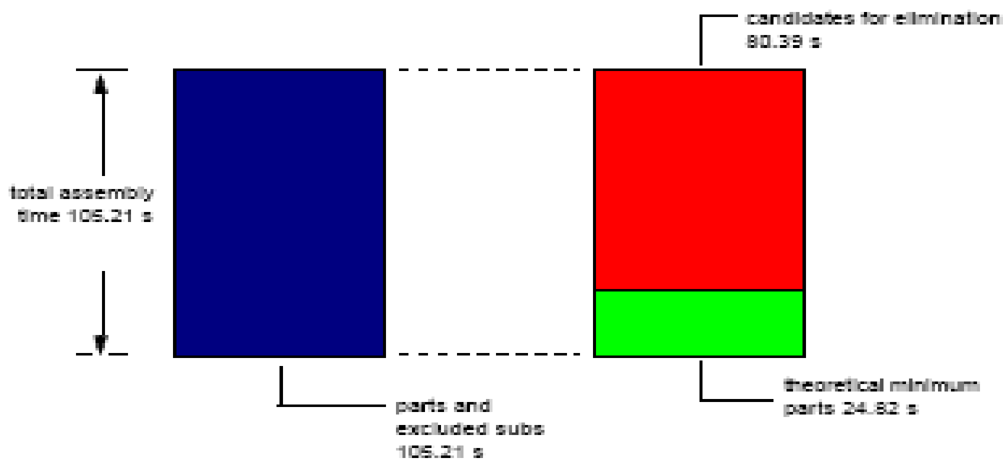
APPENDIX A1 : GANTT CHART FYP 2

Project Progress		**W 1**	**W 2**	**W 3**	**W 4**	**W 5**	**W 6**	**W 7**	**W 8**	**W 9**	**W 10**	**W 11**	**W 12**	**W 13**	**W 14**	**W 15**
1) Disassemble product	Planning															
	Actual															
2) Cad drawing	Planning															
	Actual															
3) Redesign the Product	Planning															
	Actual															
4) Analysis using Boothroyd Dewhurst	Planning															
	Actual															
5) Analysis using Hitachi AEM	Planning															
	Actual															
6) Learn Boothdroyd-Dewhurst Software	Planning															
	Actual															
7) Modification Design	Planning															
	Actual															
8) Prepare the proper thesis to submit	Planning															
	Actual															
9) Final year project 2 Presentation	Planning															
	Actual															
10) Summit the thesis	Planning															
	Actual															

APPENDIX B1 : MIDDLE CURRENT ASSEMBLY DFA SOFTWARE

Per Product data	Entries (including repeats)	Labor Time, s	Labor Cost, $
Component parts	13	105.21	0.00
Subassemblies partially or fully analyzed	0	0.00	0.00
Subassemblies not to be analyzed (excluded)	0	0.00	0.00
Standard and library operations	0	0.00	0.00
Totals	**13**	**105.21**	**0.00**

The chart shows a breakdown of time per product

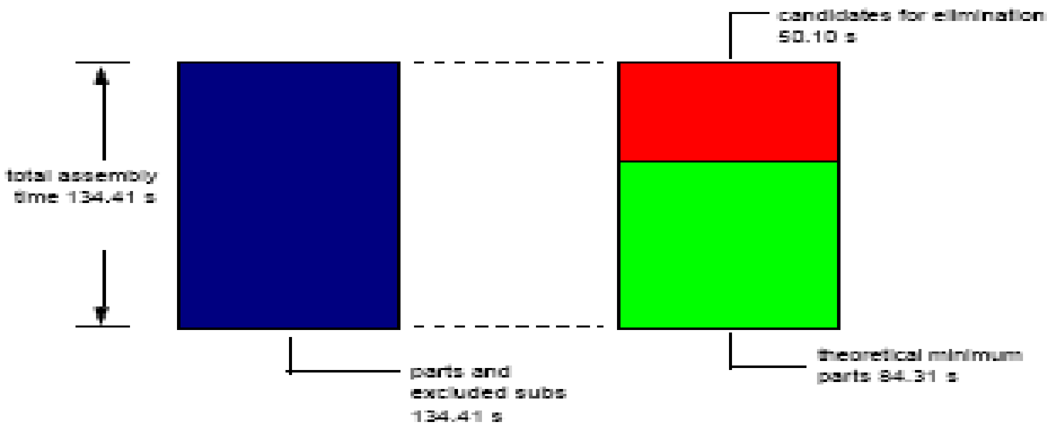


Product life volume	10,000
Number of entries (including repeats)	13
Number of different entries	6
Theoretical minimum number of items	4
DFA Index	11.1
Total weight, lb	* 0.00
Total assembly labor time, s	105.21
Total cost for manufactured items (including tooling), $	** 0.00

