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Optimization of Components Design and Assembly Process Using DFMA Analysis: A Case Study of Bread Toaster

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Abstract: Every sector needs a low-cost, high-quality product with a shorter time to market ability. Design for Manufacturing and Assembly (DFMA) is a manufacturing-related process that can be used to decrease or redesign various items. The advantage of DFMA is that it can optimize the design and assembly time of a product. The main goal of this research is to offer a new bread toaster design. In addition, in order to support the improvements, components design, manufacturing cost, assembly time, and design efficiency are being examined. The study was carried out by disassembling the bread toaster, observing the functioning of each component, 3D modeling with Solid Works software, and finally applying the DFMA design principles to the operation cost, time, and design efficiency. The selection criteria for a successful design are based on the cost of manufacture and the time of assembly. Finally, the design chosen has been proven to meet all the relevant requirements by improving in the operation cost, operation time and design efficiency. The existing product design efficiency is 33.00 % and the new design is 52.00 %. The operation time for new design also improving from 82.86 s per unit to 40.71 s per unit. In this study, the overall operation cost saved is RM16.86 per unit which is RM33.14 reduced to RM 16.28. Hence, this research manages to improve the design efficiency of the product, and this will be beneficial to manufacturers and consumers.

Keywords: DFMA, Design Efficiency, Operation Time, Operation Cost

1. Introduction

At present days, product design contains a huge number of screws, taps, covers and inessential aspects. Some aspects need to be look after in detail for the most competent approach that can create a solution for the problem using Design for Manufacturing and Assembly (DFMA) methodology [1]. As a result of more inessential parts, the time costs for the product to be presented at market will be more.

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That product would be expired at the time it meets market requirements The design process methods that focusses primarily on designing a product that is effortless to produce and assemble is called Design for Manufacture and Assembly (DFMA) which Peter Dewhurst and Geoffrey Boothroyd have implemented this method in their third edition article [2].

In addition, DFMA means design the component or system for the ease of manufacturing and assembly by exemplifying the application of DFMA aspects like, re-designing parts and optimize the design to ensure reliability, safety, the minimum number of parts, less time to market and customer satisfaction [3]. The use of the DFMA method offers many other advantages for the product, such as product quality, reduction of the number of components, optimization of components design and simplify of assembly procedures and flexibility [4]. Moreover, DFMA is actually a systematic approach that allows designers to predict the costs of manufacturing in the early stages of the design process, which includes designing a product so that the design rapidly passages into production, the product is manufactured at a less cost, manufactured with minimum effort in terms of processing and gripping and the manufactured product gains designed level of quality [5].

To apply DFMA technique, a home appliance has been chosen which is DeLonghi dual sided bread toaster. DeLonghi is well known for its home appliances machines for over the years. In the aspect of bread toaster production, DeLonghi should have the attention of DFMA. The major objectives that needs to be achieved are, to determine the initial products performance in term of design efficiency, to provide modification for the original product and also to evaluate the performance between the proposed alternative design and the original design using DFMA technique. With manual Boothroyd Dewhurst DFA table, the following objectives could be achieved. This design research can come up with some information on problems related especially to the bread toaster. The design efficiency can also be compared between the original design and the improved design of the DeLonghi dual sided bread toaster, besides accomplishing this DFMA method. Furthermore, if the bread toaster ever created by the manufacturers, it must suit the wants of the customers, and this study will be great to them.

2. Materials and Methods

DeLonghi dual sided bread toaster is chosen as the product for this study. The details of the design and the number of components has an impact on the assembly process of the product and this statement was well discussed before. With stated materials and methods for the bread toaster, the DFA analysis can be successfully applied.

2.1 Materials

The primary thing to do is to disassemble the bread toaster into parts. Upon disassembly, the component consists of 9 main parts with screws and fasteners excluded. The toaster is disassembled for dimension analysis. This toaster consists of 9 parts and those parts are main outer cover, control panel, control knob, right and left bread crumb tray, double bread holder, outer bread holder cover and toaster charger Table 1 shows the description of disassembled DeLonghi dual sided bread toaster.

