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

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Abstract: In a competitive market, a product must deliver high performance at low cost. To design a new and improved product, use Design for Manufacture and Assembly (DFMA). This thesis emphasizes the benefits of applying DFMA to a product. The DFMA method simplifies and lowers the cost of the original design. The study used manual DFA calculation on the chosen product, a hand mixer. The manual Design for Assembly (DFA) methodology was used to explain the hand mixer DFMA application. The study's methodology was explained, as was the manual DFA analysis of design efficiency. The original hand mixer design had a 293.54 s operation time and a RM115.76 operation cost. The improved design hand mixer efficiency was 60.00 %, saving RM89.23 and 223.08 seconds in cost and operation time. The original hand mixer design efficiency was 46.00 %. The new hand mixer design increased design efficiency by 30.43 percent. The manual DFA methodology was used to compare the original and improved efficiency design performance.

Keywords: DFMA, Cost Reduction and Design Improvement, Hand Mixer for Baking, DFA

1. Introduction

Design for Manufacture and Assembly (DFMA) is a system that allows for efficient manufacturing and assembly. By connecting the smaller parts, you can create a larger structure [4]. It is critical to consider both the manufacturing process of each part and the actual assembly process when creating a final product using DFMA. Manufacture has always been associated with producing, machining, and molding because the manufacturing process used a readily available resource to produce smaller parts that would later be assembled to form the final product [1]

Design for Manufacture (DFM) and Design for Assembly (DFA) are the two components of DFMA [5]. DFM is a methodology for creating individual parts, whereas DFA is primarily used for assembly [3]. Boothroyd and Dewhurst conducted numerous studies on assembly limitations during the design

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stages in 1987 in order to avoid manufacturing and assembly issues during the product development stages [7]. To achieve the lowest assembly cost, the product had to be designed with an appropriate economic assembly system in mind. It is possible to achieve this by designing a product with fewer parts and ease of assembly [6].

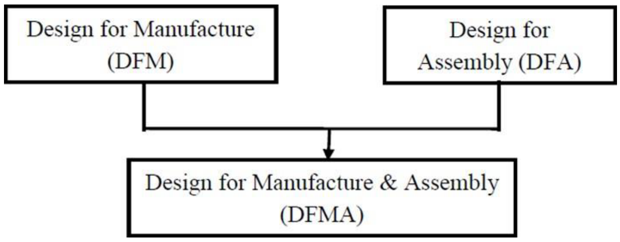


Figure 1: Definition of Design for Manufacture and Assembly (DFMA) (Dfa, 2000)

1.1 Design for Assembly (DFA)

The original DFA system came from 1960s auto-handling research. A group technology classification system for small components has been developed. In addition, designers can help make design components that are easy to manage automatically. If Design for Manufacturing (DFM) is used to make part manufacturing easier and cheaper, Design for Assembly (DFA) is used to make part assembly easier and cheaper. The simplified assembly process will save costs. DFA was created by Boothroyd and Dewhurst. DFA is the most widely used production technique [8]. DFA provides efficient design and assembly. This can be achieved by incorporating assembly and support activities into the design process [9]. According to the definition of DFA, DFM is the sequence of DFA in the manufacturing of a product. The DFA contribution will then be saved [1].

1.2 DFA Guidelines

The DFA guideline has been defined in several ways as it comes from various authors. Some author explains it in-depth, while some of them only classified it in a few lists, divided in concept to another theory. Nevertheless, the key goal of DFA is to reduce the expense of assembly [10].

Guideline as follows:

i. Reduce the number of parts: this can be achieved by reducing the total number of fasteners and designing the product with fewer parts.
ii. The minimum size of components: lower number of parts, lower assembly costs. It can be achieved by eliminating non-essential parts, but the system is still working and eventually integrating a multiple element into a single part.
iii. Minimizing the number of fasteners and their components: Screw and washer will increase assembly costs and time. To minimize costs, screws, nuts, and washers may be replaced by alternative fasteners such as the snap-fit design on the product, molded hinges brace or hook, and press fit.

1.3 Mixer

Kitchen mixing began with a stick, forks, and spoon. Electricity transforms the manual mixer into an electric mixer. High- speed mixer invented after the 1920s. An electrical mixer uses a mechanical gear system to mix ingredients. The eggbeater was the first electrical appliance. It was done by hand with an eggbeater. In 1908, Herbert Johnson proposed automating the mixer by adding a motor. Herbert John was inspired by a baker who was hand-mixing bread dough. Herbert Johnson invented the "H" mixer in 1914. [11].

