PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 5 No. 1 (2024) 378-386
https://publisher.uthm.edu.my/periodicals/index.php/peat

Optimization of Assembly Process and Design Efficiency Using DFMA: Case Study of Drill Grinder Machine

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DOI: https://doi.org/10.30880/peat.2024.05.01.040

Article Info

Received: 28 December 2023
Accepted: 18 January 2024
Available online: 15 June 2024

Keywords

DFMA, DFM, DFA, DFA Worksheet, Boothroyd Dewhurst, Drill Grinder Machine

Abstract

Design for Manufacturing and Assembly (DFMA) is a combination of Design for Manufacturing (DFM) and Design for Assembly (DFA). The main objective of this case study is to analyse and redesign the drill grinder machine by using the DFMA method to reduce the parts of the machine, minimise the manufacturing cost of the product, reduce the time for assembly parts, and reduce the cost of assembly of the parts. A drill grinder machine is a machine that is used to sharpen dull and broken twist drill bits. The Boothroyd-Dewhurst method with a DFA worksheet will be used in this case study to analyse the drill grinder machine. The results showed that the efficiency design, after being improved, was better than the original design. The efficiency of the improved design was increased to 41%. Comparing the original design, which had 36% design efficiency, the design efficiency increased to 5%. Moreover, the manufacturing cost of the original design was 2344.58 USD. After the improvements were made, the manufacturing cost was reduced to 1510.99 USD. The number of parts in the drill grinder machine was reduced from 35 to 30 parts, and the assembly time for the parts was also reduced from 236.11 seconds to 220.66 seconds. Overall, the application of the DFMA method in designing the drill grinder machine made the product better with lower cost and assembly time.

1. Introduction

Design for Manufacturing and Assembly (DFMA) is a design approach that focuses on the efficiency of the product to minimize the number of parts of a product, the cost of manufacturing the product, the cost of assembling the parts of the product, and the time for assembling the parts of the product. DFMA is a combination of Design for Manufacturing (DFM) and Design for Assembly (DFA) methods that consider the manufacturing and assembly aspects of production [1]. In the early 1970s, Geoffrey Boothroyd, a professor at the University of Massachusetts, and Peter Dewhurst, who founded Boothroyd Dewhurst, were the first to popularize the principles of DFMA.

The main objective of DFMA is to optimize the number of manufacturing steps, eliminate material waste, and improve process dependability. DFMA is commonly applied after the design stage and before the manufacturing stage to gain full value from DFMA.

In this case study, the drill grinder machine GT-200FC was chosen to be studied. Drill grinder machines are also named drill bit sharpeners, which are used to sharpen dull and broken drill bits. Before the drill grinder machine existed, craftsmen and machinists used manual processes to sharpen drill bits in the early days. They

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methodically ground the cutting edges of drill bits to restore their sharpness with handheld files or grinding stones. This method was time-consuming and heavily dependent on the operator's ability and expertise [3].

2. Literature Review

2.1.1 Design for Assembly (DFA)

Design for Assembly (DFA) is a methodical technique that attempts to reduce assembly times by doing things like reducing the overall number of components in a specific assembly and removing critical assembly jobs. It is a design strategy that is used to simplify or accelerate the assembly of product pieces or components [2]. The DFA method brings many benefits, such as:

- Reduce the number of parts needed for a product.
- Minimize manufacturing operation costs.
- Improve productivity and quality.

2.1.2 Design for Manufacturing (DFM)

DFM is an engineering practise that aims to simplify the manufacturing process for a given component's cost reduction through the following actions:

1) Choosing the type of raw material.

2) Choosing the raw materials geometry.

3) Defining the dimensional and geometrical tolerances.

4) Defining roughness.

5) Describing the specific shape constraints based on the manufacturing process.

6) Choosing the secondary processing, such as finishing.

A design technique known as "Design for Manufacturing" (DFM) aims to simplify manufacturing processes and lower production costs overall, including theprice of raw materials [4]. The need to learn just how much money may be saved with DFA software increased along with interest in it. Dr Boothroyd and Dewhurst's additional study in 1985 made it possible to integrate a "Design for Manufacturing" (DFM) module. DFM makes it possible to evaluate the should-cost of various design alternatives quickly and accurately. The two elements came together to create the current DFMA® system. The creators of BDI received the National Medal of Technology from President George H. W. Bush in 1991 because of the substantial advantages that DFMA® software offered to top manufacturers (“Design for X,” 1996).