Table 1: Data and part features for each part of the bread toaster

Part Number	Part Name	Part Quantity	Part function	Dimensions (L x W x H) mm

Main outer cover	1	Separates the internal heating mechanisms from the user.	320 x 215 x 320
Control panel	1	Attachment of control knobs interface with time and browning level	-
Control knob	1	Adjusts toast time.	24 x 46 x 17
Right bread crumb tray	1	Collects bread crumbs of the bread holder 1	152 x 20 x 158
Left bread crumb tray	1	Collects bread crumbs of the bread holder 2	152 x 20 x 158
Bread holder 1	1	Bread is loaded through compartments	80 x 80 x 265
Bread holder 2	1	Bread is loaded through compartments	80 x 80 x 265
Outer bread holder cover	1	Supports the toaster to be upright	205 x185 x 217
Toaster charger lead	1	To connect bread toaster to the power source	340 x 37 x 332

2.2 Methods

Flow process describes the process which DeLonghi dual sided bread toaster undergoes to achieve the modification and also great design efficiency. process also emphasizes the methodology in how the DFA manual analysis is made on the bread toaster. Figure 1 shows the manual DFMA methodology flow process.

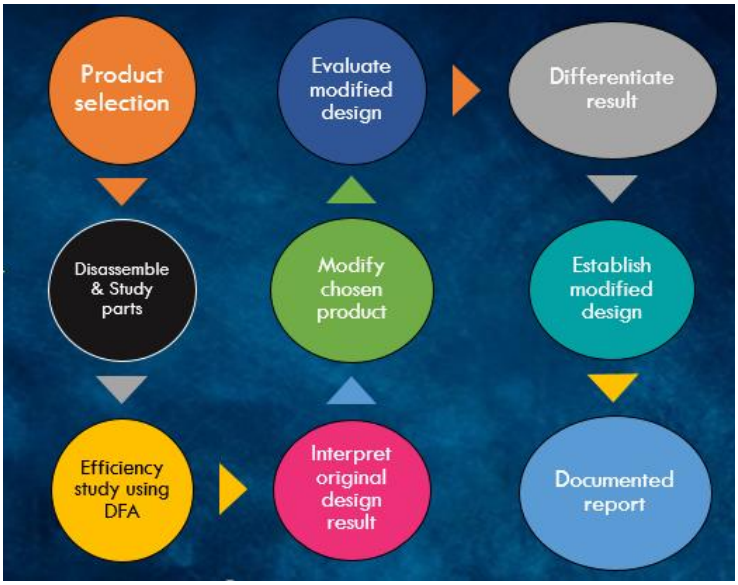

Figure 1: Manual DFMA methodology flowchart

First and foremost, DeLonghi dual sided bread toaster has been chose as a product for research. The reason DeLonghi dual sided bread toaster selected is because of its complexity in design which makes a longer time in assemble it. Next, the bread toaster has been disassembled to get parts details and ID. In addition, parts study also includes with material type and manufacturing process. This is because manufacturing cost can be reduced. Next, efficiency study using DFA manual worksheet. Below shows the DFA manual worksheet which used for efficiency evaluation.

