Optimization of Injector Gun Design Using Design for Manufacturing and Assembly (DFMA) At the Conceptual Design Stage

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Abstract

Every company wants to produce low cost, high quality products and faster time to market. Design for Manufacturing and Assembly (DMFA) is a methodology that can be applied to many products in the manufacturing industry. This study focuses on Boothroyd-Dewhurst DFMA method to analyze an injector gun, which emphasis on cost reduction and parts count reduction. The purpose of this study is to optimize the current design of injector gun for oil palm tree fertilization application at the conceptual design stage. This study applies the DFMA Boothroyd-Dewhurst software by using two types of applications. Both original and improved design of the product was analyzed using Design for Assembly (DFA) software and Design for Manufacturing (DFM) Concurrent Costing software. The results show a reduction of 52% in assembly time, 28% of the product total cost and increased of DFA index percentage from 34% to 72%, a 53% of improvement. Overall, DFMA is a good method to increase the productivity, minimize the cycle time and the cost of manufacture and assembly. Meanwhile, the DFMA software is useful to make the design process faster and easier.

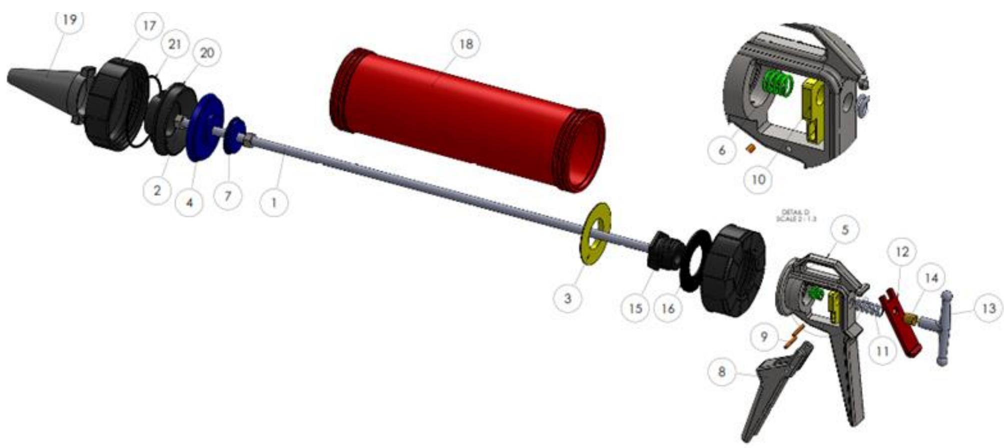
Key Words: design for assembly (DFA); design for manufacturing (DFM); design for manufacturing and assembly (DFMA); boothroyd dewhurst; conceptual design

1.0 INTRODUCTION

Nowadays, people are more demanding on something that simple and less costly in their daily requirement. In order to meet customer needs, more companies struggling with competitive markets to produce low cost products with high quality and faster to market. Many researchers and innovators have been carried out that focusing on increasing the efficiency and simplify the operation especially both assembly and manufacturing process and cost. Usually, in industry the improvement they made are based on cost reduction. The cost estimation is an essential aspect in the design stage. Moreover, this is accepted that over 70% of final product costs are determined during the design stage (Newnes, Mileham, Saravi, & Goh, 2008). DFMA is a method used by designers in a way to reduce part count, reduce assembly time or simplifying the sub-assemblies. It is a combination of DFM and the DFA. Ease of manufacturing and assembly is important for cost, productivity and quality (Boothroyd, Dewhurst, & A. Knight, 2011). Over the past few years, DFMA have attracted increasing attention and have been considered for design applications such as fluid flow control valve (Prakash et. al, 2014), dual plate check valve (B Mistry, 2013), automotive components (P. Suresh, 2015), washing machine (K. Annamalai, 2013) and aircrafts (G. F. Barbosa, 2014).

Motorola Solutions uses Boothroyd Dewhurst DFA software to benchmark designs and measure improvement in its global product portfolio (Foley, 2017). The use of the Boothroyd Dewhurst DFA Software was instrumental in being able to quickly and easily identify product cost drivers.