Today, there are two types of mixers. First, there's the stand mixer and the hand mixer. Typically, a stand mixer has a rotating built-in bowl that rotates while the mixing operation is in progress. When compared to a hand mixer, a stand mixer is far more efficient [12]. Herbert Johnston, an engineer at the Hobart Corporation, was the first to invent the stand mixer. He was inspired after witnessing a baker mix dough and reasoned that there must be a better way to accomplish the task. Development began in 1914, with the 'H-5' model being the first stand mixer he introduced. The C-10 model, introduced in 1918 and manufactured at Hobart's Troy Metal Products subsidiary in Springfield, Ohio, was the first to bear the KitchenAid name. Then comes the hand mixer. A hand mixer based on figure 2 is a type of mixer that is held in one's hand. The motor powered the gear system, which performed the mixing via the hook or beater. Because a stand mixer has a larger motor, it performs better than a hand mixer. Although hand mixers are not as powerful as stand mixers, they are the more affordable option for home appliance mixing. [13].

Figure 2: Hand Mixer (Philips HR3705/10,2018)

2. Materials and Methods

DFMA methodology was used to study the cost reduction of the hand mixer. In this study, the manual DFA method was used to evaluate the design efficiency of the existing design and improved design.

2.1 Method

The manual review of the DFA is normally carried out in five stages of:

i. Disassemble product and description of parts.
ii. Evaluation of the assembly process [2]
iii. Definition and improvement of the parts proposed.
iv. Re-evaluation of modified parts [2]
v. Evaluation of original and improved parts.

2.2 Product part detail

A total of 32 components were discovered. The hand mixer's motor was made up of 14 pieces.

Figure 3: Hand mixer parts by 'Hannah jenkin Hand mixer'

No	Part Name	Function	Material	Manufacturing Process
1	Front casing	To case the inner workings of the product, and stop anyliquids or dirt getting inside	ABS plastic	Plastic injection molding
2	Rear casing	To case the inner workings of the product, and stop anyliquids or dirt getting inside	ABS plastic	Plastic injection molding
3	Handle cover	To allow a matt surface forthe handling operation	ABS plastic	Plastic injection molding
4	Tamper proof casing Screw	To hold part together effectively	Steel	Thread rolling
5	Eject button	To pushes out beaters	ABS plastic	Plastic injection molding
6	Eject mechanism	To transform the force ofpush on the button to turnon the devices	ABS plastic(not spray painted)	Plastic injection molding
7	Gear compression spring	To ease the pressure andfriction when the eject mechanism is pushing beater out	Steel wire	Coiled and heat-treated
8	Gear holder	To hold gears in place	Aluminum	Stamped andbent.
9	Plastic helicalgear	To turn motor rotation to therotary motion on a vertical axis along the worm drive	Nylon	Plastic injection molding
10	Metal gear washer	To stop metal corroding and reduce friction	Stainless steel	Wire bending
11	Beater and hook	As the attachment to turn the rotary motion in gearinto motion	Stainless steel	Stamped, bentand heat treated
12	Turbo Boost button	To activate turbo speed	ABS plastic	Plastic injection molding
13	Turbo boost mechanism	To complete the turbomechanism	PP plastic casing with electric wire inside	Plastic injection molding
14	Switch	To connect to themechanism	ABS plastic	Plastic injection molding
15	Switch connector	To send different voltage tothe electro-magnet	PE plastic and aluminum contact	Plastic injection molding, contact bent in place
16	Switch selector	To indicate the selectedvoltage	Zinc-aluminum	Stamped andbent
17	Connector cover	To keep connector in contact with aluminum	ABS plastic	Plastic injection molding
18	Small switch screw	To hold part togethereffectively	Steel	Thread rolling
19	Switch ring	To complete circuit betweenswitch selector and electro- magnet	Zinc-aluminum	Metal stamping
20	Shock absorber	To reduce vibration of product during operation	Siliconerubber	Compression molded
21	Rear die cast	To hold motor and associated components together inside casting	Aluminum	Aluminum die casting
22	Bearing bush	To allow motor shaft to move and swivel slightly	Steel	Die casting