APPENDIX B2 : FRONT CURRENT ASSEMBLY DFA SOFTWARE

Per Product data	Entries (including repeats)	Labor Time, s	Labor Cost, $
Component parts	17	134.41	1.32
Subassemblies partially or fully analyzed	0	0.00	0.00
Subassemblies not to be analyzed (excluded)	0	0.00	0.00
Standard and library operations	0	0.00	0.00
Totals	7	134.41	1.82

The chart shows a breakdown of time per product

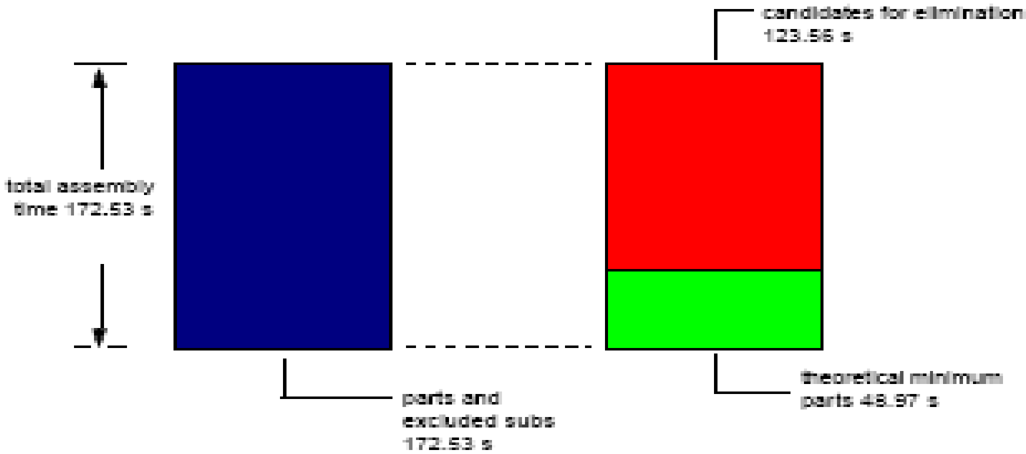


Product life volume	10,000
Number of entries (including repeats)	7
Number of different entries	13
Theoretical minimum number of items	11
DFA Index	24.0
Total weight, lb	* 0.00
Total assembly labor time, s	134.41
Total cost for manufactured items (including tooling), $	** 0.00

APPENDIX B3 : REAR CURRENT ASSEMBLY DFA SOFTWARE

Per Product data	Entries (including repeats)	Labor Time, s	Labor Cost, RM
Component parts	24	172.53	0.25
Subassemblies partially or fully analyzed	0	0.00	0.00
Subassemblies not to be analyzed (excluded)	0	0.00	0.00
Standard and library operations	0	0.00	0.00
Totals	**24**	**172.53**	**0.25**

The chart shows a breakdown of time per product

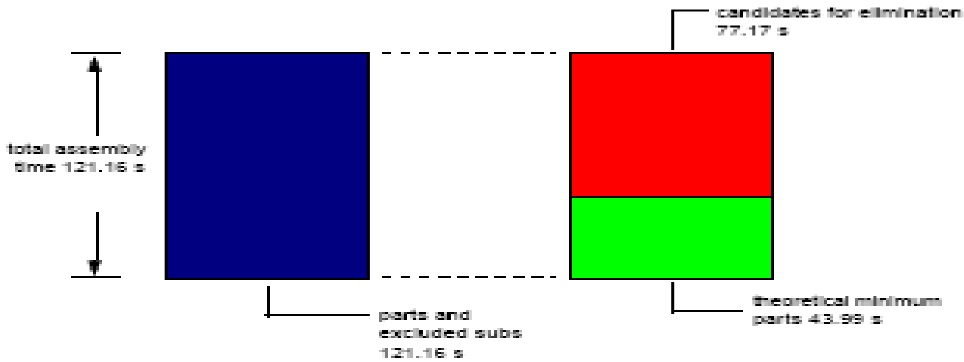


Product life volume	10,000
Number of entries (including repeats)	24
Number of different entries	13
Theoretical minimum number of items	8
DFA Index	13.6
Total weight, g	* 0.00
Total assembly labor time, s	172.53
Total cost for manufactured items (including tooling), RM	** 0.00