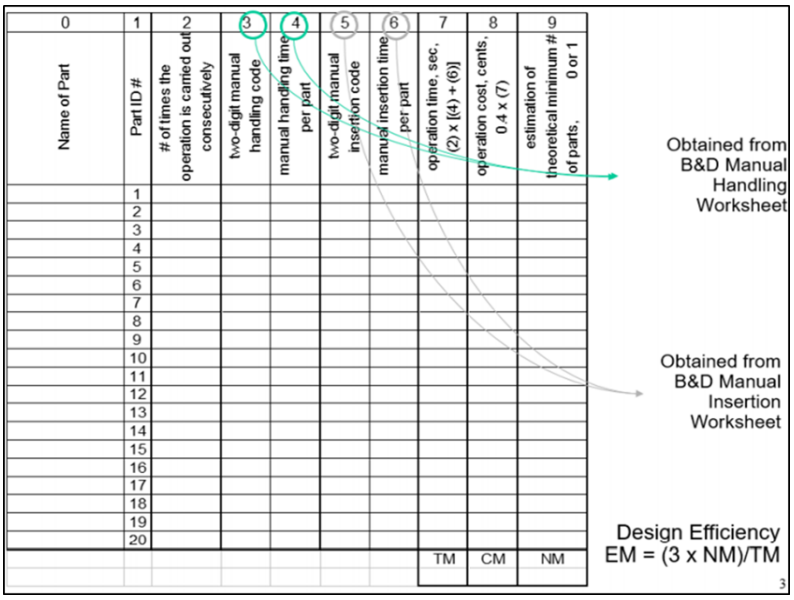

Figure 2: Manual DFA Worksheet

This DFA manual worksheet evaluates manually the operation time, manual handling code, manual handling time, manual insertion time, operation time and cost, and also estimated parts minimization. Firstly, disassembled parts is identified using numbers and this would be the part ID. Every disassembled parts should be given identity number. Next, the part operation section is based on the number of times each part is handled. Thirdly, author have to insert two-digit manual handling code and manual handling time per part. These values are referred from B & D manual handling worksheet. Below shows the B & D manual handling worksheet.

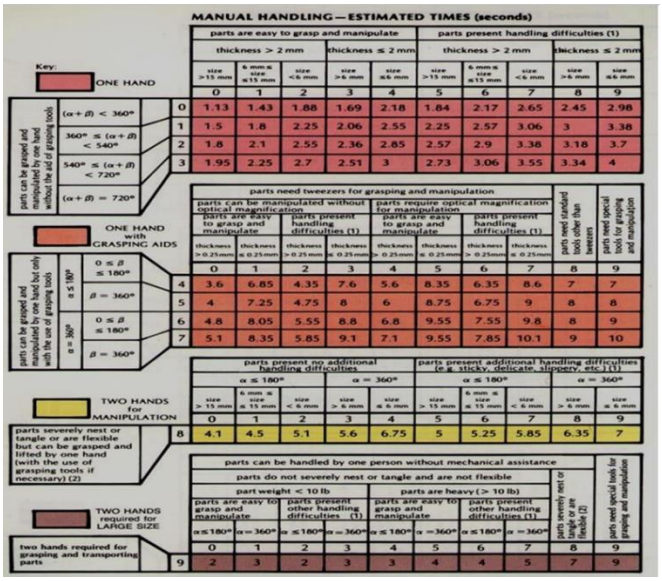

Figure 3: B & D manual handling evaluation worksheet

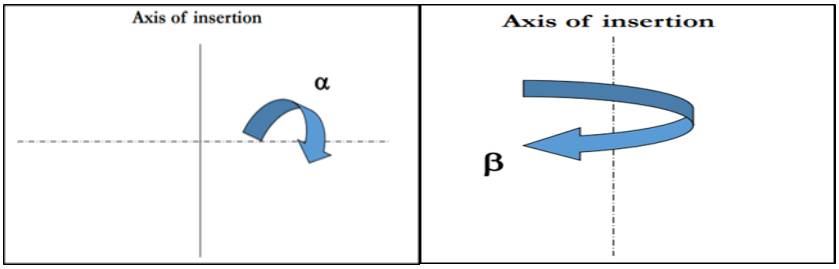

Figure 4: Alpha and Beta axis rotation symmetries

This axis symmetries is applied when assembling the parts. By total up the axis symmetries which is (0 to 360 degrees), the B & D manual handling code is referred. There are four sections in the worksheet which are one hand, one hand with grasping aids, two hand for manipulation and two hands required for large size. Most of the parts in DeLonghi dual sided bread toaster has large size parts which does not requires axis references. After identifies the handling code, insertion code is identified. The insertion code is reffered using B & D manual insertion code. Below shows the B & D manual insertion code.