23	Bush constraint	To keep the bush constrained	Aluminum	Stamped and bent
24	Motor	To turn electrical energy tomechanical rotary motion	Stainless steel, copper wire and iron plate	Thread rolling and wire winding
25	Plastic shaft washer	To stop metal corroding and reduce friction	Nylon	Wire bending
26	Metal shaft washer	To stop metal corroding and reduce friction	Steel	Wire bending
27	Shaft compression spring	To allow for slight movement in the motorshaft	Steel wire	Coiled and heat-treated
28	Flex	To deliver electricity from main supply to device.	PVC	Plastic injection molded
29	Electromagnet	To create a magnetic fieldaround the motor	Copper wireand iron plates	Cooper wirewinding andiron plate lamination
30	Long die cast	To hold part togethereffectively	Steel	Thread rolling
31	Front die cast	To hold motor and associated components together inside casting	Aluminum	Aluminumdie casting
32	Fan	To eject the hot air form operating motor to thesurrounding	PP plastic	Plastic injection molding

2.3 Assembly process evaluation [2]

The evaluation of the assembly using the Boothroyd method was conducted to this study were firstly, the usage of the DFA worksheet table as shown in Figure 4. The procedure of evaluation of the DFA worksheet can be described as:

i. The parts details and its material: As Table 1 describes, the manufacturing process of the part then recorded to the DFA worksheet like Figure 4.

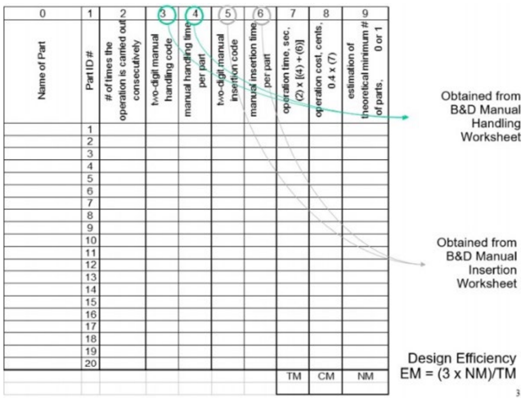


Figure 4: Manual DFA worksheet [1]

ii. The determination of the effect of part symmetry of each part:

The balance of symmetry during handling is very important for the assembly process. Alpha symmetry, α, and beta symmetry, β, are two different types of symmetry. Rotation of the alpha symmetry is shown in Figure 5, which illustrates that it is rotated at an angle to the axis of rotation. When compared 45 to Figure 6, which shows beta symmetry rotation on the axis of insertion, rotation about the axis of insertion is seen as being slower

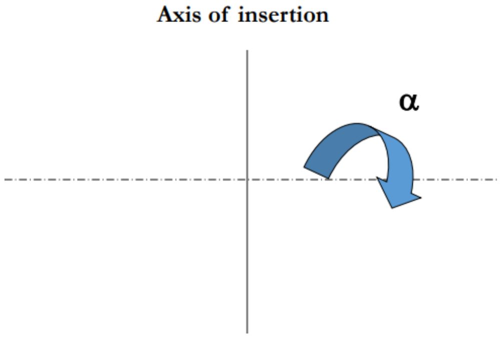


Figure 5: Alpha symmetry rotation [1]

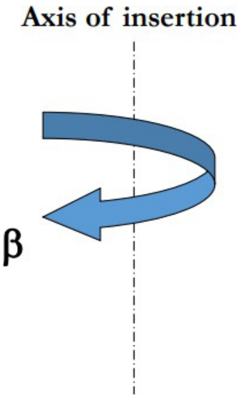


Figure 6: Beta symmetry rotation [1]

iii. Manual handling worksheet evaluation:
Using the handling symmetries, α and β, and the information of the parts. The two-digit handling code and the time taken for manual handling of each piece are obtained by manual handling, as shown in Figure 7.