Liquid injector gun is one of the consumer products that used in industry and distributed by COX North America, an exclusive distributor of COX hand-held sealant and adhesive applicators located in Haslett, Michigan. Because of the complicated existing design as shown in Figure 1, this product need to be redesigned with the aim to save the cost and ease of assembly and manufacture. Therefore, there is potential for improvement of injector gun design by using DFMA at the conceptual design stage.



Part No.	Part Name	Qty.	Part No.	Part Name	Qty.
1	Rod	1	11	Catch plate spring	1
2	M8 lock nut	2	12	Catch release plate	1
3	Yellow plastic washer	1	13	Handle	1
4	Split sachet plunger	1	14	Sleeve	1
5	Butt stock	1	15	Hexagonal zinc barrel screw	1
6	Catch release plate spring	1	16	Steel washer	1
7	Tin hat plunger	1	17	Plastic Cap	2
8	Trigger	1	18	Barrel	1
9	Pin	2	19	Nozzle	1
10	Catch plate	1	20	Nozzle holder	1
			21	O-ring	1

Figure 1: Exploded View and Bill of Material (BoM) of Injector Gun (Original Design)

2.0 METHODOLOGY

The overall structure of the research work is illustrated in Figure 2. Generally, a technique used is Boothroyd-Dewhurst DFMA method. Meanwhile, the tools used are DFA software and DFM Concurrent Costing software. This method is used because it is very useful and suitable for reducing the number of parts, assembly cost and manufacturing cost. This has been proven through a study done by Farid (2007).

As a matter of fact, computer based design of manufacture and assembly methodologies such as DFMA, which is based on Boothroyd-Dewhurts methodology becomes handy to the designers and engineers. They can easily redesign the product faster and efficiently using the computer-based methods.

2.1 Implementation of Analysis Phase

DFMA analysis is carried out twice. The first analysis carried out on the original design products, while the second analysis conducted on the improved design product. Then, both results of the analysis compared in order to see the effect of DFMA methods in product design and development.

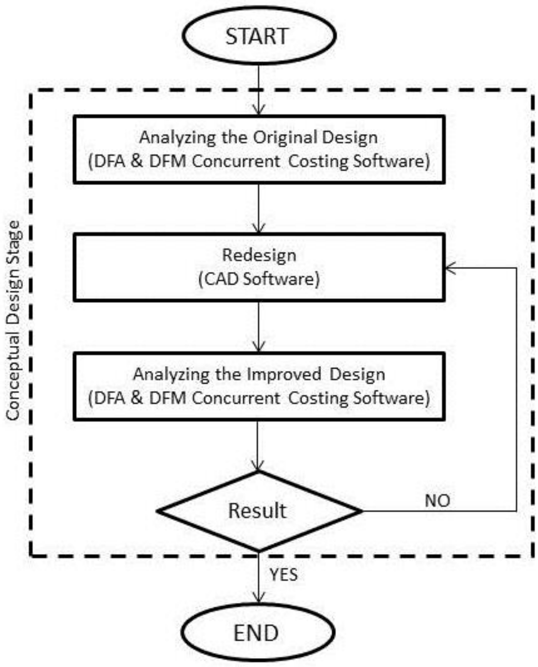


Figure 2: Product Design Optimization Using DFMA at the Conceptual Design Stage

2.2 Redesign Phase

After conducting an analysis of the original design, a new design is proposed. The original design was redesigned to make improvements in terms of reduction or consolidation of a number of parts.

Suggestions for redesign fall under a variety categories:

i. Combine connected items or attempt to rearrange the structure of the product in order to eliminate the items whose function is solely to make a connection.
ii. Reduce the number of items in the assembly by combining with others or eliminating the parts or subassemblies.
iii. Reduce separate operation times where possible. Improve or eliminate any which do not add value to the product and yet contribute significantly to assembly time.
iv. Consider redesigning the items to eliminate or reduce the handling difficulties.
v. Review the items and operations that may cause ergonomic difficulties for the assembly worker.

However, the change of the design must ensure will not affect the performance and functionality of the product (Jahangir Yadollhi Farsi, 2012 & da Silva et.al, 2013).

