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Cost Reduction of Hand Mixer Using Design for Manufacture and Assembly (DFMA)

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Abstract: As the competition of a product at the market is tight, a product must have the best performance with an affordable price. A product needs to be improved to keep competing globally thus the application of Design for Manufacture and Assembly (DFMA) is the best choices in designing the new and better version of a product. This study has emphasized the advantages of application of DFMA methodology to a product. DFMA methodology as basically to simplified the design and cost reduction to the original design. The methodology of the study was using the manual DFA calculation method on the chosen product, hand mixer. The manual Design for Assembly (DFA) methodology was conducted as the DFMA application to the hand mixer was explained. The method of the study been conducted was explained and the evaluation of the design efficiency through the manual DFA analysis can also be explained. The original design of the hand mixer with operation time per unit, 282.43 s and operation cost per second was RM0.4903. Meanwhile, the improved design hand mixer efficiency was 57.01 %, reducing the cost and operation time with RM0.4019 per second and 231.53 s respectively. The design efficiency of the original design hand mixer was of 46.70 %. The improvement of 22.08 % design efficiency was produced from the improved design hand mixer. Using the manual DFA methodology, the efficiency design performance comparison between the original design and the improved design was conducted and the improvement was able to be made.

Keywords: DFMA, DFA, DFM, Reduce Cost, Hand Mixer

1. Introduction

Design for Manufacture and Assembly (DFMA) consists of two-component that is Design for Manufacture (DFM) and Design for Assembly (DFA). DFM is a methodology concern to making individual parts while DFA principally the means of assembling them [1]. In 1987, Boothroyd and Dewhurst conducted many studies on the assembly limitation during the design stages to avoid the manufacturing and assembly issues during the product development stages [2]. To get the lowest

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assembly cost, the product had to be designed using a suitable economic assembly system. It can be achieved by designing a product with fewer parts and ease to be assembled [3]. DFMA gives an early cost profile to the product design for the engineer, therefore, the factor of how the product will be made, installed, shipped, used, and recycled can be considered during the design phase of the product development. In general, DFMA is like a base for planning and decision making for the design of product development as well as time-to-market [4].

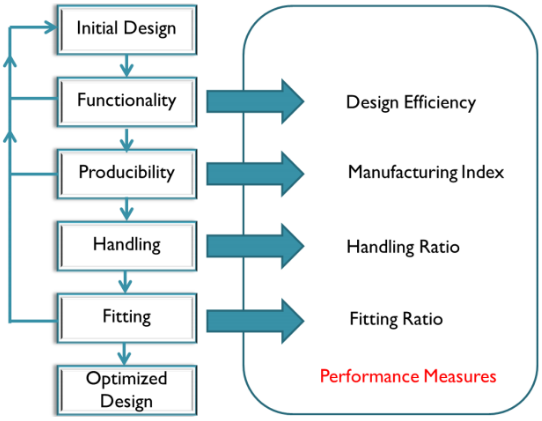

Figure 1: DFMA procedure [5]

1.1 Design for Assembly (DFA)

DFA gives an efficient of a design as well as effective in cost of the assembly process. Thus, it can be achieved by considering the assembly operation and support activities during designing process development [6]. DFA is the sequence of DFM in manufacturing of a product therefore DFA is always comprehend to the parts from manufacturing section as the parts will be assembled to form the final product. The contribution of DFA then will be converted to the cost reduction [7]. DFA contain two methods that are tool assembly analysis and assembly design. The first method of DFA, tool assembly analysis, is where the assembly time is emphasized from the start of the designing development. Next, for the second method of DFA that is assembly design, the assembly process's information and detail will be analyzed to be use in the assembly operation. [8].

1.2 DFA Guidelines

The focus of DFA truly is to reduce the assembly cost. To implement the DFA technique, a few guidelines need to be followed as below [9]:

i. Reducing the part count:
Designing least part of the product or designing a component that can use a various part to get the less count of the parts.
ii. Minimized the fastener used and their components
Designing least part of the product or designing a component that can use the various parts to get the less count of the parts
iii. Design minimum of parts
The decreased part will decrease the cost used. This essential as two or more part can be combined to work as one part.