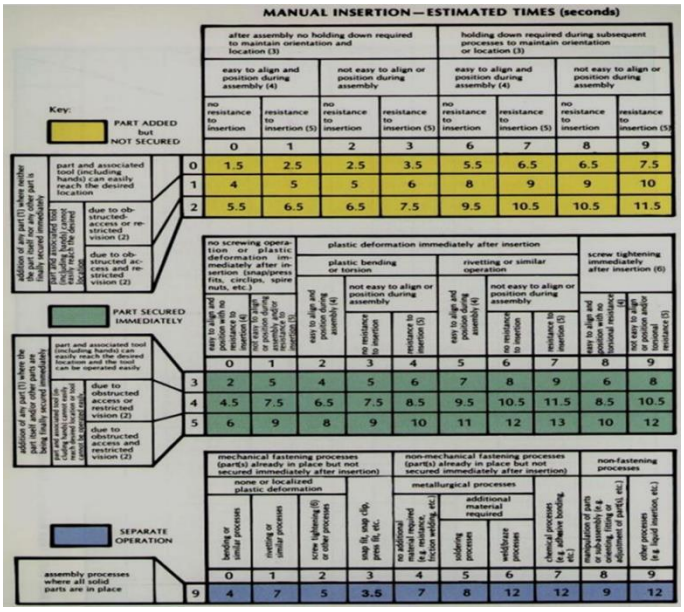

Figure 5: B & D manual insertion evaluation worksheet

This worksheet has three section which is component added but not fixed, part instantly secured, and distinct action. When the disassembled part is inserted during assembly, if the part is screwed or fixed immediately, it is part secured immediately. If the part is just assembled but not fixed, it will be part added but not secured. If the part assembled but undergoes other fixing operations, it is said to be separate operation. For DeLonghi dual sided bread toaster, most of the parts are added but not secured.

Finally, after identifies the manual handling and insertion codes, the operation time and operation cost can be calculated. By referring the design efficiency formula which Boothroyd Dewhurst has implemented, which is EM = (3 x NM) / TM. EM refers to design efficiency, NM refers to theoretical minimum number of parts and TM refers to operation time. When, design efficiency is identified for existing design, there is modification is made using Solid works software and the design is recalculated for design efficiency. If the redesign achieved greater efficiency than the existing, the study has

achieved success. If not, there will be another redesign until the value of design efficiency is higher than old design.

3. Results and Discussion

The manual DFA analysis compares the DeLonghi dual sided bread toaster's total operating time, total cost per unit, and design efficiency before and after the modification. The use of manual DFA worksheet will make the study of product easier and faster to design, making it more quality and less expensive to manufacture. The data collected in a table 2 are based on manual DFA worksheet. Table 2 shows DFA analysis on existing bread toaster design.

Table 2: DFA analysis on existing bread toaster design

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Name of part	**Part ID number**	**Number of times the operation is carried out consecutively**	**Two-digit manual handling code**	**Manual handling time per part**	**Two-digit manual insertion code**	**Manual insertion per time per part**	**Operation time, sec, (2) × [(4) + (6)]**	**Operation cost, cents, 0.4 × (7)**	**Estimation of the theoretical minimum number of parts**
Toaster charger lead	1	1	35	2.73	02	2.5	5.23	2.092	1
Control knob	2	1	00	1.13	00	1.5	2.63	1.052	1
Control panel	3	1	80	4.1	02	2.5	6.6	2.64	1
Main outer cover	4	1	80	4.1	01	2.5	6.6	2.64	1
Right bread crumb tray	5	1	30	1.95	10	4.0	11.9	4.76	1
Left bread crumb tray	6	4	30	1.95	10	4.0	11.9	4.76	1
Bread holder 1	7	1	80	4.1	10	4.0	16.2	6.48	1
Bread holder 2	8	1	80	4.1	10	4.0	16.2	6.48	1
Outer bread holder cover	9	1	80	4.1	00	1.5	5.6	2.24	1
Total							82.86s	33.144	9
							Design Efficiency	3NM/TM = 0.33	