3.0 RESULT AND DISCUSSION

3.1 Analysis Results of the Original Design

Table 1 presents the result of the Design for Assembly analysis for the original design where it can be seen that an assembly design index of 34.3% is given. This figure is obtained by comparing the estimated assembly time of 102.65s with a theoretical minimum time obtained by multiplying the theoretical minimum part count of 12 by the minimum time of assembly for each part of 3s. The higher the DFA index, the more efficient the design is (Boothroyd et al., 2002). The total assembly labor cost per product is RM0.19; it is based on the minimum wage rate of RM900 per month in Malaysia. The total cost is only RM 0.19 because there was no other cost such as process cost, tooling cost and tooling investment cost. Those costs will be calculated in the DFM Concurrent Cost analysis.

Table 1: DFA analysis result of the Original Design

Per Product Data	Result
Number of parts	21
Number of parts (including repeats)	24
Theoretical minimum number of items	12
DFA index (Design efficiency)	34.3 %
Total assembly labor time	102.65 s
Total assembly labor cost	RM 0.19

Figure 3 shows the breakdown of time per product. Labor time is the assembly time for each type is the assembly time for each type of entry multiplied by the specified labor rate (Boothroyd et al., 2002). The total labor time for the product is 102.65s. This total is distributed to component parts, 60.45s, and standard operations, 22.70s. Labor time of components parts is divided into two categories that candidates for elimination (22.48s) and theoretical parts (37.97s). The time of candidate for elimination is determined as the times wasted to assemble the parts that are not functional such as fasteners during assemble the product.

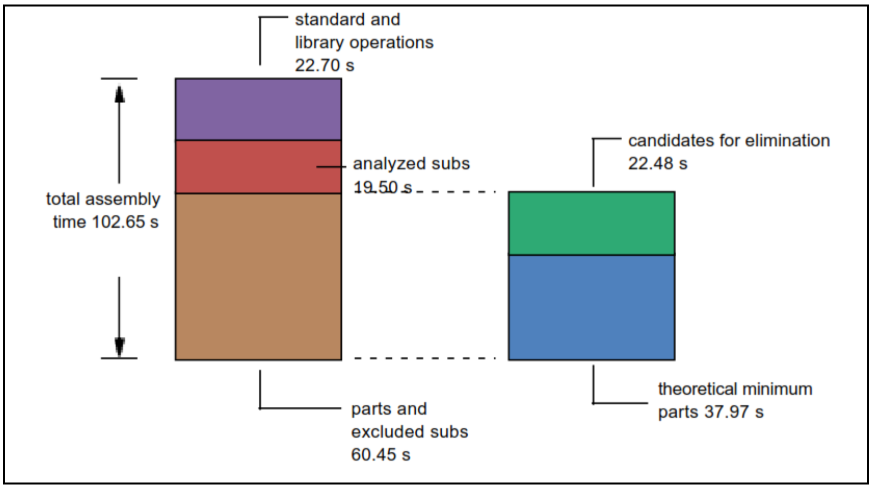


Figure 3: The Breakdown of Assembly Time per Product for the Original Design

Figure 4 shows the result of total manufacturing cost for each part. There are 5 standard parts which are not needed to fabricate by the product manufacturer. So, there are no manufacturing cost for lock nut, O-ring, pin, and springs. Among the parts, rod is involved the highest cost than other parts (RM9.24). In addition, barrel, butt stock and handle also involved the quite high cost.