1.3 Hand Mixer

The earlier form of the electrical home appliance is the egg beater. Eggbeater was used manually to mixing egg, dough and others. Herbert Johnson discovered the idea of adding the motor so that the mixer can be automated compared to manually handling in 1908. Herbert John was inspired by a baker that was manually mixing bread dough at the kitchen [10]. The hand mixer as showed in Figure 2 is a Russel Hobb 18289 mixer with hand-held type.

Figure 2: Russel Hobb 18289 Hand mixer

2. Materials and Methods

As DFMA methodology, manual DFA analysis method was chosen to analyze the chosen product. The method was chosen for a certain reason where the DFMA software is unavailable. Thus, the manual DFA analysis method by Boothroyd and Dewhurst is selected. Figure 3 shows how manual DFA analysis works.

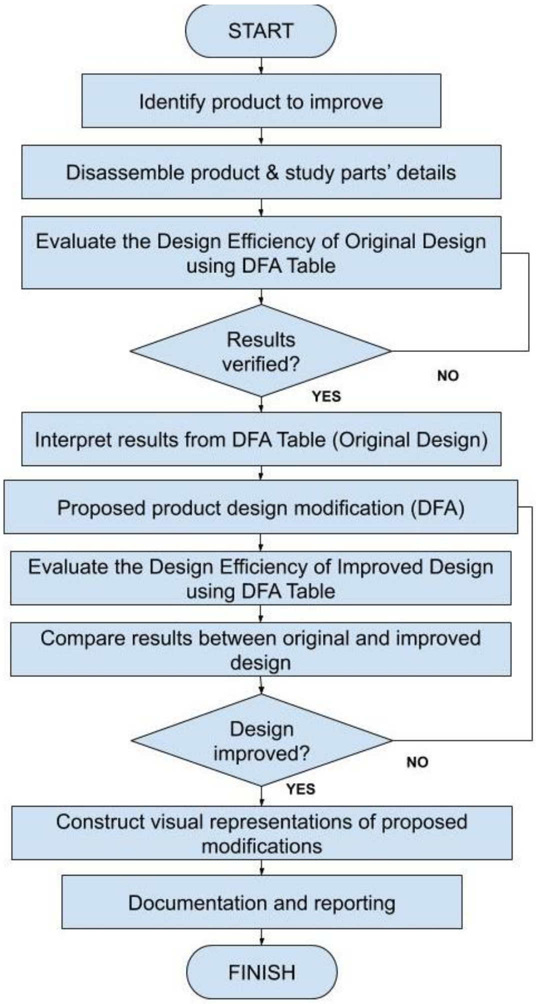

Figure 3: Manual DFA analysis flowchart

2.1 Methods

The manual DFA analysis typically is been conducted in five stages of:

i. Product dissembles and parts classification
ii. Assembly process evaluation (Boothroyd Dewhurst Method)
iii. Description and modification of proposed parts
iv. Reevaluation of modified parts (Boothroyd Dewhurst Method)
v. Comparison between original and modified parts

2.1.1 Product dissembled and parts classification

The hand mixer was dissembled as Figure 4. The total of 31 parts was found. The motor of the hand mixer contained with 14 parts. The Table 1 showed the details on the art descriptions.