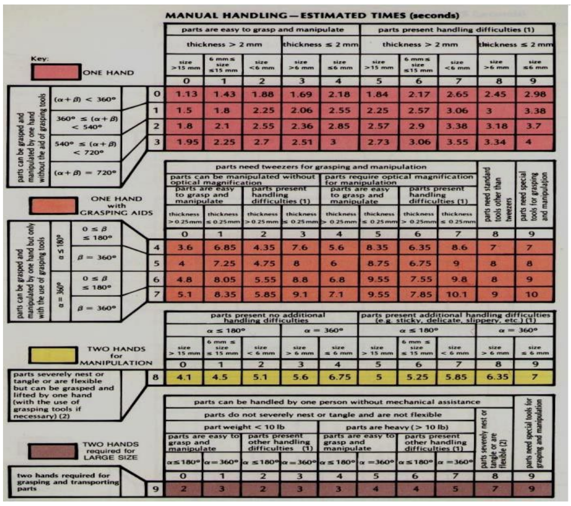


Figure 7: Manual handling worksheet [1]

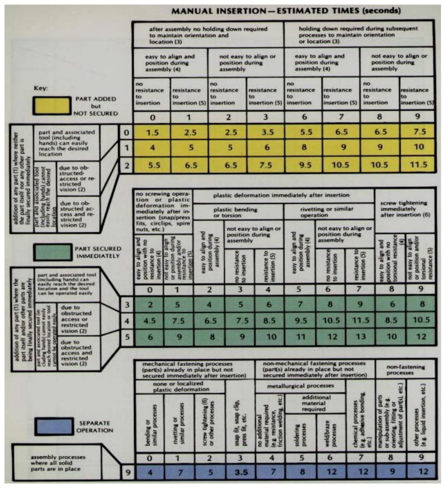


Figure 8: Manual insertion worksheet [1]

iv. Manual insertion worksheet evaluation
Manual insertion worksheet assessment showed when Figure 8 also uses the handling symmetries, α and β, and the parts described to achieve two-digit manual insertion and time taken for each part during insertion.

v. Operation time and cost calculation:
The operation time is determined by the part quantity multiplied by the manual handling and insertion time for each part. The design efficiency is measured by a 0.4 scale for the cost of operation. The cost of operation is 0.4 times the time before each component.

$$operation\ time = c2(c4 + c6)$$

$$operation\ cost = 0.4c7 \qquad Eq.1$$

a) C2=number of times the operation is carried out consecutively,

b) C4=manual handling time per part

c) C6 stand for manual insertion per time per part

d) C7 stand for operation time in second.

3. Results and Discussion

This section focuses mainly on the results of the review of the data. This section aims to improve the study's goal by reducing the number of parts and making a better-quality product than the original design. These analyses will be carried out via the DFA Manual.

3.1 Manual DFA analysis on original design

Table 2 below shows the analysis of the original design of a hand mixer. The study has been done using DFA table. The table will generate the operation time, operation cost and design efficiency on the original design.

Table 2: Boothroyd Dewhurst DFA Evaluation Worksheet of Original Hand Mixer

Part ID No	Number of times	Manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion & fastening time per part	Operation time	Operation cost	Estimation of theoretical minimum number of parts	Part Name
32	1	30	1.95	08	6.5	8.45	3	1	Front casing
31	1	30	1.95	08	6.5	8.45	3	1	Rear casing
30	1	31	2.25	30	2.0	4.45	1.7	0	Handle cover
29	4	11	1.8	39	8.0	39.2	15	0	Tamper proof casing Screw
28	1	21	2.10	30	2.0	4.10	1.6	1	Eject button
27	1	31	2.25	07	6.5	8.75	3.5	1	Eject mechanism
26	2	05	1.84	00	1.5	6.68	2.672	2	Gear compression spring
25	2	34	3.00	30	2.0	10.0	4	2	Gear holder
24	2	10	1.50	00	1.5	4.00	1.6	2	Plastic helical gear
23	2	04	2.18	00	1.5	7.36	2.9	2	Metal gear washer
22	2	20	1.80	40	4.5	12.6	5	2	Beater and hook
21	1	30	1.95	00	1.5	3.45	1.38	1	Turbo Boost button
20	1	30	1.95	00	1.5	3.45	1.38	1	Turbo boost mechanism
19	1	30	1.95	06	5.5	7.45	2.98	1	Switch
18	1	30	1.95	00	1.5	3.45	1.38	1	Switch connector
17	1	39	4.00	06	5.5	9.50	3.8	1	Switch selector
16	1	31	2.25	31	5.0	7.25	2.9	0	Connector cover
15	3	11	1.8	39	8.0	29.4	11.7	3	Small switch screw
14	5	04	2.18	00	1.5	18.4	7.36	5	Switch ring/washer