APPENDIX B4 : FRONT WHEEL CURRENT ASSEMBLY DFA SOFTWARE

Per Product data	Entries (including repeats)	Labor Time, s	Labor Cost, RM
Component parts	19	121.16	0.17
Subassemblies partially or fully analyzed	0	0.00	0.00
Subassemblies not to be analyzed (excluded)	0	0.00	0.00
Standard and library operations	0	0.00	0.00
Totals	**19**	**121.16**	**0.17**

The chart shows a breakdown of time per product

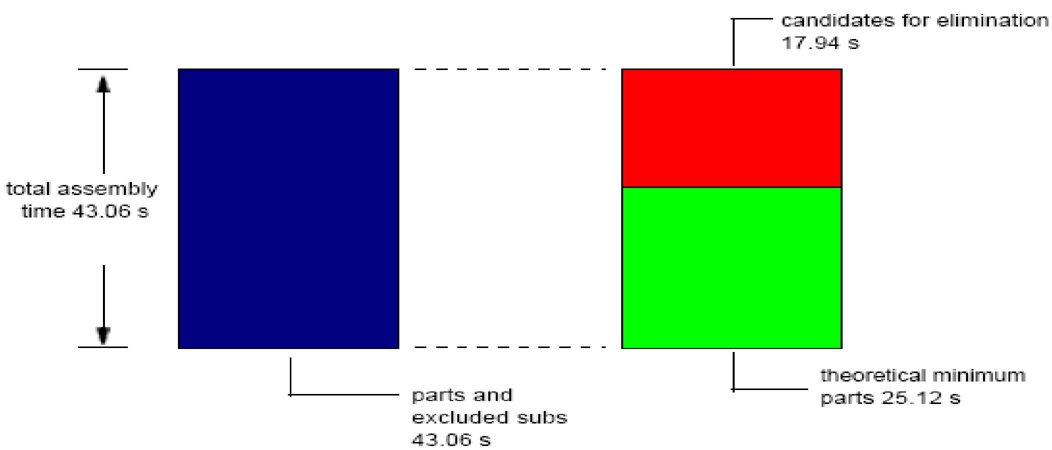


Product life volume	10,000
Number of entries (including repeats)	19
Number of different entries	11
Theoretical minimum number of items	8
DFA Index	19.3
Total weight, g	* 0.00
Total assembly labor time, s	121.16
Total cost for manufactured items (including tooling), RM	** 0.00

APPENDIX C1 : MIDDLE IMPROVEMENT ASSEMBLY DFA SOFTWARE

Per Product data	Entries (including repeats)	Labor Time, s	Labor Cost, $
Component parts	6	43.06	0.00
Subassemblies partially or fully analyzed	0	0.00	0.00
Subassemblies not to be analyzed (excluded)	0	0.00	0.00
Standard and library operations	0	0.00	0.00
Totals	**6**	**43.06**	**0.00**

The chart shows a breakdown of time per product

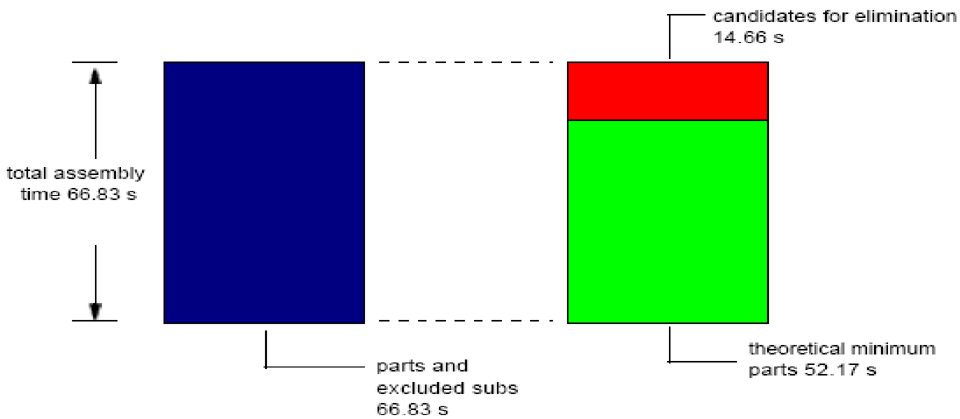


Product life volume	10,000
Number of entries (including repeats)	6
Number of different entries	4
Theoretical minimum number of items	4
DFA Index	27.2
Total weight, g	* 0.00
Total assembly labor time, s	43.06
Total cost for manufactured items (including tooling), $	** 0.00