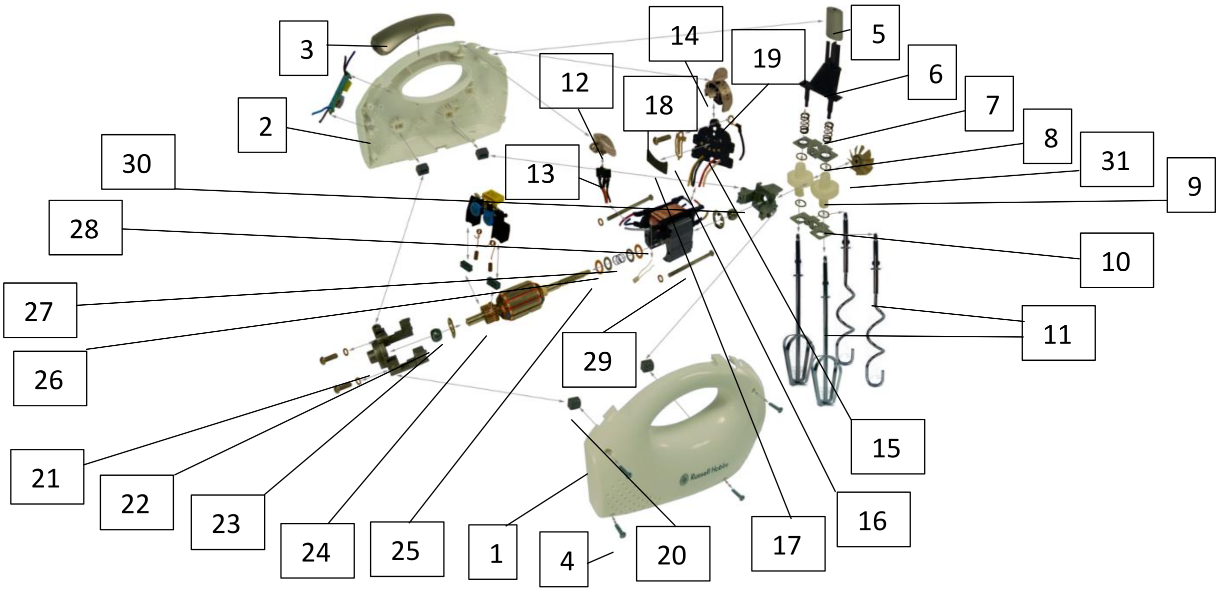

Figure 4: Hand mixer disassembled parts

Table 1: Part Description

Part No	Part Name	Quantity	Material	Function
1	Front casing	1	ABS plastic	To case the inner workings of the product, and stop any liquids or dirt getting inside
2	Rear casing	1	ABS plastic	To case the inner workings of the product, and stop any liquids or dirt getting inside
3	Handle cover	1	ABS plastic	To allow a matt surface for the handling operation
4	Tamper proof casing Screw	4	Steel	To hold part together effectively
5	Eject button	1	ABS plastic	To pushes out beaters
6	Eject mechanism	1	ABS plastic (not spray painted)	To transform the force of push on the button to turn on the devices
7	Gear compression spring	2	Steel wire	To ease the pressure and friction when the eject mechanism is pushing beater out
8	Gear holder	2	Aluminium	To hold gears in place
9	Plastic helical gear	2	Nylon	To turn motor rotation to the rotary motion on a vertical axis along the worm drive
10	Metal gear washer	2	Stainless steel	To stop metal corroding and reduce friction
11	Beater and hook	2	Stainless steel	As the attachment to turn the rotary motion in gear into motion

12	Turbo Boost button	1	ABS plastic	To activate turbo speed
13	Turbo boost mechanism	1	PP plastic casing with electric wire inside	To complete the turbo mechanism
14	Switch	1	ABS plastic	To connect to the mechanism
15	Switch connector	1	PE plastic and aluminium contact	To send different voltage to the electro-magnet
16	Switch selector	1	Zinc-aluminium	To indicate the selected voltage
17	Connector cover	1	ABS plastic	To keep connector in contact with aluminium
18	Small switch screw	3	Steel	To hold part together effectively
19	Switch ring	5	Zinc-aluminium	To complete circuit between switch selector and electro-magnet
20	Shock absorber	4	Silicone rubber	To reduce vibration of product during operation
21	Rear die cast	1	Aluminium	To hold motor and associated components together inside casting
22	Bearing bush	2	Steel	To allow motor shaft to move and swivel slightly
23	Bush constraint	2	Aluminium	To keep the bush constrained
24	Motor	1	Stainless steel, copper wire and iron plate	To turn electrical energy to mechanical rotary motion
25	Plastic shaft washer	2	Nylon	To stop metal corroding and reduce friction
26	Metal shaft washer	2	Steel	To stop metal corroding and reduce friction
27	Shaft compression spring	1	Steel wire	To allow for slight movement in the motor shaft
28	Electro magnet	1	Copper wire and iron plates	To create a magnetic field around the motor
29	Long die cast	2	Steel	To hold part together effectively
30	Front die cast	1	Aluminium	To hold motor and associated components together inside casting
31	Fan	1	PP plastic	To eject the hot air form operating motor to the surrounding

2.2.2 Assembly Process evaluation (Boothroyd Dewhurst Method)

The evaluation of the assembly using the Boothroyd method was conducted to this study where firstly, the usage of the DFA worksheet table. The procedure of evaluation of the DFA worksheet can be described as:

i. The parts details and its quantity:
As Table 1 describes, the dimension and quantity of the part were been taken measured in this DFA worksheet.

ii. The determination of the effect of part symmetry of each part:
As an important factor for the assembly process, part of symmetry during handling is very important. There are two kinds of symmetry that are alpha symmetry, α and beta symmetry, β.