13	4	21	2.10	30	2.0	16.4	6.56	4	Shock absorber
12	1	30	1.95	00	1.5	3.45	1.38	1	Rear die cast
11	2	11	1.8	00	1.5	6.60	2.64	2	Bearing bush
10	2	14	2.55	00	1.5	8.10	3.24	2	Bush constraint
9	1	30	1.95	11	5.0	6.95	2.78	1	Motor
8	2	04	2.18	00	1.5	7.36	2.94	2	Plastic shaft washer
7	2	04	2.18	00	1.5	7.36	2.94	2	Metal shaft washer
6	1	06	2.17	00	1.5	3.67	1.46	1	Shaft compression spring
5	1	33	2.51	44	8.5	11.1	4.4	1	Flex
4	1	30	1.95	00	1.5	3.45	1.38	1	Electromagnet
3	2	10	1.50	38	6.0	15.0	6	1	Long die cast
2	1	30	1.95	00	1.5	3.45	1.38	1	Front die cast
1	1	12	2.25	30	2.0	4.25	1.7	1	Fan
				Total		293.54 TM	115.764 CM	45 NM	Design efficiency = 3NM / TM = (3)(45) / 293.54= 0.460@ 46%

3.2 Assembly Cost and Design Efficiency of Original Design

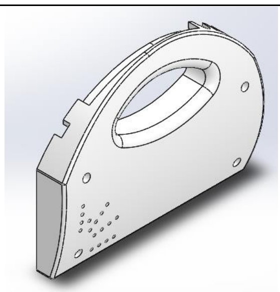
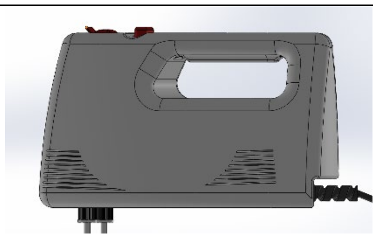
From Table 2, the operation time per unit is 293.54 second and the operation cost per unit is RM 115.76.

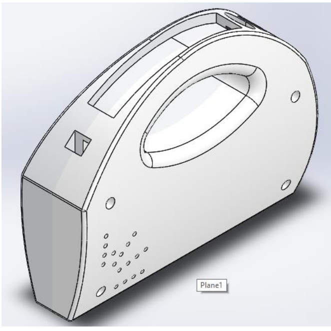
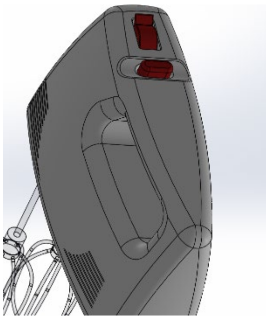
3.3 Modification design concept

The hand mixer is a machine that allows you to mix food while holding it. So, the hand mixer must be portable. The hand mixture machine has flaws, such as the excessive use of fasteners. Because the machine vibrated a lot while the hand mixer was running, fasteners were not recommended because they could be loosened. As a result, the hand mixer's design was modified to address the issues.

The current number of parts, 32, is too many for the hand mixture machine. Using fewer parts reduces labour requirements, and reducing the number of unique parts reduces assembly costs. The rules for reducing the number of parts include those that do not move relative to other assembled parts, those that are made of a different material than the assembled parts, and those that must be separated from other assembled parts. Precision will be improved as parts are built within process capability and designed for one-way assembly. It is also recommended to use flexible components sparingly because handling and assembly are more difficult. Instead of threaded fasteners like nuts and bolts, the example uses snap-fits and adhesive bonding. A product's basic component should be designed to locate other components quickly and precisely.

Table 3: The modification suggestion for hand mixer

Part	New design
	 Description: The original design used four screws as the fastener for the

Original product Front and rear casing (eliminate fastener)	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.
 Original product Front and rear casing (eliminate handle cover)	 Description: The original design utilized a handle cover to provide a secure grip on the hand mixer. As a result, because the handle cover was to slip, a modification to the handle cover was proposed. Then, as shown in the illustration above, the gripping mechanism provided to the base handle. The modified design reduced the assembly process while maintaining the original process's performance