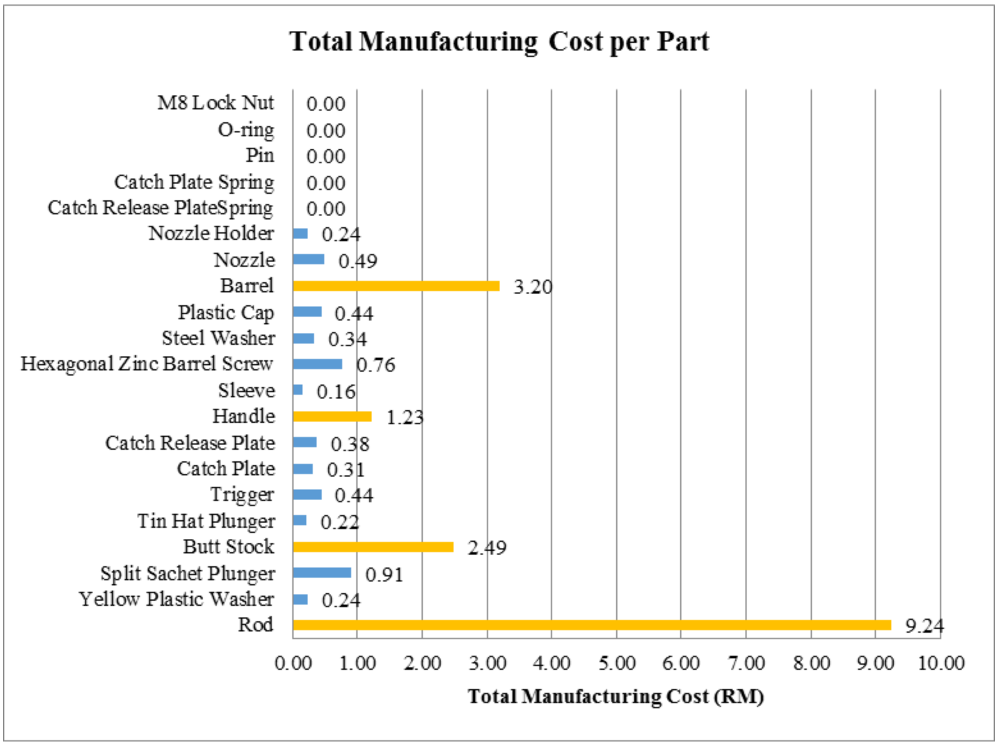


Figure 4: Total Manufacturing Cost per Part for Original Design

DFMA analysis presents assembly and manufacturing data. Its purpose is to present the overall cost of manufacturing the original design of injector gun. It includes both assembly and manufacturing cost data. Table 2 shows the DFMA analysis for original design of injector gun. From the table, it shows the cost per product and product life cost for the original design of the injector gun. For the per product data, the total entries, the total number of different parts, total assembly time, total assembly labor cost, total item cost and total weight has been obtained. For total costs, it is based on a product life volume of 10,000. Figure 5 shows the chart of cost breakdown per product. It shows that the total cost per product are consist of labor cost, item cost, piece part cost and manufacturing tooling cost per product.

Table 2: DFMA Analysis for Original Design Injector Gun

Product Data	Result
Product life volume	10,000
Number of parts	21
Number of parts (including repeats)	24
Theoretical minimum number of items	12
DFA index (Design efficiency)	34.3 %
Total weight	1.28 kg
Total assembly labor time	102.65 s
Total assembly labor cost	RM 0.19
Total cost for manufactured items including tooling	RM 62.34
Manufacturing tooling cost per product	RM 7.81
Total cost per product	RM 62.53