Figure.5 shows the rotation of the alpha symmetry where it is rotated about an axis perpendicular to the axis of rotation. Meanwhile, beta symmetry rotation is on the axis of insertion as shown in Figure 6.

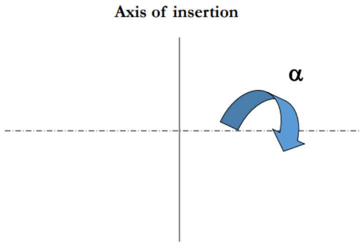

Figure 5: Alpha symmetry rotation [11]

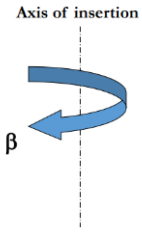

Figure 6: Beta symmetry rotation [11]

iii. Manual handling worksheet evaluation:
Using the symmetries of handling, α and β, and the parts detail, the two-digit handling code and time for manual handling each part was obtained through the manual handling worksheet.

iv. Manual insertion worksheet evaluation:
The manual insertion worksheet evaluation was using the symmetries of handling, α and β, and the parts detail at Table 1 to achieve the two-digit manual insertion and time taken for each part during insertion.

v. Operation time and cost calculation:
The operation time can be calculated by the quantity of part multiplied by the sum of manual handling and insertion times taken for each part. For the operation cost, the operation cost can be calculated by the costs of the labour multiplied by the operation times for every part. [12].

vi. Estimation for theoretical minimum parts
For the value of estimation for theoretical minimum parts, which a value of 1 was recorded if the part related to the rules. Some rules must be followed during this stage such as:

- Does the part move relative to all other assembled parts during the product operation?
- Must the part material different from the already assembled parts?
- Must part separate from all already assembled parts?

2.2.3 Description and modification of proposed parts

The design modification or improvement must be based on the DFA guideline as the previous chapter explains. These can achieved by identifying the potential parts that can be simplified, combined, eliminate or redesign for better performance and cost reduction. Besides, the manual DFA worksheet also gives an important consideration needs to be taken for design modification or improvement such as:

i. The opportunity for parts number reduction when at the manual DFA worksheet, the value in column 9 is lower than the value in column 2.

ii. In the manual DFA worksheet, the operation cost and times was examined and pinpoint the potential reduction.

2.2.4 Reevaluation of modified parts (Boothroyd Dewhurst Method)

Using the manual DFA analysis as mentioned before the improved design. The improved design was recalculated and reevaluated to obtain the efficiency of the new design.

2.2.5 Comparison between original and modified parts

The terms of total parts, assembly operation time and cost, and assembly design efficiency of the original design and the improved design were compared

3. Results and Discussion

The purpose of analysis is to implement an improvement by decreasing the number of parts and making a better quality product compared to the original design. Those analyses will be done through the DFA Manual calculation method that was conducted.

3.1 Calculation of Assembly Cost

The assembly cost used in the DFA analysis worksheet needs to be calculated before starting the analysis. As the standard average working hours for an operator in Malaysia are 8 hours per day and 5 days per week. The average labour cost for an operator per month in this current time is RM1000. The assembly cost can be calculated as:

Malaysia Labour Cost Calculation: (RM / Second)
Normal labour cost for an operator per month (manufacturing company): RM1000
Working hour per day: 8 hours`
Working day per week: 5 days
Total working hours per week: 5 x 8 (hours) = 40 hours
Total working hours per month: 4 x 40 (hours) = 160 hours
Total working second per month: 160 x 3600 (Second/ Hour) = 576000 s
Malaysia Labour Rate in RM/ Second = RM1000 / 576000 (s) = RM0.001736 / Sec

3.2 DFA Manual Analysis on Hand Mixer

The hand mixer design was evaluated through the manual DFA analysis method. The product design will be evaluated, modified, reevaluated and lastly, the design efficiency of both original design and modified design were compared. Table 2 shows the analyzed data using the Boothroyd Dewhurst DFA analysis.