3. Methodology

3.1 Project Flow Chart

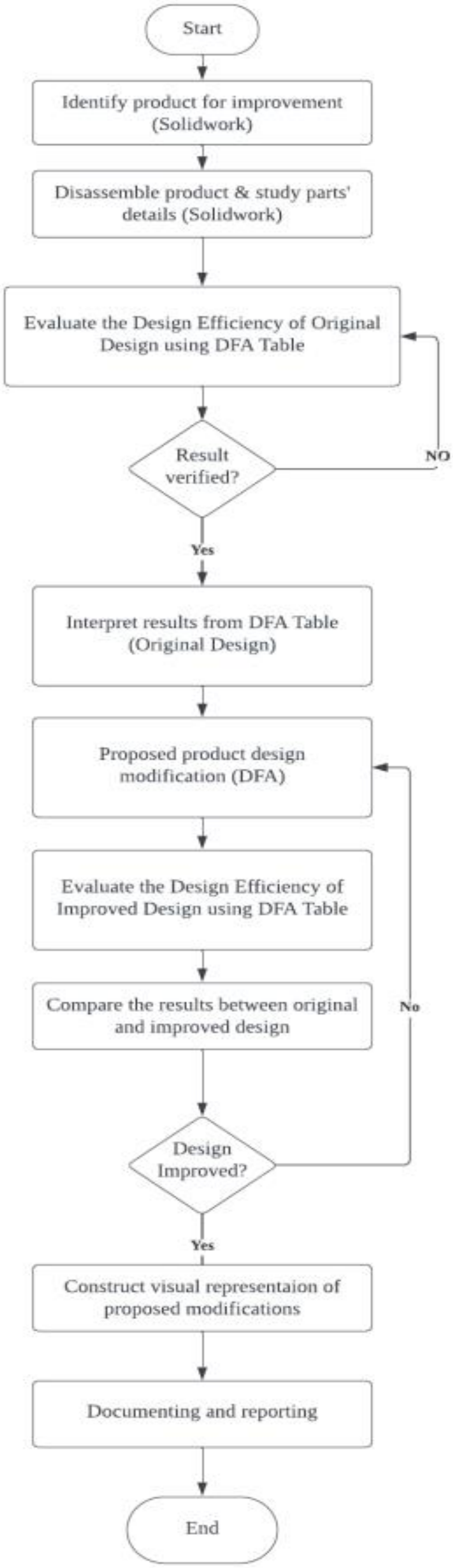


Fig. 1 *Flow Chart of DFA Manual Analysis Methodology*

Figure 1 shows the study flow chart process. In this flow chart of study process, the main and important events are redesigning the original design and evaluating the design efficiency and cost of design. Those actions will take in result and analysis parts. The actions will repeat if the cost of new design is not less than the original design.