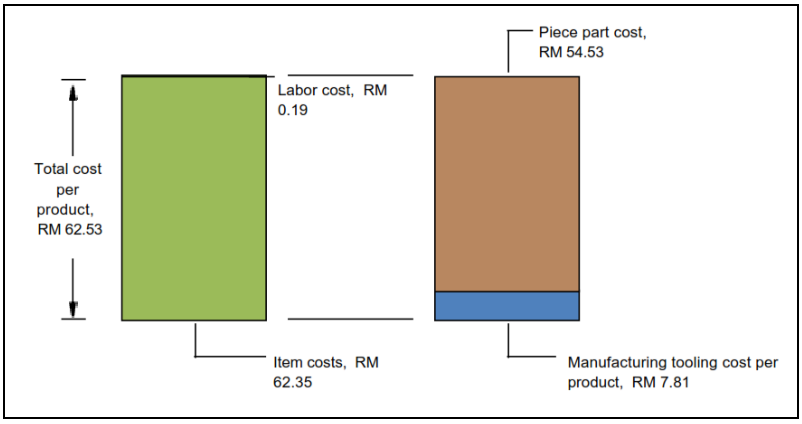
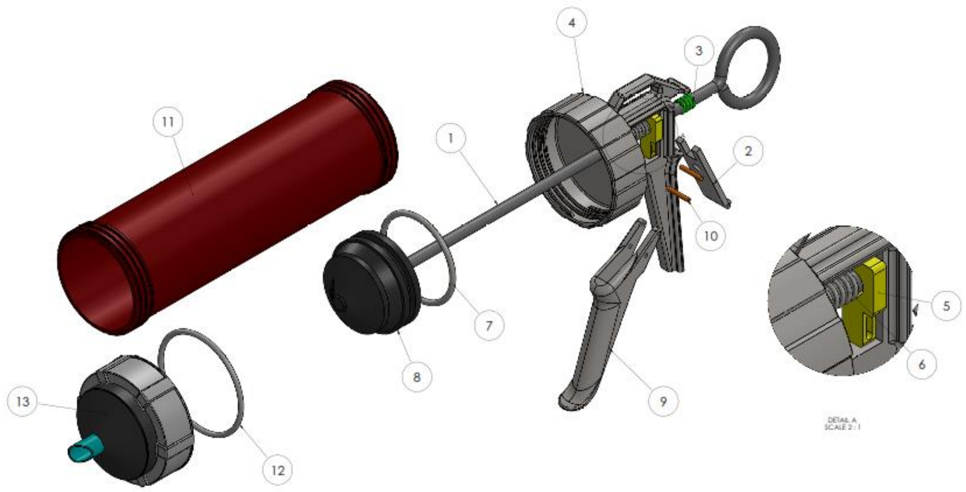


Figure 5: Chart of Cost Breakdown per Product for Original Design

3.2 Modification of Original Design

There are several parts that have been redesigned or modified to ease the assembly process and to reduce cost. Figure 6 shows the new design of injector gun. The original design consists of 21 parts while the new design consists of 13 parts only.

It is a result of the changes made to the old design, where there are some parts that have been eliminated, redesigned and combines some parts into one part. However, all modifications retain the performance and functionality of the product.



Part No.	Part Name	Qty.	Part No.	Part Name	Qty.
1	Rod	1	8	Plunger	1
2	Catch Release Plate	1	9	Trigger	1
3	Release Plate Spring	1	10	Pin	2
4	Butt Stock	1	11	Barrel	1
5	Catch Plate	1	12	Nozzle O-ring	1
6	Catch Plate Spring	1	13	Nozzle	1
7	Butt Stock O-ring	1			

Figure 6: Exploded View and Bill of Material (BoM) of Injector Gun (New Design)

3.3 Comparison between Original Design and New design

Table 3 summarized the comparison between the DFMA result of original design and the new design. It calculates based on 10,000 of product life volume. The number of parts has reduced by 38%. This decrease causes the reduction of the complexity of product structure and simplifies the assembly process, thereby reducing the assembly time of product by 52%. While the product has been modified, total of theoretical minimum parts remains the same, namely a total of 12 parts. This is to ensure the functionality of the product is not affected. Thus, the percentage of the index has increased to 72% and has reached the optimum level of design efficiency as determined by the Boothroyd-Dewhurst method, at least 70%

(Boothroyd et al. 2002). The manufacturing cost of each part is compared between the original design and new design. However there are 6 parts that do not have any changes in its design which means that the cost of the part remains the same. Based on Table 3, total manufactured cost for the new design decreased by 24% from RM54.53 to RM41.36. This is contributed by the reducing of the number of parts. When there is a reduction of the number of components, the manufacturing process can also be reduced and some are not required anymore. This follows from combining several parts that produced from a number of manufacturing processes becomes a part that derived from a single process only.