3.3 Evaluation of Hand Mixer

The chosen product that is the hand mixer will undergo the evaluation of Boothroyd Dewhurst DFA manual analysis where the DFA manual evaluation worksheet is used to obtain the design efficiency of the original design. As the analysis was conducted, the final result of original design efficiency measured is 46.70 % as showed in Table.2.

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Table 2: Boothroyd Dewhurst DFA Evaluation Worksheet of Hand Mixer

Part ID No	Number of times the operation is carried out consecutively	Alpha symmetry, α	Beta symmetry, β	Manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion & fastening time per part	Operation time (sec)	Operation cost (RM)	Estimation of theoretical minimum number of parts	Name of assembly
1	1	360	360	30	1.95	08	6.5	8.45	0.01467	1	Front casing
2	1	360	360	30	1.95	08	6.5	8.45	0.01467	1	Rear casing
3	1	360	360	31	2.25	30	2.0	4.45	0.007725	0	Handle cover
4	4	360	0	11	1.8	39	8.0	39.20	0.0605	0	Tamper proof casing Screw
5	1	360	180	21	2.10	30	2.0	4.10	0.007118	1	Eject button
6	1	360	360	31	2.25	07	6.5	8.75	0.01519	1	Eject mechanism
7	2	180	0	05	1.84	00	1.5	6.68	0.01156	2	Gear compression spring
8	2	360	360	34	3.00	30	2.0	10.00	0.01736	2	Gear holder
9	2	360	0	10	1.50	00	1.5	4.00	0.006944	2	Plastic helical gear
10	2	180	0	04	2.18	00	1.5	7.36	0.01278	2	Metal gear washer
11	2	360	180	20	1.80	40	4.5	12.60	0.02187	2	Beater and hook
12	1	360	360	30	1.95	00	1.5	3.45	0.005989	1	Turbo Boost button
13	1	360	360	30	1.95	00	1.5	3.45	0.005989	1	Turbo boost mechanism
14	1	360	360	30	1.95	06	5.5	7.45	0.01293	1	Switch
15	1	360	360	30	1.95	00	1.5	3.45	0.005989	1	Switch connector
16	1	360	360	39	4.00	06	5.5	9.50	0.01649	1	Switch selector
17	1	360	360	31	2.25	31	5.0	7.25	0.01259	0	Connector cover
18	3	360	0	11	1.8	39	8.0	29.40	0.05104	3	Small switch screw
19	5	180	0	04	2.18	00	1.5	18.40	0.03194	5	Switch ring/washer
20	4	360	180	21	2.10	30	2.0	16.40	0.02847	4	Shock absorber
21	1	360	360	30	1.95	00	1.5	3.45	0.005989	1	Rear die cast

No.	# of times the operation is carried out consecutively	Alpha symmetry, α	Beta symmetry, β	Manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion & fastening time per part	Operation time (sec)	Operation cost (RM)	Estimation of theoretical minimum # of parts	Part Name
22	2	180	180	11	1.8	00	1.5	6.60	0.01146	2	Bearing bush
23	2	360	0	14	2.55	00	1.5	8.10	0.01406	2	Bush constraint
24	1	360	360	30	1.95	11	5.0	6.95	0.01207	1	Motor
25	2	180	0	04	2.18	00	1.5	7.36	0.01278	2	Plastic shaft washer
26	2	180	0	04	2.18	00	1.5	7.36	0.01278	2	Metal shaft washer
27	1	180	0	06	2.17	00	1.5	3.67	0.006371	1	Shaft compression spring
28	1	360	360	30	1.95	00	1.5	3.45	0.005989	1	Electro magnet
29	2	180	0	10	1.50	38	6.0	15.00	0.02604	1	Long die cast
30	1	360	360	30	1.95	00	1.5	3.45	0.005989	1	Front die cast
31	1	360	0	12	2.25	30	2.0	4.25	0.007378	1	Fan
							Total	282.43	0.4903	44	Design efficiency = 3NM / TM = (3)(44) / 282.43 = 0.467@ 46.7%
TM = Total manual assembly time CM = Total cost of manual assembly NM = Theoretical minimum number of parts								TM	CM	NM	