3.4 Manual DFA analysis on modification design

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

Part ID No	Number of times	Manual handling code	Manual handling time per part	Two-digit manual insertion code	Manual insertion & fastening time per part	Operation time	Operation cost	Estimation of theoretical minimum number of parts	Part Name
27	1	30	1.95	08	6.5	8.45	3.38	1	Rear casing
26	1	21	2.10	30	2.0	4.10	1.64	1	Eject button
25	1	31	2.25	07	6.5	8.75	3.5	1	Eject mechanism
24	2	05	1.84	00	1.5	6.68	2.672	2	Gear compression spring
23	2	34	3.00	30	2.0	10.0	4	2	Gear holder
22	2	10	1.50	00	1.5	4.00	1.6	2	Plastic helical gear
21	2	04	2.18	00	1.5	7.36	2.944	2	Metal gear washer
20	2	20	1.80	40	4.5	12.6	5.04	2	Beater and hook
19	1	30	1.95	00	1.5	3.45	1.38	1	Turbo Boost button
18	1	30	1.95	00	1.5	3.45	1.38	1	Turbo boost mechanism
17	1	30	1.95	06	5.5	7.45	2.98	1	Switch

16	1	30	1.95	00	1.5	3.45	1.38	1	Switch connector
15	1	39	4.00	06	5.5	9.50	3.8	1	Switch selector
14	3	11	1.8	39	8.0	29.4	11.76	3	Small switch screw
13	5	04	2.18	00	1.5	18.4	7.36	5	Switch ring/washer
12	4	21	2.10	30	2.0	16.4	6.56	4	Shock absorber
11	1	30	1.95	00	1.5	3.45	1.38	1	Rear die cast
10	2	11	1.8	00	1.5	6.60	2.64	2	Bearing bush
9	2	14	2.55	00	1.5	8.10	3.24	2	Bush constraint
8	1	30	1.95	11	5.0	6.95	2.78	1	Motor
7	2	04	2.18	00	1.5	7.36	2.944	2	Plastic shaft washer
6	2	04	2.18	00	1.5	7.36	2.944	2	Metal shaft washer
5	1	06	2.17	00	1.5	3.67	1.468	1	Shaft compression spring
4	1	30	1.95	00	1.5	3.45	1.38	1	Electromagnet
3	2	10	1.50	38	6.0	15.0	6	1	Long die cast
2	1	30	1.95	00	1.5	3.45	1.38	1	Front die cast
1	1	12	2.25	30	2.0	4.25	1.7	1	Fan
				Total		223.08 TM	89.232 CM	45 NM	Design efficiency = 3NM / TM = (3)(45) / 223.08= 0.605@ 60%

From Table 4, the operation time per unit is 223.08 second and the operation cost per unit is RM 89.23 The design efficiency can be calculated by using Eq. 2 below.

Design efficiency = (3s NM / TM) *Eq.*2

= (3x45)/223.08

= 0.605 @ 60 %

3.5 Discussion

The comparison between the original design and the modified design will be differentiated in the discussion of this study. To begin, the original design with 32 different parts and a total quantity of 53 parts could be reduced to 27 different parts and a total quantity of 47 parts. According to the DFMA methodology guidelines, the assembly process can be reduced when the number of parts is reduced, and thus the improved design was able to reduce the assembly cost. Furthermore, both the original and improved designs are analyzed using the Boothroyd Dewhurst DFA manual analysis to determine design efficiency. The hand mixer's original design had an operation time per unit of 293.54s and an operation cost per second of RM115.76. The original design hand mixer had a design efficiency of 46.00 %. Meanwhile, the improved design hand mixer efficiency was 60.00 %, lowering operating costs and time by RM89.23 and 223.08 per second, respectively.

4. Conclusion

Based on the results of the analysis, it is possible to conclude that the Design for Assembly (DFA) process is very useful for evaluating current hand mixers. This method is also very useful in optimizing production performance and operating costs for the product under consideration. When design efficiency and assembly costs are compared before and after improvement, this method shows a significant improvement. It is also possible to conclude that reducing the number of parts will improve design efficiency and thus lower assembly costs. According to the findings of this study, the DFA method is very useful in reducing production costs as well as the number of parts. The effectiveness of this approach prompted Boothroyd Dewhurst, Inc. to develop technological tools based on the DFA approaches that were being used. The objectives of this study were met because the original design hand mixer was measured, and the design efficiency was evaluated using the manual DFA analysis method. The original design hand mixer had a design efficiency of 46.00 %. Furthermore, at 60.00 % design efficiency, an improved design with better performance and lower assembly costs was produced. The difference between the original and improved designs can be interpreted as a design improvement of 30.43 percent.

Acknowledgement

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