As stated in Table 2, the total operation time and cost per unit of existing DeLonghi dual sided bread toaster have been determined. The total operation time is 82.86 s and the total operation cost is RM 33.15. The design efficiency calculated is 33.00 %. Based on the design efficiency, modifications made on the toaster's disassembled parts. New design efficiency is calculated for modified design using manual DFA worksheet. Table 3 shows DFA analysis on modified bread toaster design.

Table 3: DFA analysis on existing bread toaster design

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Name of part	**Part ID number**	**Number of times the operation is carried out consecutively**	**Two-digit manual handling code**	**Manual handling time per part**	**Two-digit manual insertion code**	**Manual insertion per time per part**	**Operation time, sec, (2) × [(4) + (6)]**	**Operation cost, cents, 0.4 × (7)**	**Estimation of the theoretical minimum number of parts**
Toaster charger lead	1	1	35	2.73	02	2.5	5.23	2.092	1
Control knob	2	1	00	1.13	00	1.5	2.63	1.052	1
Control panel	3	1	80	4.1	02	2.5	6.6	2.64	1
Main outer cover	4	1	80	4.1	01	2.5	6.6	2.64	1
Bread crumb tray	5	1	30	1.95	10	4.0	5.95	2.38	1
Bread holder	6	1	80	4.1	10	4.0	8.1	3.24	1
Outer bread holder cover	7	1	80	4.1	00	1.5	5.6	2.24	1
Total							40.71s	16.284	7
							Design Efficiency		3NM/TM = 0.52

Parts including bread crumb tray and bread holder is modified. As stated in Table 3, the total operation time and cost per unit of modified DeLonghi dual sided bread toaster have been determined. The total operation time is 40.71 s and the total operation cost is RM 16.28. The design efficiency calculated is 52.00 %.

3.2 Discussions

The total values calculated for existing design and original design of DeLonghi dual sided bread toaster is tabulated in a table for comparison. Table 4 shows the performance comparison of bread toaster. Criteria including total disassembled parts, total operation time (T.M), total operation cost and design efficiency are tabulated.

Table 4: Example of presenting data using a table

	Existing design	Modified design
Total disassembled parts	9 units	7 units

Total operation time (T.M)	82.86s	40.71s
Total cost	Rm 33.14	Rm16.28
Design efficiency	33%	52%

From table 4, the performance of DeLonghi dual sided bread toaster is compared. There is a lot of differences between exiting and modified design of DeLonghi dual sided bread toaster in term of total disassemble parts, total operation time, total cost and also design efficiency. The total parts of existing bread toaster design have been reduced from 9 units to 7 units and making it huge difference in efficiency when compared with modified design. When parts decreased, the total operation time also decreases because there will be needed les time to handle the manufacturing and assembly process. Furthermore, the operation cost also shows bigger difference which will absolutely would be a cost saving product for users. So, the modification made on DeLonghi dual sided bread toaster have made the design more efficient and also reduced in assembly process.

Based on previous research [6], the author has redesigned a joystick using the same methodology. Based on the author's result, the design efficiency which achieved by the redesign is 5.40 %, which is 20.40 % to 25.80 %. When compared to bread toaster case study, the design efficiency achieved is greater than previous study with just minimizing two parts and redesigned two parts. The previous joystick study made differences in minimizing a total number of parts from 38 to 33 units. The assembly time minimization is also higher in this case study rather than previous study which is 42.15 s for bread toaster and 61.76 s for joystick. So, this discussion shows that modification made on DeLonghi dual sided bread toaster is clearly a successful design efficiency achievement rather than joystick.