Table 3: DFMA Results Comparisons between Original and New Improved Design of Product

NO.	ITEMS	ORIGINAL DESIGN	NEW DESIGN	IMPROVEMENT
1.	Product life volume	10,000	10,000	-
2.	Number of part	21	13	38% reduced
3.	Component part	24	14	-
4.	Theoretical minimum part	12	12	-
5.	DFA index	34%	72%	53% increased
6.	Total assembly labor time	102.65 s	48.82 s	52% reduced
7.	Total Weight	1.28 kg	0.67 kg	48% reduced
8.	Total assembly labor cost per product	RM 0.19	RM 0.09	53% reduced
9.	Total manufacturing piece part cost	RM 54.53	RM 41.36	24% reduced
10.	Manufacturing tooling cost per product	RM 7.81	RM 3.85	51% reduced
11.	Total cost per product	RM 62.53	RM 45.30	28% reduced

Figure 7 clearly shows that the total cost per product for original design have reduced by RM15.96, from RM62.61 to RM46.65. Even though the assembly labor cost is increased by RM1.18, the piece part cost has reduced from RM54.53 to RM46.65 and provide significant changes to the total cost per product. The manufacturing tooling cost per product also decreased due to the reduction of the number of parts.

The result obtained agreed with previous work carried out by Daleel (2013) in designing the slicing machine, where the results shown that the new design of slicing machine has 26% improvement from original design in DFA index and the cost of the new design is 45.27% lower than the original design from RM9500.07 to RM5199.07.

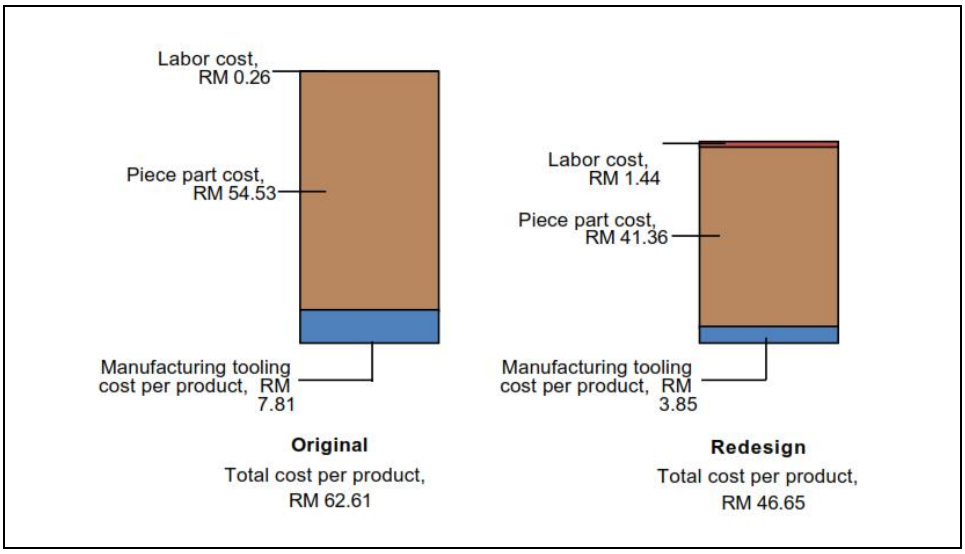


Figure 7: Comparison between Original Design and New Design for an Injector Gun by Cost Breakdown Chart

4.0 CONCLUSION

This study was devoted to analyze an injector gun by using the Boothroyd-Dewhurst DFMA method. This was performed by reducing the cost and parts count. The results shows that the injector gun design has been improved from 21 parts to 13 parts, where is 38% part reduction using the Boothroyd-Dewhurst DFA software. In addition, the DFA index has improved and achieved to 72%. Finally, the problem statement of this project has been solved, where the complexity of the product structure can be overcome by making modifications that have been suggested by the software itself. Apart from DFA there is also software called Boothroyd-Dewhurst DFM Concurrent Costing which is a tool that select suitable material and process for producing the fertilizer injector gun. The total part cost per product has saved. This shows that DFMA methodology can be utilized in a variety of ways to bring value to manufactured products and processes of the injector gun. Basically the original design can be able to optimized using DFMA and furthermore shortens the design process.

There are a few recommendations that can be considered in order to improve the analysis in doing the comparison for an original design injector gun with new design injector gun using Design for Manufacture and Assembly (DFMA) method. FEA (Finite Element Analysis) should be implemented for the future study to maintain the reliability of the product. Other methods such as Design for Disassembly (DFD) and Design for Environment (DFE) also should be integrated with DFMA method for the next research and to implement concurrent engineering. Other DFMA tool such as TEAMSET software also should be conducted in the future to validate the results.

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