APPENDIX C2 : FRONT IMPROVEMENT ASSEMBLY DFA SOFTWARE

Per Product data	Entries (including repeats)	Labor Time, s	Labor Cost, $
Component parts	13	66.83	0.00
Subassemblies partially or fully analyzed	0	0.00	0.00
Subassemblies not to be analyzed (excluded)	0	0.00	0.00
Standard and library operations	0	0.00	0.00
Totals	**13**	**66.83**	**0.00**

The chart shows a breakdown of time per product

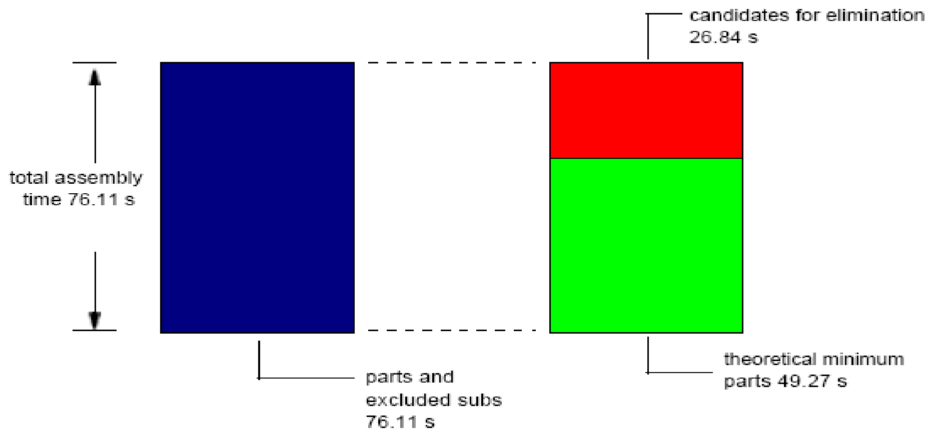


Product life volume		10,000
Number of entries (including repeats)		13
Number of different entries		11
Theoretical minimum number of items		11
DFA Index		48.2
Total weight, kg	*	0.00
Total assembly labor time, s		66.83
Total cost for manufactured items (including tooling), $	**	0.00

APPENDIX C3 : REAR IMPROVEMENT ASSEMBLY DFA SOFTWARE

Per Product data	Entries (including repeats)	Labor Time, s	Labor Cost, $
Component parts	13	76.11	0.00
Subassemblies partially or fully analyzed	0	0.00	0.00
Subassemblies not to be analyzed (excluded)	0	0.00	0.00
Standard and library operations	0	0.00	0.00
Totals	**13**	**76.11**	**0.00**

The chart shows a breakdown of time per product

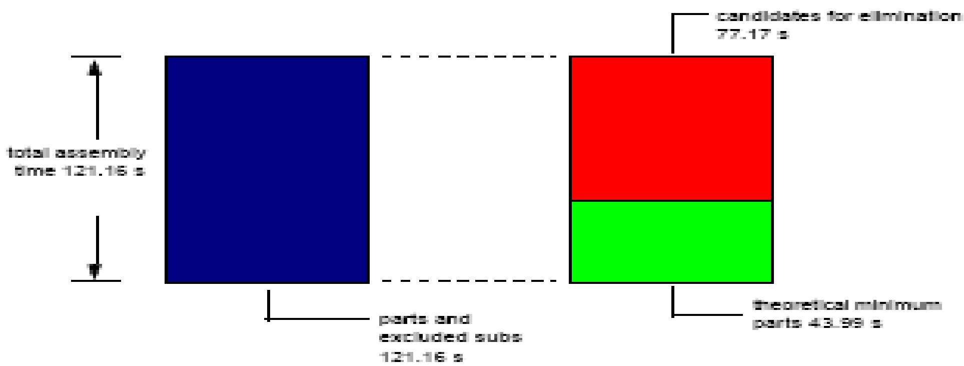


Product life volume		10,000
Number of entries (including repeats)		13
Number of different entries		8
Theoretical minimum number of items		8
DFA Index		30.8
Total weight, kg	*	0.00
Total assembly labor time, s		76.11
Total cost for manufactured items (including tooling), $	**	0.00