3.4 Figures

The parts which is chose to undergo modification is presented below. There are total of four parts of bread toaster is modified. They are bread crumb tray, bread holder, bread holder covers and control knob. Figure 6 shows bread crumb tray before and after modification.

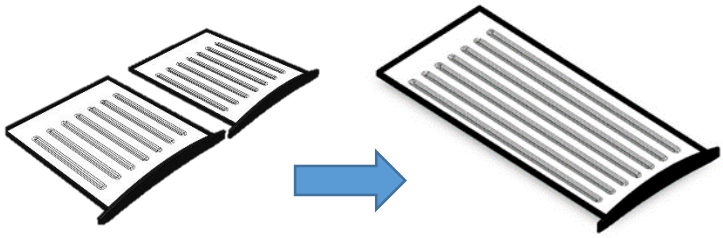

Figure 6: Bread crumb tray which is existing and modified

Before the modification, there are two bread crumb trays which is right and left bread crumb trays. With a length of 150 mm, it consumes time to assemble two bread crumb trays into the dual sided bread toaster. So, the two bread crumb trays are combined into one. As a result, the assembly time is and also cost is reduced. Figure 7 shows the second modified part of the toaster.

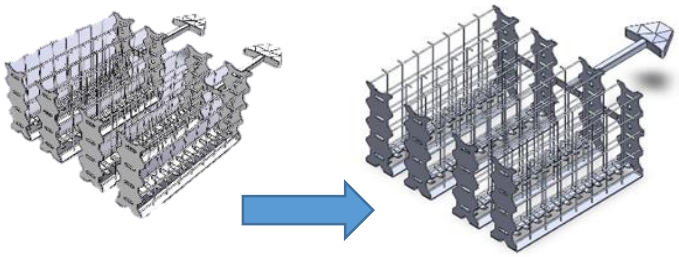

Figure 7: Bread holder tray design which is existing and modified

There are two pairs of bread holders in the existing bread toaster design which is able to toast two sets of bread toaster at a time, But, to assemble them is a bit critical. To maximize performance, two pairs of bread holder is combined into one, making it having a single handle for a whole pair of bread holder. Figure 8 shows, the third modified parts which was an impact from second modification. Because double handle became one, the bread holder cover is redesigned.

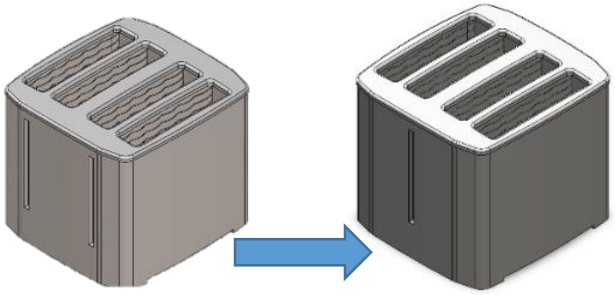

Figure 8: Bread holder cover design which is existing and modified

For the single handle to fit into the bread holder cover, the bread holder cover undergoes modification and resulted as shown in figure 8. The final part that is modified is control knob. Figure 8 shows the control knob which is disassembled form DeLonghi dual sided bread toaster.