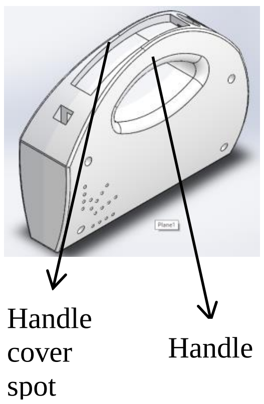
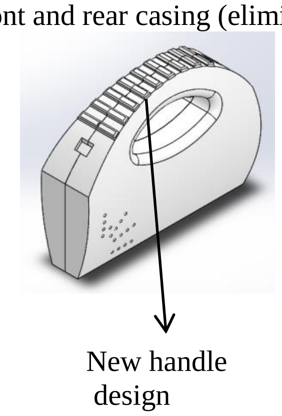
3.4 Proposed Modifications

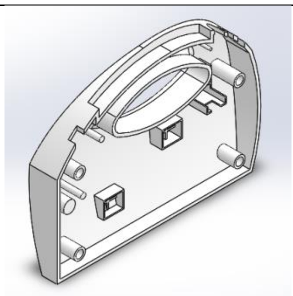
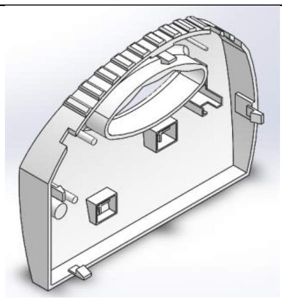
The hand mixer is machines that mix a food ingredient by holding the machine by a hand. Thus, the hand mixer needs to be a lightweight handheld device. Unfortunately, there are problems in the hand mixture machine, for example, the product was built with many fasteners. During hand mixer running, the machine produced a high vibration thus the usage of fasteners is not good as the fasteners can be loosened during the vibration. Thus, the modification on the existing design of the hand mixer was conducted to produce the improved design in to handle the problems.

Minimize the number of parts was proposed as currently the numbers of the parts are too many for hand mixture machine which is 31 parts. By using fewer parts, the amount of labour required also decreased, and reducing the number of unique parts, DFMA can significantly lower the cost of assembly. But there are rules that must be followed for reducing the number of parts such as the parts that do not move relative to all other parts that had been assembled, the parts that had different material than the assembled parts and the parts must be separated from all other parts that had been assembled. Part tolerances will also be improved because parts should be built to be within process capability where the parts should be designed so that they can only be assembled in one way. Besides, minimize the use of flexible components, such as rubber parts, gaskets, cables and so on, should be restricted as handling and assembly are usually more difficult. For a quick assemble, a non-fasteners method was develop in the example, using snap-fits and adhesive bonding instead of threaded fasteners such as nuts and bolts. Where possible, a product with a basic component should be designed to locate other components quickly and precisely.

Table 3 showed the modification that was completed for this study where the main improvement was proposed. The first improvement involved removing an unnecessary part while the second improvement reduced the part by eliminating the fasteners. Lastly, the third improvement where two parts combined, reducing the number of parts.