3.2 Steps for Manual DFMA

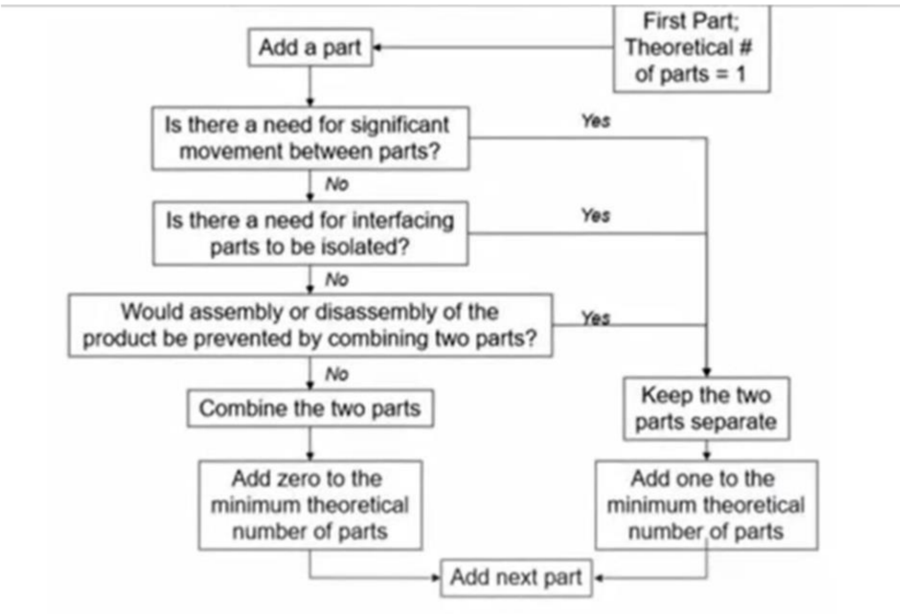
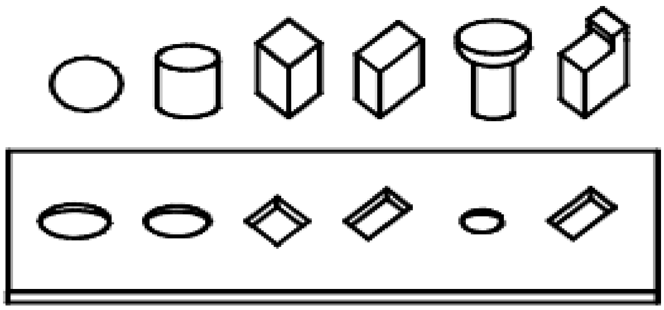


Fig. 2 *Flowchart to Reduce Part Count*

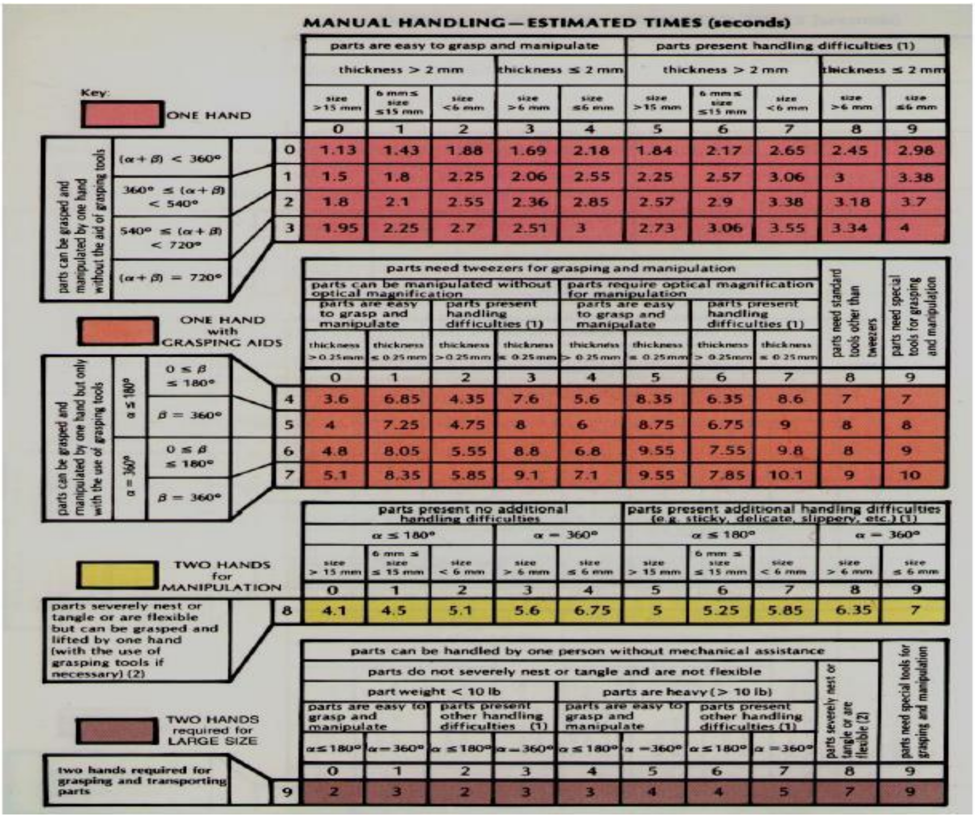
This ability enables to disassemble the product and have a good, close look at the components it is made up of. Also, the author shall identify the components' sizes, functions, and order of assembly through part identification. This way helps to improve and redesign the parts.