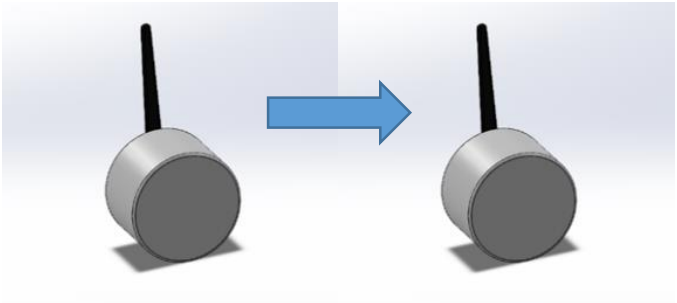

Figure 9: Control knob existing and modified design

Based on figure 9, the existing design of control knob is unchanged, but the material type of control knob is replaced. Old control knob is made up of Aluminum which is slightly costly. When determining performance of product, it also emphasizes on cost. To minimize the cost, the aluminum material is replaced with PP Plastic and the overall cost for control knob is reduced. Figure 10 shows the assembly of DeLonghi dual sided bread toaster before and after modifications. This assembly shows the optimum design that toaster could have for best performance with greater efficiency.

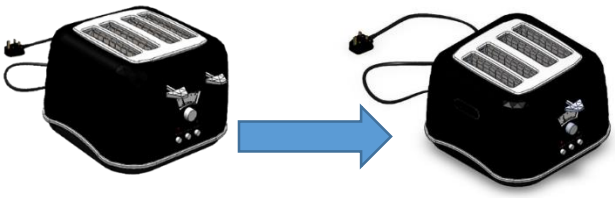

Figure 10: DeLonghi dual sided bread toaster assembly before and after modification

Figure 11 and 12 shows the exploded view of DeLonghi dual sided bread toaster. These shows a clear vision of assembly where the existing design and modified design's parts and structures.

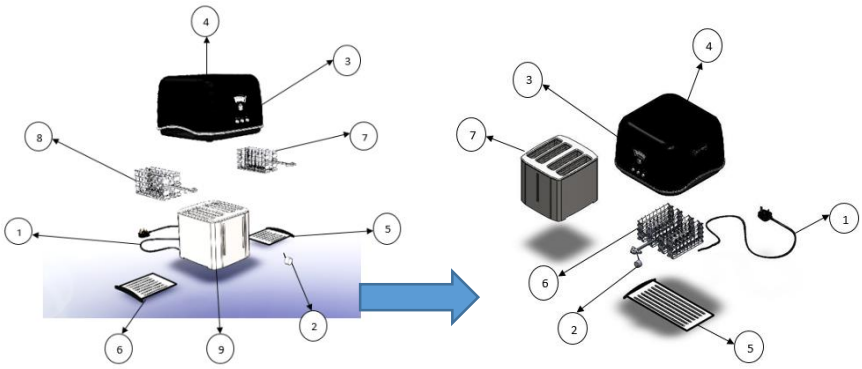

Figure 11: DeLonghi dual sided bread toaster exploded view before and after modification

4. Conclusion

The major goal of this research is to assess the available DeLonghi dual sided bread toaster's design and create a modified bread toaster version by using the Design for Manufacturing Assembly approach. This research requires variables such as enhancing the product's design, reducing the number of components and parts, and also lowering the product's cost. By manual DFA analysis technique, all the required objectives of this study have been achieved. The first objective which is to estimate the performance of original product for its efficiency is achieved by tabulating all the values requires for design efficiency of bread toaster. By, interpreting the efficiency using formula stated in methods part, the best design efficiency is acquired. The second objective was to propose an alternative design of original product. After estimating design efficiency of existing design, a new design was proposed for parts and using Solid works software, the proposed design is designed. Moreover, third objective which is to compare the performance between the chosen alternative design and the original design using DFMA method. As mentioned in Table 4, the values immerse from manual DFA worksheet, which is chosen method of DFMA, of existing and modified designs is compared and it is proven that modified design with optimum parts performs well in terms of operation time, cost and design efficiency. The existing design achieved a design efficiency value of 33.00 %, total disassembled parts of 9 units, total operation time of 82.86 s and total operation cost of RM 33.14. Whereas, the modified DeLonghi dual sided bread toaster design acquired a design efficiency of 52%, total disassembled parts of 7 units, total operation time of 40.71 s and total operation cost of RM 16.28. This shows that the modification made achieved success when compared to previous study.

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