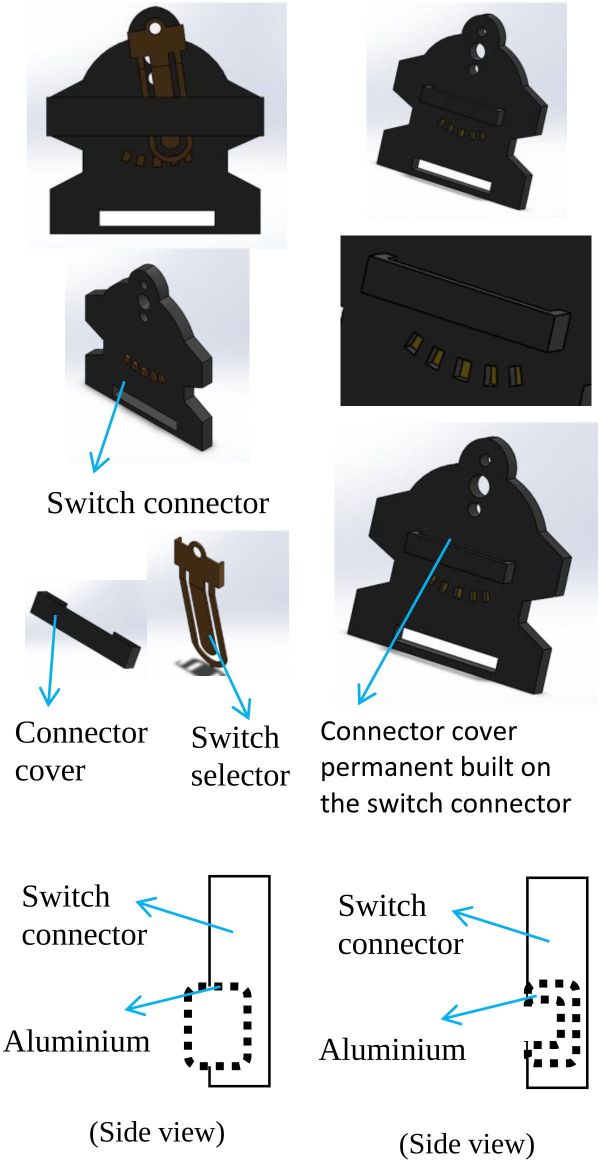
Table 3: Comparison of Original Design and Proposed Design

Part No.	Original Design	Modified Design	Description
1	Front and rear casing (eliminated handle cover)		
			The original design used a handle cover to give a comfortable hand griping while handling the hand mixer. Thus, a modification on the handle cover was proposed because the handle cover was eliminated. Then, the griping mechanism provided to the base handle as the picture beside to eliminate the handle cover part can reduce the assembly time. The modified design reduced the assembly process with the same performance as the original process.
2	Front and rear casing (eliminated fastener)		

The original design used four screws as the fastener for the rear casing and front casing. Meanwhile, the modified design used the snap-fit concepts where can be differentiated between the pictures above. A few parts can be reduced through the rear and front casing redesign, such as the four screws. Snap-fit used was not added to the raw material used for the product as it replaced the removed slot for the screw at both rear and front casing.

3 Switch connector and switch selector



The original design as the picture, three parts was switch connector, switch selector and connector cover. Connector cover was used to make sure that the switch selector is in the right place.

Thus, the modified design was to redesign the switch connector permanent joint with the connector cover that initially used glue as the joint mechanism.

The aluminium on the switch connector working as the electric connector. It was redesigning to be bulging inside compared to the original that bulging outside. By bulging inside the position of the selector are better.

3.5 Evaluation of Modified Hand Mixer

Table 4: Boothroyd Dewhurst DFA Evaluation Worksheet of Modified Hand Mixer

Part ID No	Number of times the operation is carried out consecutively	Alpha symmetry, α	Beta symmetry, β	Manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion & fastening time per part	Operation time (sec)	Operation cost (RM)	Estimation of theoretical minimum number of parts	Name of assembly
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2	1	360	360	30	1.95	08	6.5	8.45	0.01467	1	Rear casing
3	1	360	180	21	2.10	30	2.0	4.10	0.007118	1	Eject button
4	1	360	360	31	2.25	07	6.5	8.75	0.01519	1	Eject mechanism
5	2	180	0	05	1.84	00	1.5	6.68	0.01156	2	Gear compression spring
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12	1	360	360	30	1.95	06	5.5	7.45	0.01293	1	Switch
13	1	360	360	30	1.95	00	1.5	3.45	0.005989	1	Switch connector
14	1	360	360	39	4.00	06	5.5	9.50	0.01649	1	Switch selector
15	3	360	0	11	1.8	39	8.0	29.40	0.05104	3	Small switch screw
16	5	180	0	04	2.18	00	1.5	18.40	0.03194	5	Switch ring/washer
17	4	360	180	21	2.10	30	2.0	16.40	0.02847	4	Shock absorber
18	1	360	360	30	1.95	00	1.5	3.45	0.005989	1	Rear die cast
19	2	180	180	11	1.8	00	1.5	6.60	0.01146	2	Bearing bush