3.3 Manual Handling Worksheet



α	0	180	180	90	360	360
β	0	0	90	180	0	360

Fig. 3 *Alpha and Beta rotational symmetric for various part [7]*



MANUAL HANDLING—ESTIMATED TIMES (seconds)

Key: ONE HAND — parts can be grasped and manipulated by one hand without the aid of grasping tools

		parts are easy to grasp and manipulate: thickness > 2 mm, size >15 mm	thickness > 2 mm, 6 mm ≤ size ≤15 mm	thickness > 2 mm, size <6 mm	thickness ≤ 2 mm, size >6 mm	thickness ≤ 2 mm, size ≤6 mm	parts present handling difficulties (1): thickness > 2 mm, size >15 mm	thickness > 2 mm, 6 mm ≤ size ≤15 mm	thickness > 2 mm, size <6 mm	thickness ≤ 2 mm, size >6 mm	thickness ≤ 2 mm, size ≤6 mm
		0	1	2	3	4	5	6	7	8	9
$(\alpha+\beta) < 360°$	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

Key: ONE HAND with GRASPING AIDS — parts can be grasped and manipulated by one hand but only with the use of grasping tools

		parts need tweezers for grasping and manipulation; parts can be manipulated without optical magnification; parts are easy to grasp and manipulate: thickness > 0.25 mm	thickness ≤ 0.25 mm	parts present handling difficulties (1): thickness > 0.25 mm	thickness ≤ 0.25 mm	parts require optical magnification for manipulation; parts are easy to grasp and manipulate: thickness > 0.25 mm	thickness ≤ 0.25 mm	parts present handling difficulties (1): thickness > 0.25 mm	thickness ≤ 0.25 mm	parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
		0	1	2	3	4	5	6	7	8	9
$\alpha \le 180°$, $0 \le \beta \le 180°$	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