APPENDIX C4 : FRONT WHEEL IMPROVEMENT ASSEMBLY DFA SOFTWARE

Per Product data	Entries (including repeats)	Labor Time, s	Labor Cost, RM
Component parts	19	121.16	0.17
Subassemblies partially or fully analyzed	0	0.00	0.00
Subassemblies not to be analyzed (excluded)	0	0.00	0.00
Standard and library operations	0	0.00	0.00
Totals	19	121.16	0.17

The chart shows a breakdown of time per product



Product life volume		10,000
Number of entries (including repeats)		19
Number of different entries		11
Theoretical minimum number of items		8
DFA Index		19.3
Total weight, g	*	0.00
Total assembly labor time, s		121.16
Total cost for manufactured items (including tooling), RM	**	0.00

APPENDIX D1 : HITACHI AEM PENALTY SCORES

Table for Penalty Scores

- **Direction of motion of a part:**

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

- **Fixture & forming requirements:**

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, ..)

- **Joining & processing requirements:**

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

- **Other symbols without penalty points:**

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

APPENDIX D2 : BOOTHYORD DEWHURST MANUAL HANDLING

MANUAL HANDLING — ESTIMATED TIMES (seconds)

Key

ONE HAND

		parts are easy to grasp and manipulate					parts present handling difficulties (1)				
		thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand without the aid of grasping tools: $(\alpha+\beta) < 360°$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
$360° \le (\alpha+\beta) < 540°$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
$540° \le (\alpha+\beta) < 720°$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
$(\alpha+\beta) = 720°$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

ONE HAND with GRASPING AIDS

		parts need tweezers for grasping and manipulation								parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
		parts can be manipulated without optical magnification				parts require optical magnification for manipulation					
		parts are easy to grasp and manipulate		parts present handling difficulties (1)		parts are easy to grasp and manipulate		parts present handling difficulties (1)			
		thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm		
		0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand but only with the use of grasping tools: $\alpha \le 180°$, $0 \le \beta \le 180°$	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
$\alpha \le 180°$, $\beta = 360°$	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
$\alpha = 360°$, $0 \le \beta \le 180°$	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
$\alpha = 360°$, $\beta = 360°$	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS for MANIPULATION

		parts present no additional handling difficulties					parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		$\alpha \le 180°$			$\alpha = 360°$		$\alpha \le 180°$			$\alpha = 360°$	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS required for LARGE SIZE

		parts can be handled by one person without mechanical assistance									two persons or mechanical assistance required for parts manipulation
		parts do not severely nest or tangle and are not flexible								parts severely nest or tangle or are flexible (2)	
		part weight < 10 lb				parts are heavy (> 10 lb)					
		parts are easy to grasp and manipulate		parts present other handling difficulties (1)		parts are easy to grasp and manipulate		parts present other handling difficulties (1)			
		$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$		
		0	1	2	3	4	5	6	7	8	9
two hands, two persons or mechanical assistance required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

APPENDIX D3 : BOOTHYORD DEWHURST MANUAL INSERTION

MANUAL INSERTION—ESTIMATED TIMES (seconds)

Key:

PART ADDED but NOT SECURED

		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
		easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
		no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
		0	1	2	3	6	7	8	9
addition of any part (1) where neither the part itself nor any other part is finally secured immediately: part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

PART SECURED IMMEDIATELY

		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
				plastic bending or torsion			rivetting or similar operation				
					not easy to align or position during assembly			not easy to align or position during assembly			
		easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position during assembly (4)	no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
		0	1	2	3	4	5	6	7	8	9
addition of any part (1) where the part itself and/or other parts are being finally secured immediately: part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	bulk plastic deformation (large proportion of part is plastically deformed during fastening)	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	9
assembly processes where all solid parts are in place	9	4	7	5	3.5	7	8	12	12	9	12