No.	# of times the operation is carried out consecutively	Alpha symmetry, α	Beta symmetry, β	Manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion & fastening time per part	Operation time (sec)	Operation cost (RM)	Estimation of theoretical minimum # of parts	Part Name
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21	1	360	360	30	1.95	11	5.0	6.95	0.01207	1	Motor
22	2	180	0	04	2.18	00	1.5	7.36	0.01278	2	Plastic shaft washer
23	2	180	0	04	2.18	00	1.5	7.36	0.01278	2	Metal shaft washer
24	1	180	0	06	2.17	00	1.5	3.67	0.006371	1	Shaft compression spring
25	1	360	360	30	1.95	00	1.5	3.45	0.005989	1	Electro magnet
26	2	180	0	10	1.50	38	6.0	15.00	0.02604	1	Long die cast
27	1	360	360	30	1.95	00	1.5	3.45	0.005989	1	Front die cast
28	1	360	0	12	2.25	30	2.0	4.25	0.007378	1	Fan
							Total	231.53	0.4019	44	**Design efficiency = 3NM / TM = (3)(44) / 231.53 = 0.5701@ 57.01%**
TM = Total manual assembly time CM = Total cost of manual assembly NM = Theoretical minimum number of parts								**TM**	**CM**	**NM**	

3.6 Design Efficiency Comparison

The design efficiency of the original design of hand mixer is 46.70 % meanwhile the modified design is 57.01 %. Thus, the modified design had better efficiency compared to the original design of the hand mixer was shown in Table 5.

Table 5: Comparison between original design and improved design

	Original Design	Improved Design	Improvement
Total assembly time (s)	282.43	231.53	18.02%
Number of different parts	31	28	9.68%
Total number of parts	53	47	11.32%
Total assembly cost (RM)	0.4903	0.4019	18.03%
Design efficiency	0.4670	0.5701	22.08%

3.7 Discussion

As for the discussion of this study, the comparison between the original design and modified design will be differentiated. Firstly, the original design with 31 different parts and the total quantity of 53 parts were able to be reduced to 28 different parts with a total of 47 parts.

Furthermore, using the Boothroyd Dewhurst DFA manual analysis, both the original design and the improved design are analysed to obtain the design efficiency. The original design of the hand mixer with operation time per unit, 282.43 s and operation cost per second was RM0.4903. The design efficiency of the original design hand mixer was of 46.70 %.

Meanwhile, the improved design hand mixer efficiency was 57.01 %, reducing the cost and time of operation with RM0.4019 per second and 231.53 s respectively. The improved design hand mixer as shown in Figure 7 was achieved through the DFMA methodology.

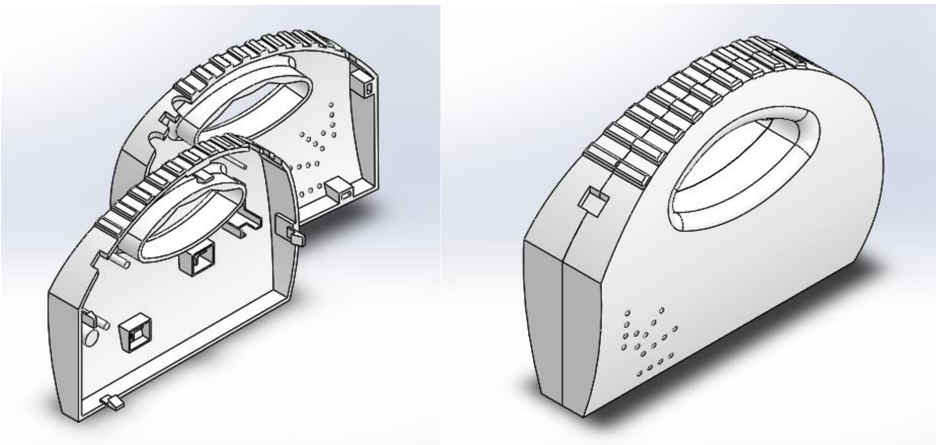

Figure 7: Modified design of hand mixer

4. Conclusion

The design efficiency of the original design hand mixer was 46.70 %. Furthermore, an improved design was produced with a better performance with the lower cost of assembly at 57.01 % design efficiency. The comparison the original design and the improved design can interpret as the design improvement was made was 22.08 %.

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