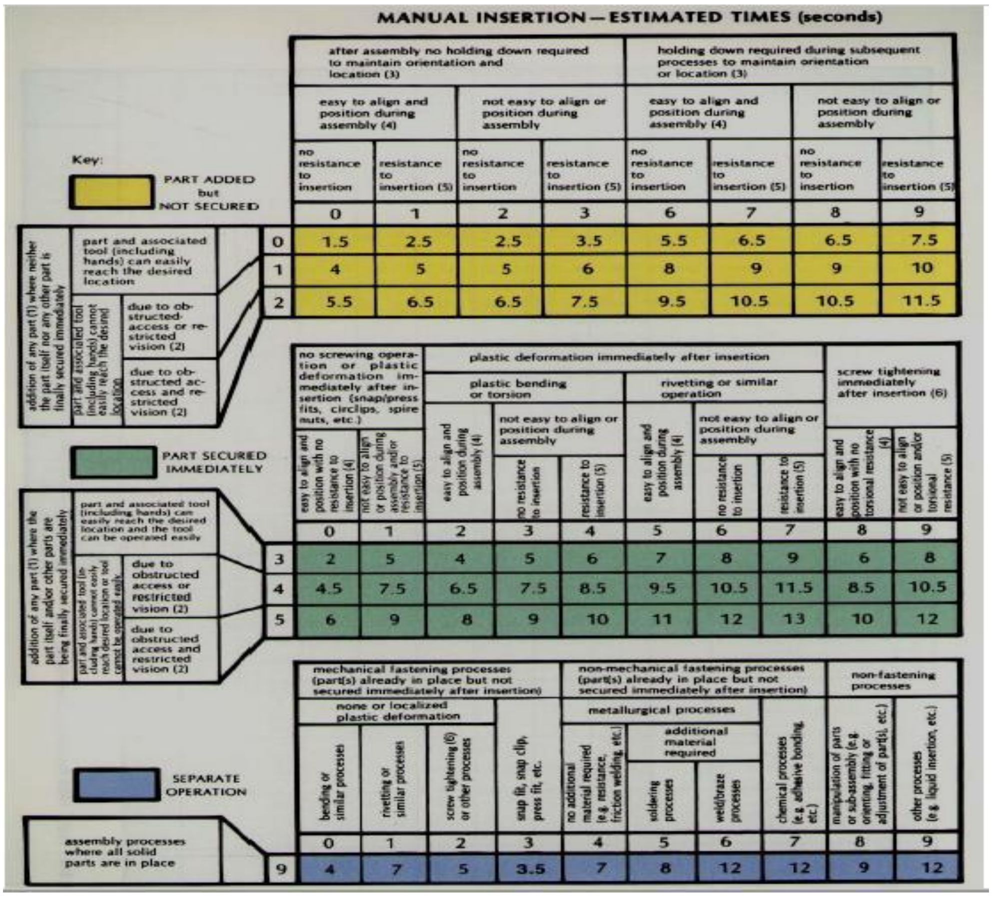
Key: TWO HANDS for MANIPULATION

		parts present no additional handling difficulties: $\alpha \le 180°$, size > 15 mm	$\alpha \le 180°$, 6 mm ≤ size ≤ 15 mm	$\alpha \le 180°$, size < 6 mm	$\alpha = 360°$, size > 6 mm	$\alpha = 360°$, size ≤ 6 mm	parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1): $\alpha \le 180°$, size > 15 mm	$\alpha \le 180°$, 6 mm ≤ size ≤ 15 mm	$\alpha \le 180°$, size < 6 mm	$\alpha = 360°$, size > 6 mm	$\alpha = 360°$, 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

Key: TWO HANDS for LARGE SIZE

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

Fig. 4 *The original classification of insertion handling [8]*



MANUAL INSERTION—ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED — addition of any part (1) where neither the part itself nor any other part is finally secured immediately

		after assembly no holding down required to maintain orientation and location (3); easy to align and position during assembly (4): no resistance to insertion	easy to align: resistance to insertion (5)	not easy to align or position during assembly: no resistance to insertion	not easy to align: resistance to insertion (5)	holding down required during subsequent processes to maintain orientation or location (3); easy to align and position during assembly (4): no resistance to insertion	easy to align: resistance to insertion (5)	not easy to align or position during assembly: no resistance to insertion	not easy to align: resistance to insertion (5)
		0	1	2	3	6	7	8	9
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
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

Key: PART SECURED IMMEDIATELY — addition of any part (1) where the part itself and/or other parts are being finally secured immediately

		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.): 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)	plastic deformation immediately after insertion; plastic bending or torsion: easy to align and position during assembly (4)	plastic bending or torsion, not easy to align or position during assembly: no resistance to insertion	plastic bending or torsion, not easy to align: resistance to insertion (5)	rivetting or similar operation: easy to align and position during assembly (4)	rivetting, not easy to align or position during assembly: no resistance to insertion	rivetting, not easy to align: resistance to insertion (5)	screw tightening immediately after insertion (6): 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
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
due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

Key: SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion); none or localized plastic deformation: bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	snap fit, snap clip, press fit, etc.	non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion); metallurgical processes: no additional material required (e.g. resistance, friction welding, etc.)	additional material required: soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	non-fastening processes: manipulation of parts or subassembly (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

Fig. 5 *The original classification of insertion handling times [8]*

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Identify the rotational symmetry of the pieces using Figure 3 (Alpha and Beta rotational symmetry for various parts). Find the id portions in Figure 4 (the original classification of insertion handling times) using the information from Figure 5 (Alpha and Beta rotational symmetry for various parts). After gathering the data, fill out the DFA table and perform the calculations [8].

3.4 SolidWorks

SOLIDWORKS is used to create mechatronic systems from beginning to end. The software was initially used for planning, visual ideation, modelling, feasibility assessment, prototyping, and project management. The programmed is then used to create mechanical, electrical, and software aspects. Finally, the software can be used for administration, such as device management, analytics, data automation, and cloud services [9].

SolidWorks can help in product design analysis by disassembling the product's 3D model. It can aid in the process of analysing product parts by exploring the original design of the product. Furthermore, SolidWorks offers a feature called SolidWorks Express that helps save time and money by testing designs on the computer rather than expensive and time-consuming field tests. It allows physical product testing to be reduced before the final product design is completed [9]. SolidWorks also has a feature called SolidWorks Costing, which can estimate the manufacturing cost for each part.

4. Drill Grinder Machine Details

Fig. 6 *Drill Grinder Machine, GT-200FC*

Lida Iron Works Co. Ltd (飯田鉄工所) is a Japanese factory that is under Izushi Company (株式会社). The location of the factory is located at 21, Ozai Shinhoya, Jimokuji-cho, Kaibe-gun, Aichi Prefecture in Japan. Lida Iron Works Co. Ltd was founded on May 1, Showa 9 (1 May 1934) and established on Showa 43, August 28 (28 August 1968) [6]. The main product of this factory is manufactured and sold tools grinders. Figure 3 shows the drill grinder machine, GT-200FC made by Lida Iron Works Co. Ltd.

4.1 Theoretical Minimum Number of Parts of Drill Grinder Machine

The analysis begins by listing all parts or components of the drill grinder machine and eliminating or reducing the parts theoretically. Table 1 shows the results of the theoretical minimum number of parts in the drill grinder machine.

Table 1 *Theoretical Minimum Number of Parts of Drill Grinder Machine*

No.	Part Name	Quantity	Theoretical Minimum Number
1	Base 1	1	1
2	Base 2	1	1
3	Base 3	1	1
4	Gear 2	1	1
5	Gear shaft	1	1
6	Handle 1	1	1
7	Rack	1	1
8	Skew	1	1
9	Then Base 1	1	1
10	Then Base 2	1	1
11	Cache Shaft 1	1	1
12	Cache Shaft 2	1	0
13	Chuck	1	1
14	Chuck Clam	6	6
15	Flange Rotary	1	1
16	Lock	1	1
17	Pin Lock	1	1
18	Shaft	1	1
19	Cover Tool Cutting	1	1
20	Column Mounter	1	1
21	Grinder Tool	1	1
22	Mica Cover	1	0
23	Mounter Base	1	1
24	Mounter	1	1
25	Handle 2	1	1
26	Hexagon Socket Head	3	0
27	Hexagon Bolt	2	1

5. Results and Data Analysis

5.1 Results Analysis for DFA Tables

Table 2: *Comparison Between Original Design and Improved Design*

	Design Efficiency	Number of Parts	Operation Time (seconds)	Operation Cost (USD)
Original	0.36	35	236.11	94.44
Improved	0.41	30	220.66	88.26
Differences	0.05	5	15.45	6.18

By comparing the performance of the original design and improved design, the design efficiency has been increasing from 0.36 or 36% to 0.41 or 41% which increasing 0.05 or 5%. The number of parts to build the drill grinder machine has been reduced from 35 to 30 parts. Following by the reduction of operation time from 236.11s to 220.66s. The operation cost also dropped to 6.18, which was from 94.44 to 88.26. Overall, design efficiency has increased after improvements have been made.

5.2 Results Analysis for DFM Tables

Table 3: *Comparison Between Total Manufacturing Cost of Original Design and Improved Design*

	Total Cost (USD)
Original Design	2344.58
Improved Design	1510.99

By comparing the total manufacturing cost of the original design and the improved design, the manufacturing cost for the original design has been reduced from 2433.58 to 1510.99, which reduces the total manufacturing cost to 922.59. The manufacturing method for five parts has been changed from machining to casting to reduce the manufacturing cost of those parts.

6. Conclusion

This research is focused on evaluating an assessment of the current drill grinder machine, the GT-200FC, and developing a new design using the DFMA methodology. In this research, the DFA worksheet assessment was used to find the design efficiency for both original and improved designs. SolidWorks costing was used in this research to calculate the manufacturing cost for each part of the drill grinder machine.

According to the results, the overall results of the improved design were better than the original design. The improved design efficiency was 41%, which was 5% higher than the original design efficiency of 36%. The total manual assembly operation time decreased from 236.11 seconds to 220.66 seconds. After that, the total manual assembly operation cost also decreased from 94.44 USD to 88.26 USD. The manufacturing cost for the improved design, 1510.99 USD, was 922.59 USD lower than the original design, 2344.58 USD.

In conclusion, by using DFMA method, the production efficiency of drill grinder machine was improved and the costs for production of drill grinder machine was reduced. The time for manual assembly the drill grinder machine also reduced, and the unnecessary parts of drill grinder machine were eliminated to save the cost of manufacturing and time of manual assembly, also the cost of manual assembly.

Acknowledgment

The authors would like to thank the Faculty of Engineering Technology, Universiti of Tun Hussein Onn Malaysia for its support.

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